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COMMONWEALTH OF AUSTRALIA

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THE CAMBRIAN AND ORDOVICIAN GEOLOGY OF THE SOUTHERN PART OF THE BONAPARTE GULF BASIN AND THE CAMBRIAN AND DEVONIAN GEOLOGY OF THE OUTLIERS, WESTERN AUSTRALIA

by

J.A. Kaulback & J.J. Veevers

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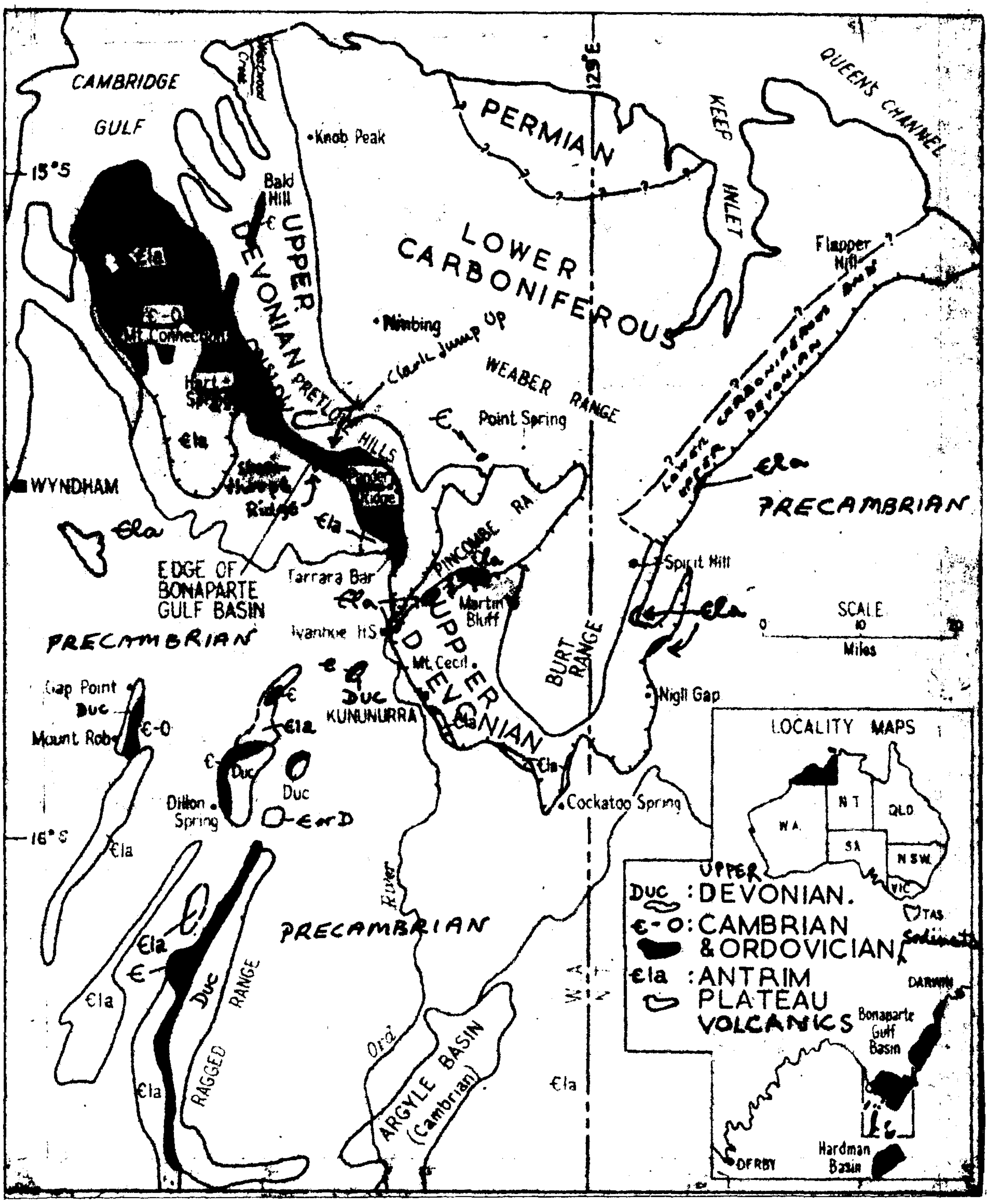
SOLID GEOLOGY. FAULTS OMITTED

(After Veevers et al., 1964)



Bureau of Mineral Resources, Geology and Geophysics. March 1965. To accompany Record 1965/49 **AUS/1/41**

SUMMARY

The Cambrian and Ordovician rocks of the southern part of the Bonaparte Gulf Basin, and the Cambrian and Devonian rocks of the outliers crop out over an area of some 500 square miles, and have a composite thickness that exceeds 5,000 feet. They unconformably rest on Precambrian sedimentary rocks, and the Cambrian and Ordovician rocks are unconformably overlain by Upper Devonian and Lower Carboniferous sedimentary rocks.

The base of the Cambrian and Lower Ordovician sequence consists of an unmeasured thickness of Lower Cambrian Antrim Plateau Volcanics, mainly basalt flows, unconformably overlain by about 400 feet of late Lower Cambrian dolomitic quartz sandstone and siltstone and dolomite (Blatchford Formation) in the Ragged Range, and by 200 feet (and possibly as much as 1,300 feet) of early Middle Cambrian shale, sandstone, and dolomite (Tarrara Formation) in the Bonaparte Gulf Basin.

The Tarrara Formation is overlain by a conformable sequence of 1200 feet of Middle Cambrian red quartz sandstone (Hart Spring Sandstone), 200 feet of Middle and Upper Cambrian dolomite and sandstone (Skewthorpe Formation), 400 feet of Upper Cambrian white quartz sandstone (Pretlove Sandstone), 750 feet of Upper Cambrian glauconitic sandstone and white quartz sandstone (Clark Sandstone), and, finally, 600 feet of Lower Ordovician dark glauconitic sandstone (Pander Greensand).

Except the Hart Spring Sandstone and the Pretlove Sandstone, which are sparsely fossiliferous, the sedimentary sequence contains abundant fossils, mainly trilobites, which provide a basis for local and wider correlation.

In all the outliers except the Ragged Range, the Antrim Plateau Volcanics are succeeded by Lower or Middle Cambrian red sandstone and dolomite (either the Blatchford Formation or Tarrara Formations). At Gap Point and Mount Rob, the sequence continues upward into Upper Cambrian Sandstone and possibly into Lower Ordovician sandstone; the aggregate thickness of Cambrian sediments here is about 2700 feet.

The Cambrian rocks of the outliers are unconformably overlain by white and red quartz sandstone (Cockatoo Sandstone) and in the Ragged Range by conglomerate and conglomeratic sandstone (Ragged Range Conglomerate). Pelecypods in the sandstone of the Ragged Range and Dillon outlier probably indicate Upper Devonian, equivalent to part of the Cockatoo Sandstone of the Bonaparte Gulf

Basin. The thickest Devonian deposit is 3,000 feet at Gap Point.

Rhythmically deposited quartz sandstone, sandy dolomite, and stromatolitic dolomite in the Skewthorpe Formation are related to strand, lagoon, and algal reef deposition in successive transgressions of a shallow sea.

The rapid replacement of one fauna by another in the Clark Sandstone is another instance of the wide-spread faunal crisis that took place in the Upper Cambrian.

Differential movement, probably along faults, during the Upper Cambrian is indicated by rapid changes in thickness and by faunal breaks in the Pretlove Sandstone.

The Cambrian-Ordovician sequence was uplifted and warped before deposition was renewed in the Upper Devonian; the main diastrophism (tilting, and profound faulting) that affected the Cambrian, Ordovician, and Upper Devonian rocks took place in the early Lower Carboniferous. This diastrophism and consequent erosion broke up what must have been a continuous sheet of Cambrian, Ordovician, and Devonian rocks of unknown south-western extent into the present pattern.

The petroleum prospects of the severely faulted outcropping Cambrian and Ordovician sedimentary rocks are poor. If, as is expected, less deformed equivalents of these rocks extend north-eastward under younger rocks, they would provide an attractive target for the drill.

INTRODUCTION

The Bonaparte Gulf Basin is a structural basin whose limits are shown in Figure 1. By the term "the Palaeozoic outliers of the Bonaparte Gulf Basin" we refer to the Cambrian and Devonian sediments of the Ragged Range, Mount Rob, Gap Point, and Dillon Spring areas.

Location and access.

Most of the outcropping rocks described in this report lie within the Cambridge Gulf 1:250,000 Sheet area; the Ragged Range is in the Lissadell 1:250,000 Sheet area, and intermittent outcrops of the Antrim Plateau Volcanics lie at the south-eastern edge of the Bonaparte Gulf Basin in the Auvergne 1:250,000 Sheet area. Altogether, the outcrops described here cover an area of about 500 square miles. No bores in the Bonaparte Gulf Basin have penetrated Cambrian or Ordovician rocks, and this report is thus restricted to studies of outcrop.

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 Wyndham-Nicholson Road cross the area and numerous tracks serve the cattle stations.

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

Acknowledgements

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Previous work

Of the pioneer geologists who have carried out regional studies in the East Kimberleys (Hardman, 1885; Wade, 1924; Matheson and Teichert, 1948; Reeves, 1948), only Matheson and Teichert (1948) and Reeves (1948) described rocks considered in this report. Reeves was the first to record Cambrian fossils (determined by Teichert) from the Carlton Hill area and from the Ragged Range; Matheson and Teichert worked in the Argyle, Rosewood, and Hardman Basins, and they described only a few outcrops (Martin's Bluff and the Ord River near Tarrara Bar) in the area described here.

Noakes, Öpik, and Crespin (1952) reviewed earlier work, and introduced new information on the Cambrian and Ordovician rocks of the Carlton area. As part of a reconnaissance of the Ord-Victoria region, Traves (1955) mapped the Bonaparte Gulf Basin. Since Traves' work, which, together with contributions by Öpik, was included in Öpik (1956), practically no work on the Cambrian and Ordovician of the Bonaparte Gulf Basin was done until 1963. Oil company studies were concentrated on Devonian or younger sediments, as was Drummond's report of 1963.

In 1963 a photo-geological map of the Cambridge Gulf Sheet area was prepared by Ruker (1963), and later that year, a Bureau geological party spent six months mapping the area (Veevers et al., 1964). J.A. Kaulback mapped the main area of Cambrian and Ordovician outcrop in the Bonaparte Gulf Basin, at Gap Point and south of Mount Rob; J.J. Veevers mapped the outliers at Dillon Spring and Ragged Range. P.J. Jones spent a week with J.A. Kaulback collecting fossils from some of the more important localities found by Traves and Öpik (Traves 1955). A.A. Öpik has made a preliminary study of the fossils (Appendix 3) and he is responsible for the division of the Cambrian and Ordovician sequence into faunal units, and for the palaeontological correlation of various sections.

Distribution

Cambrian and Ordovician sedimentary rocks crop out in two principal areas: (1) the main area, along the south-western margin of the Bonaparte Gulf Basin; and (2) the outliers of Gap Point, Mount Rob, Dillon Spring, and Ragged Range (Figure 1). South and east of these areas, which are the theme of this report, in the Lissadell and Dixon Range 1:250,000 Sheet areas, lie three major structural basins of Cambrian sediments: the Argyle Basin, the Rosewood Basin, and the Hardman Basin. The

Cambrian sediments overlie the Lower Cambrian Antrim Plateau Volcanics, which stretch in almost continuous outcrop from the Flora Valley, south of the Hardman Basin, to the Bonaparte Gulf Basin, and thence north-westward to the Katherine-Darwin region. To the north, Cambrian sediments re-appear in the Litchfield area and Daly River Basin of the Katherine-Darwin region.

TOPOGRAPHY

The Cambrian and Ordovician rocks of the Bonaparte Gulf Basin underlie part of the "Cambridge Gulf Lowlands" (Traves, 1955, Fig. 6; and see Cambridge Gulf 1:250,000 Topographic Sheet-SD52-14), a large area of sandy lowlands, grass-covered "black soil", and sandstone ranges up to 1,000 feet high, transected by water-courses and salt-arms. A belt of relatively high hills (Onslow and Pretlove Hills) 600 to 1,000 feet high and about 20 miles long, and elongated along the north-west strike, constitute the main Cambrian and Ordovician outcrop of the Bonaparte Basin. Two dendritic drainage basins, that of Sandy Creek, draining to the north-east and east, and that of Reedy Creek, draining into the Ord River to the south-west, have cut back on either side of this belt of hills, almost to the watershed, so that the belt is divided into two parts: the Onslow Hills to the north-west, and the Pretlove Hills to the south-east. The only planed and deeply weathered surface seen in the area is at locality 236, in the Onslow Hills.

Within the Bonaparte Gulf Basin, most of the Cambrian and Ordovician outcrops owe their eminence to faults, along which the originally friable sediments have been silicified into resistant exposures; thus, virtually all the prominent exposures within the Bonaparte Basin are bounded by faults.

The Cambridge Gulf Lowlands are bounded to the north by swampy salt-flats and the sea, to the south-west by the dissected Precambrian Kimberley Plateau, to the east by the dissected Victoria River Plateau, and to the south and south-east by the Carr Boyd Ranges and Burt Range, which, together with the Pincombe Range, mark the north-easternmost limit of a belt of highlands.

The Palaeozoic outliers south-west of the Bonaparte Gulf Basin lie within the Kimberley Plateau, with its high strike-ridges and mesas of Precambrian rocks. Within this province, and with the exception of the Ragged Range, the low strike-ridges of soft Palaeozoic sediments occupy broad valleys. The Ragged Range, with its impressive west-facing Blatchford Escarpment, is a cuesta, 25 miles long and four miles wide, that lies between hills of Proterozoic rocks.

STRATIGRAPHICAL SUCCESSION

NEW OBSERVATIONS

New observations made during field work in the Cambrian and Ordovician rocks in 1963, were included in Veevers, Roberts, Kaulback and Jones (1964), and are summarized below:

The following outcrops (thicknesses in brackets), hitherto mapped as Precambrian, were found to contain Cambrian fossils: Mount Connection (700 ft), the westernmost known outcrop of Cambrian rocks in the Bonaparte Gulf Basin; the Mount Rob outlier (3000 ft); the Gap Point outlier (700 ft); and the bed of the Ord River from Tarrara Bar three miles upstream (700 ft).

Outcrops hitherto mapped as Devonian and now found to contain Cambrian fossils are: a line of outcrops from a point five miles north of Hart Spring to Bald Hill; two hills five miles south-west of Point Spring (400 ft); the basal part of the Dillon Spring outlier; and Biconulites dolomite (5 ft), seven miles south-west of Ivanhoe Homestead.

The greater part of the Pretlove Hills, and the bulk of the Ragged Range (1,350 ft), which were hitherto mapped as Cambrian, were found to contain Devonian fossils; no fossils were found in the Elder Sandstone of the Hardman Basin, but all except the basal part of it is thought to be Devonian on other evidence.

GENERAL SUCCESSION

Precambrian.

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 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 relatively undeformed succession of sedimentary rocks.

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 Dam Site and continues into the Northern Territory, roughly along the eastern margin of the Bonaparte 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.

By far the greatest area of outcrop of Precambrian rocks consists of the younger undeformed 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 further 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.

Cambrian and Ordovician

Before 1963, the Cambrian and Ordovician rocks of the Bonaparte Gulf Basin and outliers were known from isolated fault blocks only. Traves (1955) wrote "... the sediments are strongly strike-faulted, so that, without detailed work, it is impossible to obtain a complete sequence. The strike faults, marked only by small quartz veins and some slickensides, are very hard to discern; but the displacement may be over 1,000 ft. and, within a few yards, the section may change from Middle Cambrian to Upper Cambrian or even Ordovician in age."

During 1963 three unbroken sequences were found in the Bonaparte Gulf Basin and near Mount Rob, which, together with smaller sections, indicate a total composite thickness of 4,500 feet of Cambrian and Ordovician sediments overlying the Antrim Plateau Volcanics. If the Blatchford Formation is added, the total is 4,900 feet.

In the Bonaparte Gulf Basin these sediments were collectively called the Carlton Formation by Noakes et al. (1952) and the Carlton Group by Traves (1955). They consist of a sandstone and dolomite sequence, which is divided into seven formations (Fig.2), all of which, except the Tarrara and Blatchford Formations (new names), were defined by Traves (1955). In descending order, these formations are:

	maximum thickness in feet	
Pander Greensand	600	+
Clark Sandstone	750	
Pretlove Sandstone	400	+
Skewthorpe Formation	200	
Hart Spring Sandstone	1260	
Tarrara Formation	1300	
Blatchford Formation	390	+
Total	4900	+

Except for the new formations, and with few stratigraphical corrections, this sequence is the same as that which Traves and Öpik (in Traves 1955) determined on fossil evidence alone, from isolated fault blocks.

MEASURED SECTIONS

In this chapter, we briefly describe the field relations, lithology, and palaeontology of the Cambrian and Ordovician rocks (and, in addition, for completeness, of the Devonian rocks of the outliers), as seen in certain favourable places. These details provide a basis for the description of formations, given in the next chapter.

The thickness of well-exposed sections was measured direct with an Abney level attached at right angles to a five-foot Jacob staff (Lahee, 1961, p.455). This method avoids over-estimating the thickness, as is done when thickness is measured using the geologist's eye-height as scale. This error is negligible (1.5% for 10° dip) in low-dipping rocks, but rapidly increases (5% for 18° dip, 10% for 25° dip, 15% for 32° dip) in rocks with steeper dips. Dips of 10° to 40° are common in the rocks described here, and hence the Jacob staff was almost universally used. Only rough estimates of thickness, based on horizontal distance and the dip of isolated outcrops, are available for sections whose outcrop is too poor for direct measurement.

Due to the faulted and scattered nature of the outcrops, about forty stratigraphical sections were studied in order to obtain an overall picture of the Cambrian and Ordovician stratigraphy. The thickest and most useful sections are described below. Measured columnar sections are illustrated at the back of this report, and in Figs. 9 and 19, where they are arranged in approximate order from north to south, and correlated with reference to known faunal units.

In the Bonaparte Gulf Basin and outliers, the lithologies of the Cambrian and Ordovician sediments and also of the younger Palaeozoic rocks are monotonous. Parts of certain units which are stratigraphically far apart are lithologically indistinguishable. The widespread strike-faulting in the Bonaparte Gulf Basin has juxtaposed many such units so that correlation and identification based on lithology alone is unreliable; fossils are the only means whereby isolated outcrops may be correlated.

A. Bonaparte Gulf Basin.

Southern Pretlove Hills: ssctions 232 and 245.

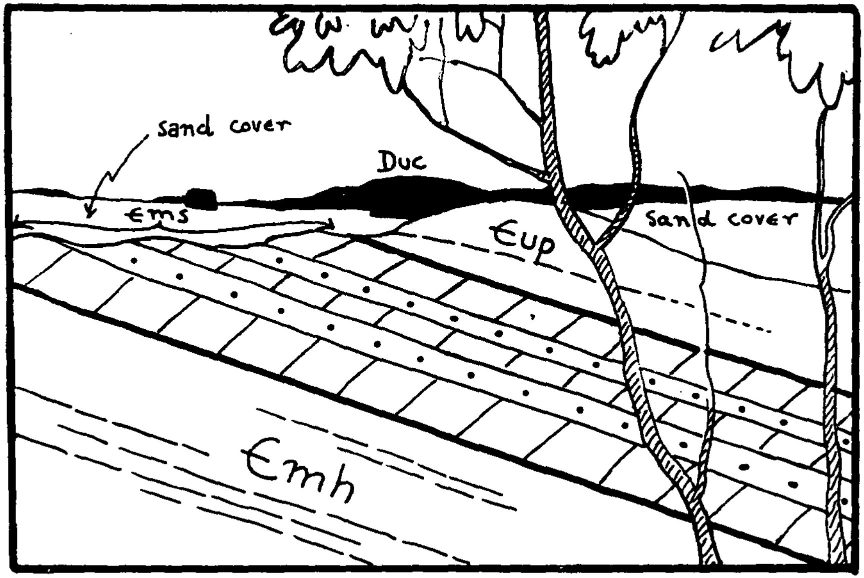
Section 232 (Fig. 3 and columnar sections) was measured along a creek bed in the sandy plain about two miles south of Skewthorpe Ridge. Combined with section 245 it provides an unbroken sequence from the lower Middle Cambrian to the Lower Ordovician. At the base of the section the Antrim Plateau Volcanics (fine-grained, dark, red-brown weathering amygdaloidal basalt in thin layers, with a north-east dip of 14^{o}, overlying vesicular brecciated basalt) are underlain by micaceous green and grey shale and mudstone indurated by silica, interbedded with poorly outcropping medium-grained quartzite. The shale and quartzite are probably Proterozoic, and dip north-east at 20^{o}-25^{o}. Further downstream (to the south-west) are poor exposures of shale and basalt. If this basalt is the same as that found upstream, its outcrop here indicates either the uneven erosional surface over which it flowed, or faulting.

Upstream, overlying an estimated 150 feet of Antrim Plateau Volcanics, are exposed about 40 feet of interbedded green and brown soft shale and mudstone, containing white veins of rubbly travertine (Plate 1A). The shale and mudstone are separated from the basalt by an estimated 100 feet of poorly outcropping, sand-covered green shale, and are succeeded upstream by an estimated 430 feet of no outcrop. This gap, which is inferred to indicate a continuation of the soft shale, is followed by 680 feet of fairly well-exposed fine-grained laminated red silty quartz sandstone with abundant mudflakes. Above the sandstone are 38 feet of prominently-bedded, grey algal dolomite with *Biconulites* and fragments of brachiopods and trilobites (an indeterminable species of *Redlichia*). This part of the section, underlain by the Antrim Plateau Volcanics, and extending up to, and including, the dolomite; is assigned to the Tarrara Formation. Further upstream, and overlying the dolomite, are about 1230 feet of Hart Spring Sandstone, a fine - to medium-grained, red-brown, silty, thin-bedded quartz sandstone with mudflakes, very similar to the sandstone of the Tarrara Formation. The Hart Spring Sandstone is overlain by the Skewthorpe Formation, which is cut off by a strike fault, which throws the Skewthorpe Formation down into renewed contact with an outcrop of Hart Spring Sandstone to the north. The section is assumed to be uninterrupted by major faults (see under "Tarrara Formation").

Section 245.

Section 245 (Fig. 3, and columnar section 245) was measured across a ridge south-west of Pander Ridge. On the southern side of the ridge, the Hart Spring Sandstone rises from the sandy plain in a steep 500-feet south-west-facing scarp of barren, fine - to medium-grained, cross-bedded and ripple-marked, silty, red-brown quartz sandstone with scattered mudflakes. About 400 feet of Hart Spring Sandstone were measured from the top of the scarp, so that the total thickness exposed is estimated to exceed 1,000 feet. The Skewthorpe Formation overlies the Hart Spring Formation, and its grass-covered, subdued yellow and grey outcrop contrasts with the ridged, spinifex-covered red and black scarp of the thinly-bedded

FIG. 4



The two sandstone interbeds in the Skewthorpe Formation at section 245, looking North towards the Devonian Cockatoo Sandstone in the background.

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Hart Spring Sandstone (Plate 1B). The Skewthorpe Formation consists of 135 feet of well-bedded oolitic and stromatolitic dolomite with some thin, flaggy, silty dolomite beds, interbedded with poorly outcropping, scree-covered, medium - to fine-grained quartz sandstone (fig.4), some of which is dolimitic. The sandstone makes up about one third of the Skewthorpe Formation in this section. Phosphatic brachioped shells occur throughout the dolomite, and most abundantly in the silty dolomite.

Overlying the Skewthorpe Formation, and extending down the dip-slope to the north-east, almost to the plain at the foot of the hills, lies the Pretlove Sandstone, 200 feet of white, pink, or yellowish, locally iron-stained, well-sorted medium-grained flaggy quartz sandstone, which contains sparsely fossiliferous beds with brachiopods, gastropods, and trilobite fragments, and is characterized by ferruginous and ripple-marked planes.

About 720 feet of greenish to reddish medium-grained glauconitic and friable red quartz sandstone of the Clark Sandstone overlie the Pretlove Sandstone in low, ribbed ridges which become isolated in the plain to the north-east. The Clark Sandstone contains abundant glauconite in its upper half, except for a few interbeds with no glauconite; the lower half is mainly of non-glauconitic quartz sandstone, yellow, sugary-white, or red, with a few glauconite sandstone beds, such as the very dark glauconitic sandstone with phosphatic brachiopod shells in the creek bed at the foot of the dip-slope of the hill.

Compared with the Pretlove Sandstone, the lower beds of the Clark Sandstone are more feldspathic, the lower friable, darker, more ferruginous, comparatively poorly sorted, richly fossiliferous, and more variable in lithology from bed to bed. The Clark Sandstone weathers black in rounded lumps which disintegrate at the blow of a hammer; outcrops are characteristically low, ribbed strike-ridges. In contrast, the Pretlove Sandstone is pink or yellowish, except where locally ironstained (it has a ferruginous matrix), generally harder, partially silicified, well sorted and very poorly fossiliferous; it contains little or no feldspar and has a uniform lithology from top to bottom. It crops out in pinkish-brown angular strike-ridges and (in other sections) in indurated high scarps and cliffs which readily break up into a scree.

The Upper Cambrian Clark Sandstone is overlain by the Lower Ordovician Pander Greensand. In this locality the contact is obscured by sand, on both sides of which the dip is 25°; elsewhere (p.16) the Clark Sandstone is seen to pass without a break into the Pander Greensand.

The Pander Greensand consists mainly of highly glauconitic poorly cemented quartz sandstone with numerous fragments of white phosphatic fossils. Some of the glauconite grains have broken down to iron oxides, giving a red, green and white speckled appearance to the rock. In places where the glauconite is not altered to iron oxides, the rock is dark-green. In other places there are interbeds and bands of medium-grained iron-stained quartz sandstone.

No determinable trilobites or brachiopods were found in the Pander Greensand of this locality, but some beds contain conodonts, which are visible under a hand-lens, a few with the unaided eye (sample CG245/17). From a preliminary examination, P.J. Jones (pers. comm.) determined these conodonts as Ordovician, including the same forms recorded by Öpik (in Traves, 1955).

The 150 feet of Pander Greensand measured in this section are cut off by poor outcrop and probably by strike-faulting, indicated by seree of slickensided silicified sandstone. To the north-west of the inferred fault are exposed 15 feet of fine-grained reddish-brown quartz sandstone with mudflakes and, in a ridge, about 60 feet of hard, silicified, thinly bedded fine- to medium-grained reddish quartz sandstone. Overlying this, in a low hill, are about 100 feet of pink and brown dolomite and dolomitic sandstone, dipping at 15° to the north-east. At the foot of the hill were found a floater of glauconitic dolomite with indeterminate obolid phosphatic brachiopods and a loose block of red sandstone containing poorly preserved Crustacea, probably phyllocariids. Fragments of obolid brachiopods were also found in situ in a dolomite bed. These brachiopods are not known to range beyond the Cambrian and Ordovician, and as Ordovician dolomite is not known in the Cambridge Gulf area, this dolomite outcrop is probably a down-faulted part of the Skewthorpe Formation. There is evidence of faulting (slickensides, quartz veins), and the occurrence of numerous strike faults, with a displacement of up to 2000 ft, has been proved in the broad valley to the north-west and elsewhere in Lower Palaeozoic rocks.

Hart Spring and the Onslow Hills: sections 209 and 236.

Between locality 245 and the Onslow Hills, numerous incomplete sections of Cambrian and Ordovician rocks have been measured (Figs. 3 and 5) at outcrops isolated and disrupted by faults. These sections confirm the succession shown in sections 232 and 245, and indicate lateral changes in individual formations. Some of them (section 240 and locality 243) are relatively large outcrops extending over three or four formations; others are little more than hillocks (e.g., Pander Ridge, Clark Jump Up), which contain incomplete sections only. The first complete section north of locality 245 was found near Hart Spring, in the Onslow Hills.

Hart Spring: Section 209.

At localities 208 and 209 (Figs. 6 and 7 and columnar sections), a cliff of thinly-bedded Hart Spring Sandstone overlies about 100 feet of dolomite and dolomitic sandstone of the Tarrara Formation, which is well exposed in two long benches, each capped by resistant dolomite, and separated from each other by about 40 feet of poorly exposed fine red sandstone. The lower bench is capped by a distinctively weathering 6-inch oncolite bed which contains, besides Biconulites, trilobite fragments (Redlichia) similar to those found in the equivalent dolomites of section 232 (sample CG232/4). No outcrop was found below the Tarrara Formation dolomite at localities 208 and 209, but in the creek bed in the valley immediately to the south-west were found poor outcrops of basalt, which are probably the Antrim Plateau Volcanics.

Section 209, measured through Hart Spring, contains about 520 feet of Hart Spring Sandstone with a north-easterly dip of 5° - 12°. The section was measured to a point at the foot of a small hill at locality 220 (Fig. 6), where measured section 220 (columnar sections) showed a further 85 feet of Hart Spring Sandstone which is overlain by the basal beds of the Skewthorpe Formation.

Section 236

At locality 236, about three miles east of Hart Spring the Cambrian succession is continuous from the Hart Spring Sandstone to the middle of the Clark Sandstone (Figs. 6, 8 and columnar sections). The Cambrian sediments crop out as a chain of hills which stretch approximately NNE/SSW along a fault separating them from a downfaulted block of Devonian sandstone to the west. The Cambrian (and Devonian) sandstones are silicified and strengthened along this fault, which has resulted in very good exposure throughout this section, so that a more complete fossil record is available from it than from the stratigraphically longer section 245, where outcrop is generally poor and fossils can be collected from low horizons only.

The formations are readily distinguishable in section 236 (Fig 8 and columnar sections). The rounded, locally rubble-covered slopes of the thinly-bedded Hart Spring Sandstone (of which only about 100 feet are exposed in the valley in which the section was measured) are overlain by the Skewthorpe Formation, which forms cliffs. The Skewthorpe Formation can easily be followed round the curve of the valley to its northern flank, where 150 feet of it are impressively exposed in a south-facing cliff (Section 238). The Skewthorpe Formation here consists predominantly of 5 to 10 feet beds of buff-grey, frequently iron-stained, hard sandy dolomite, which is partly stromatolitic and partly oolitic, and is rhythmically interbedded with soft brown friable sandstone. Lithological details are given below under the heading "Rock Units".

Above the Skewthorpe Formation lie 250 feet of Pretlove Sandstone, the lower two-thirds of which are in places almost obscured by scree. The upper part is exposed in a cliff of brown weathering, flaggy, white to pink, medium- to fine-grained iron-stained quartz sandstone which contains numerous ferruginised and ripple-marked planes.

450 feet of Clark Sandstone overlie the Pretlove Sandstone and extend to the top of the ridge (fossil locality CG236/13), where they overlook the downfaulted Devonian sandstone to the west. Along the top of the ridge is a hard, horizontal, ferruginised platform up to

2 feet thick, which cuts across the gentle dip of the Cambrian beds. This is probably an old land surface (Fig.8). To the north of fossil locality CG236/13 is a steep-sided narrow east/west-aligned valley, on the north side of which the section is continued (fossil localities CG236/13½-15) to the top of the northernmost ridge of the Cambrian outcrop. Here again the horizontal ferruginised plane truncates the gently dipping Clark Sandstone.

The lower third of the Clark Sandstone exposed in this section consists of a dark-red, medium-grained, glauconitic quartz sandstone with a ferruginous cement, similar to the equivalent part of the Clark Sandstone in section 245. This is succeeded by a sugary, friable, well-sorted medium-grained white quartz sandstone with rare glauconite (CG236/13½) and scattered small quartz pebbles at its top, which form the middle part of the Clark Sandstone. It is overlain conformably by a red, glauconitic, medium-grained quartz sandstone with an iron-oxide cement, which becomes increasingly ferruginous towards the top of the outcrop. The glauconite is altered to iron oxide, except in a few beds. Öpik (Appendix 3) finds a sharp break between the faunal assemblage at the top of the sugary white sandstone (faunal unit IX, Fig.9), and that collected from the ferruginous red sandstone only a few feet above it (faunal unit X, Fig. 9). The fossils in the upper red sandstone are fragmented (CG236/14-15), whereas fossils in the underlying white sandstone are comparatively intact (taking into account the common preservation of trilobites as glabellae or pygidia only). These observations, together with the difference in lithology between the two sandstone, and the presence of scattered pebbles along their contact, suggest an abrupt change in some important factor or factors controlling sedimentation at the end of the deposition of the white sandstone.

Ord River: Tarrara Bar - section 278, and Little Tarrara Bar - section 277.

Tarrara Bar: Section 278.

The Antrim Plateau Volcanics form a bar across the river (Fig.10) which gives its name to this locality and to the Tarrara Formation. The well-layered amygdaloidal, violet volcanics dip 30° in the direction of 70°. Overlying it, and upstream along the northern bank of the river, are exposed about 200 feet of the Tarrara Formation.

The exposed section consists of poorly outcropping fine red micaceous silty quartz sandstone (105 ft.), overlain by about 100 ft. of red, green and chocolate mudstone and shale, in the middle of which is a 20 ft. bed of green and grey silicified dolomite containing Biconulites and fragments of an indeterminable Redlichia. The shale above the dolomite bed contains abundant Biconulites.

Little Tarrara Bar: Section 277 (Fig. 10).

Almost two miles farther upstream (to the south), at Little Tarrara Bar, 510 ft.of dark-red fine-grained ripple-marked silty micaceous quartz sandstone are exposed along the eastern bank of the Ord River. They dip 20° - 45° in a south-easterly direction, and are overlain by about 85 ft of reddish dolomite. The dolomite contains beds of oolite, stromatolites, and quartz sandstone, and a dolomitic breccia (sample CG277/11, see Appendix 2), and a few glauconitic dolomite bands with phosphatic brachiopods similar to those found in the Skewthorpe Formation in most localities farther north. This dolomite is identified as the Skewthorpe Formation, and the underlying sandstone as the Hart Spring Sandstone. The Skewthorpe Formation dolomite is overlain by 150 ft of flaggy white to red iron-stained medium-grained quartz sandstone with silty shale bands at its top, which contains poorly preserved gastropods and brachiopods. This is probably the Pretlove Sandstone. Outcrop continues sporadically upstream on both sides of the river, but is complicated by faults.

South of Pincombe Range - Martin's Bluff: section 283

About 100 ft of Antrim Plateau Volcanics (amygdaloidal basalt) are exposed on the northern and western scarp of Martin's Bluff. Above the basalt, and separated from it by a 10-foot conglomerate of rounded, ill-sorted basalt pebbles in a coarse quartz sandstone matrix, are about 170 ft of barren finely banded chocolate, green and purple mudstone, shale, siltstone, and sandstone, which become more flaggy and poorly exposed towards their top, where they contain bands of basalt pebbles. This sequence is unconformably overlain by white quartz sandstone of the Devonian Cockatoo Sandstone. The striking lithological similarity of this shale and siltstone to that of the Tarrara Formation at Tarrara Bar, and their position overlying the Antrim

Plateau Volcanics indicate that they are probably part of the Tarrara Formation. In the absence of fossils, however, identification must be regarded as provisional only. The "agglomerate" referred to by Matheson and Teichert (1948) was not seen.

B. PALAEOZOIC OUTLIERS WEST AND SOUTH-WEST OF KUNUNURRA

Seven areas of outlying Palaeozoic rocks have been found west and south-west of Kununurra (Fig. 11). The localities are Ragged Range (Cambrian and Devonian), Mount Rob (Cambrian and probable Devonian), Gap Point (Cambrian, probable Ordovician and Devonian), Dillon Spring (Cambrian and Devonian), Deception Range (probable Cambrian and Devonian), an area 10 miles north-east of Dillon Spring (Cambrian), and an area 7 miles south-west of Ivanhoe Homestead (Cambrian and probable Devonian). The Dillon Spring, Deception Range, and Ivanhoe outliers were first described by Traves (1955, pp. 60, 61, pl.1), who regarded these outliers as Devonian; fieldwork in 1963 has shown that the basal parts of the Dillon and Ivanhoe outliers are Cambrian. The outliers of Mount Rob and Gap Point were discovered in 1963, following the air-photograph interpretation of Ruker (1963). Reeves (1948) and Traves (1955) regarded the entire Ragged Range as Cambrian; fieldwork in 1963 showed that the upper, conglomeratic part of the Range is Devonian.

GAP POINT SECTION 275 (Figs. 12 and 13).

About two miles south of Gap Point, and on either side of the Great Northern Highway where it crosses one of the upper tributaries of Parry Creek, lies a graben within the Precambrian terrain, consisting of 500 ft of fossiliferous Upper Cambrian and probably Lower Ordovician sediments which dip 25° to the south-east, unconformably overlain by an estimated 3000 feet of probable Devonian Cockatoo Sandstone, which dip 15° to the south-east.

The basal 200 ft of the Cambrian outcrop is a barren red medium- to fine-grained quartz sandstone with mudflakes, similar to the Hart Spring Sandstone. This is overlain, apparently conformably, by a medium- to coarse-grained quartz sandstone which ranges from yellow to red and becomes increasingly glauconitic towards its top. This sandstone contains trilobites and brachiopods (sample CG275/4) which indicate the uppermost time unit of the Upper Cambrian (unit X, Fig.9); this and the lower sandstone are identified as the Clark Sandstone. The overlying 50 ft of sandstone immediately below the unconformable Devonian Cockatoo Sandstone contains abundant glauconite, fragments of phosphatic brachiopods, and has the speckled, green, yellow and white colour of the PanderGreensand, but in the absence of microfossils and of diagnostic macrofossils, the identification of these beds as Pander Greensand remains tentative.

Using the K-Ar method on glauconite, M. Bofinger (pers. comm.) has determined the minimum age of these beds as 470 million years, or Lower Ordovician.

MOUNT ROB: SECTION 274 (Figs. 12 and 13)

An estimated 2700 feet of Cambrian sediments crop out south of Mount Rob (which itself is Precambrian). They probably form a continuous succession from the Antrim Plateau Volcanics to the Clark Sandstone, and are unconformably overlain by Devonian sediments about 3,000 feet thick. The Palaeozoic rocks are faulted down to the west against the Proterozoic. To the east, the Antrim Plateau Volcanics unconformably overlie the Proterozoic. Along the unconformity the Devonian sediments have a dip generally shallower by about 5° than the Cambrian.

The Antrim Plateau Volcanics cover large areas but in most places are obscured by soil and rubble; only 150 ft were measured in this section. The Cambrian sediments crop out in low, ribbed strike ridges with a general westerly dip of 25° - 35°. Overlying the basalt in section 274 (which includes sections 54 and 55) are 175 ft of fine to medium silty red quartz sandstone with mudflakes, which are overlain by a 20 ft, grey Biconulites dolomite, exposed in the creek bed at CG54/6 and in several localities farther south. These beds are identified as either the Blatchford Formation or the Tarrara Formation and for simplicity of presentation, and without prejudice, are denoted on the map as Tarrara Formation. The contact between them and the underlying Antrim Plateau Volcanics is concealed in section 274, but farther south, in section 273, it is marked by a thin bed of brecciated sandstone and siltstone, with rare basalt clasts (sample CG273/12). In section 273 the sandstone member of the Tarrara Formation is 500 ft thick.

800 ft of barren fine- to medium-grained red silty quartz sandstone with mudflakes overlies the dolomite of the Tarrara Formation. These beds have been placed in the Hart Spring Sandstone because of their lithology and position overlying the Biconulites dolomite. They are overlain by a 10-foot bed of dolomite, another 100 ft of similar red medium-to-fine silty quartz sandstone, and a second 30 foot dolomite bed (locality CG54/3). No fossils have been found in the dolomites or in the sandstone between them: the dolomites are pink, vuggy and locally flaggy, and are interbedded with thin dolomitic sandstone beds. The dolomites and the intervening sandstone are tentatively identified as the Skewthorpe Formation; they lack fossils, oolites, and stromatolites, and are closest in lithology to the Skewthorpe Formation exposed at Little Tarrara Bar (section 277).

Overlying the dolomite beds are about 830 ft of sandstone very similar (but containing slightly larger quantities of glauconite) to the quartz sandstone between the Skewthorpe Formation dolomites, and to the Hart Spring and Tarrara Formation sandstones in this section. Towards the top of this sandstone, at locality CG55/1, trilobites belonging to faunal unit V (Mindyallan) indicate correlation with the Pretlove Sandstone (Fig. 9). The three prominent dolomite marker beds in this section provide the only means of dividing the 2000 ft of lithologically homogeneous sandstone below locality CG55/1 into formations.

A distinct lithological change marks the boundary between the Pretlove Sandstone and the overlying 560 ft of Clark Sandstone, which contains diagnostic trilobites and brachiopods. The lower third of the Clark Sandstone in this locality consists of fossiliferous red, dark-red, and yellow medium quartz sandstone with some white phosphatic brachiopod fragments, and differs from the underlying Pretlove Sandstone mainly in its high glauconitic content. The upper two-thirds are medium to coarse, red yellow, and buff,dark-weathering ripple-marked and cross-bedded glauconitic quartz sandstone, with interbeds containing abundant white phosphatic brachiopods (usually fragmented). In the middle of the formation is a three-inch ferruginised quartz-pebble band, which marks the break between faunal unit IX (sample CG274/2) below it, and faunal unit X (sample CG274/4) above it. This is the same break which is found in the equivalent part of the Clark Sandstone in sections 236, 245 and 202/4, and it is emphasised here, as in the other sections where it has been observed, by fragmented fossils in the overlying beds.

(?) DEVONIAN

No fossils have been found in the rocks that unconformably overlie the Cambrian and probable Ordovician rocks at Gap Point and Mount Rob, so that the identification of the overlying rocks as the Upper Devonian Cockatoo Sandstone is tentative. This identification is based on similarities with the Cockatoo Sandstone exposed 12 miles eastward in the Dillon outlier, which comprises 2,400 feet of white, red-brown, and yellow quartz sandstone, with minor dolomitic beds, and one sandstone bed containing pelecypods.

The (?) Cockatoo Sandstone at Gap Point and Mount Rob is poorly exposed in low strike ridges, and continuous sections cannot be measured. Sufficient dips, however, were measured to provide a basis for constructing the cross-sections shown in Figure 13. The (?) Devonian sequence at Mount Rob is an estimated 3,000 feet of quartz sandstone with interbedded dolomitic sandstone beds at the top, and at Gap Point an estimated 3,000 feet of quartz sandstone.

The lower part of the sequence is friable buff to pink medium-grained quartz sandstone (samples 273/7A,B, 274/8,11). The grains (predominantly quartz, minor chert and feldspar) are coated with overgrowths, and weakly cemented with films of limonite. At Gap Point, the basal sandstone (275/6) contains rare grains of glauconite.

The dolomitic sandstone in the upper part of the sequence (273/2,3) also contains rare glauconite, and is interbedded with green biotitic siltstone. Tubes, possibly worm tubes, are found in these rocks. The youngest preserved beds (273/1) consist of pink fine-grained quartz sandstone, which is a mosaic of overgrown quartz grains. As in the Cockatoo Sandstone of the Dillon outlier, tourmaline is a common accessory.

Dillon Spring outlier (Fig.11, and columnar section 83-48-49).

The Palaeozoic outlier at Dillon Spring is a half structural basin with its original eastern part cut off by a major, unnamed, fault. Excluding the Antrim Plateau Volcanics, which occupy an unmeasured thickness at the base, the Palaeozoic rocks have an estimated total thickness exceeding three thousand feet, comprising an estimated 860 feet of Cambrian red-brown quartz sandstone, with a thin bed of fossiliferous dolomite near the base, unconformably overlain by 2,180 feet of Devonian (probably Upper Devonian) white and red-brown sandstone, with minor dolomite bands, and one pelecypod-bearing bed.

Antrim Plateau Volcanics. Broad areas of black soil in the northern part of the basin, and three isolated areas in the north-west and west parts, are underlain by Antrim Plateau Volcanics. Outcrop is poor, and no estimate of thickness was made. Two samples were collected: 83/1A is deeply weathered basalt with laths of plagioclase and irregular masses of hematite, containing amygdales of quartz, hematite, and magnetite; 83/1B is a tholeitic basalt, porphyritic in plagioclase and augite. As mentioned above, the Volcanics occupy the base of the basin; but a possible exception is on the southern edge, at Optic Hill, where silicified closely jointed quartz sandstone overlies Proterozoic quartzite. The sandstone is probably Devonian Cockatoo Sandstone, and the junction is probably an unconformity and not a fault, so that in the southern part of the Dillon outlier, the Cambrian basalt and sediments are overlapped by Devonian sandstone. Another outcrop of sandstone, 1 mile south-east of Optic Hill, is also regarded as probably Cockatoo Sandstone.

Cambrian sedimentary Rocks (Fig. 11). These comprise a poorly exposed basal unit, with a six-inch bed of *Biconulites* dolomite (83/3) near the junction with the Antrim Plateau Volcanics, overlain by an estimated 650 feet of thin-bedded fine to coarse red-brown quartz sandstone. *Biconulites* is the only fossil so far found in this sequence, which may be closely compared, on the one hand, with the Tarrara Formation and the overlying Hart Spring Sandstone of Cambridge Gulf, and, on the other, with the Blatchford Formation of the Ragged Range. For simplicity of presentation, and without prejudice, we designate the unit at the base of the sedimentary succession of the Dillon outlier as Tarrara Formation, and the overlying red-brown sandstone as Hart Spring Sandstone. This uniformly thin-bedded sandstone contains rare beds with ripple mark, tabular cross-bedding, and mud pellets, and, 60 feet beneath the unconformity, pebbles of quartz and quartzite. Sample 48/1 contains rare glauconite. In the sandstone, quartz grains have been enlarged by secondary growths of quartz over originally well-rounded grains coated with hematitic clay. The sandstone lacks cement except for small areas cemented by hematite, and is consequently friable and highly porous.

The boundary between the Hart Spring Sandstone and the overlying Cockatoo Sandstone is an erosional unconformity, without visible angular discordance. The erosional unconformity is best seen four miles north of Optic Hill, at the base of section 49. At this locality, 230 feet of Hart Spring Sandstone are exposed in the scarp, and are overlain by white quartz sandstone of the Cockatoo Sandstone. One mile north of 49/1, the Hart Spring Sandstone gives way laterally to Cockatoo Sandstone, which occupies the whole scarp. The Devonian rocks of this locality are not faulted, and the relief on the unconformity (at least 230 feet) indicates the minimum erosional relief that existed before Devonian deposition.*

Devonian. The Devonian succession of the Dillon outlier (columnar section 83-48-49) exceeds 2,000 feet of quartz sandstone, white at the base and top, elsewhere red-brown and yellow, with minor dolomitic beds, and one sandstone bed containing peleoypods. Traves (1955) overlooked the unconformity at the base of the Devonian succession, and grouped with the Devonian what is now regarded as the Hart Spring Sandstone.

The several subdivisions of the succession are readily visible in the air photographs. The basal unit (interval 0 - 480 feet) and the topmost unit (1880-2180) consist of strongly jointed friable white sandstone, indistinguishable from parts of the Cockatoo Sandstone east

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* The section through the Cockatoo Sandstone was measured above the outcropping Hart Spring Sandstone at locality 49, and the thickness was found to be 2,180 feet. The Cockatoo Sandstone is at least 230 feet thicker one mile north of locality 49/1, to give a total thickness of 2,410 feet.

of Kununurra. The interval between these units (480-1880) is red-brown to pink friable quartz sandstone with minor beds of grey glauconitic sandy dolomite and dolomitic quartz sandstone. Throughout the Devonian section, the quartz sandstone lacks cement; the originally rounded quartz grains are now angular with secondary overgrowths.

Dickins (in Traves, 1955, p.61) identified pelecypods from 880 feet above the base as Parallelodontidae gen.cf. Leptodesma sp., and says (pers. comm.) that they are indistinguishable from forms collected from the Cockatoo Sandstone at Mount Cecil and from the Ragged Range Conglomerate.

Deception Range outliers

The outlying Palaeozoic rocks of the Deception Range lie west of a zone of intensely sheared and silicified rocks cut by the Ivanhoe Fault. At locality 32 (Fig. 11 and columnar section 32), discovered following Ruker (1963), a sequence of 220 feet of red and grey quartz sandstone and 530 feet of white quartz sandstone occupy a half structural basin which is a copy, on a smaller scale, and without fossils, of the nearby Dillon outlier. This basin unconformably overlies Proterozoic sandstone. The basal 220 feet of grey-green chalcedonic quartz sandstone and red-brown quartz sandstone are tentatively identified as Hart Spring Sandstone, and are overlain, probably at an erosional unconformity, by 530 feet of white sandstone, tentatively identified as Cockatoo Sandstone, which on the south side of the basin, rests direct on Proterozoic rocks. Lying close to the Ivanhoe Fault, the entire section is affected by close joints and small-throw faults. No fossils were found.

A few miles southward, at locality 33, vertical dolomitic quartz sandstone lies on the western side of the Ivanhoe Fault. Two miles westward, at locality 34, the Palaeozoic rocks are less obviously affected by the Fault, and the steepest dip is 15°. Forty feet of medium-bedded pink sandy dolomite overlain by 100 feet of quartz feldspathic sandstone are faulted down against basalt. The dolomite in a micro-grained mosaic contains 15% of poorly sorted angular quartz grains, and small amounts of mica, tourmaline, and glauconite, and is indistinguishable from samples from locality 49/11, in the Devonian part of the Dillon outlier. At locality 34/1, the overlying sandstone contains abundant ripple marks, and one-and-a-half miles south-westward, at locality 34/4, abundant tabular cross-beds. Measurements of these sedimentary structures are summarized in Table 1 and Figure 14.

No fossils were found at localities 33 and 34, and these rocks are regarded merely as undifferentiated Palaeozoic, probably Cambrian Tarrara Formation and Hart Spring Sandstone, or Devonian Cockatoo Sandstone, because of their similarities with parts of both the Cambrian and Devonian successions of the Dillon outlier. Traves (1955, plate 1) mapped these localities as Cockatoo Sandstone, heedless of the warning expressed in the name of this area.

Localities 83/2 and 84/1.

At locality 83/2, 10 miles north-east of Dillon Spring, basalt of the Antrim Plateau Volcanics is overlain by a thin bed of grey glauconitic dolomite with Biconulites (tentatively identified as Tarrara Formation) in turn overlain by red-brown glauconitic dolomitic quartz sandstone with clay pellets (Hart Spring Sandstone). These rocks are affected by the same fault that cuts the Dillon outlier, and some beds are overturned.

At locality 84/1, 7 miles south-west of Ivanhoe Homestead, and immediately east of the Ivanhoe Fault, glauconitic dolomite with Biconulites (probably Tarrara Formation) is succeeded by red-brown quartz sandstone (Hart Spring Sandstone) and white quartz sandstone (Cockatoo Sandstone). These rocks are locally silicified and sheared, and no estimates of their thickness can be made. Traves (1955, p.61) doubtfully referred the dolomite and the brown sandstone to the Cockatoo Sandstone.

Directional sedimentary structures

Measurements of directional sedimentary structures in the Dillon and Deception Range areas, corrected for secondary tilt, are summarized in Table 1, and those with significant means in Figure 14; the distribution of ripple-mark azimuths at locality 34/1, with an insignificant mean, is also given for comparison.

Localities 49/2 and 49/3 lie within the basal 200 feet of the Cockatoo Sandstone of the Dillon outlier, and the difference between their mean dip azimuths is insignificant. In turn, the mean dip azimuths of 270° and 285° at these localities do not differ significantly from the dip azimuth of 268° at locality L14, 100 feet above the base of the Ragged Range Conglomerate. This dip azimuth is not general in the Ragged Range, as is shown by measurements on the same bed at 53/1, ¾-mile north of L14, which have a mean of 200°, showing that the depositing currents shifted from south-south-westward to westward. Nevertheless, the agreement between one of the mean dip azimuths of the Ragged Range and the mean of corresponding beds in the Dillon outlier indicates that at least some of the basal beds of the Cockatoo Sandstone at the Dillon outlier and of the Ragged Range Conglomerate were deposited from dominantly westward currents.

The mean dip azimuth at locality 34/4 (Palaeozoic, probably either Cambrian or Devonian) of 213° lies within the range 200° to 268 ° found near the base of the Ragged Range Conglomerate, but the precise age of the rocks at 34/4 is unknown, and as yet this azimuth cannot be related to azimuths of coeval rocks.

TABLE 1 : statistics of directional sedimentary structures

Locality	n	θ	P_{θ}	s^2	s_{θ}^2	difference between means	significance (p)
		A. Tabular cross-bedding					
34/4	18	213°	$<10^{-5}$	-	-		
48	9	312°	> 0.05	-	-		
49/2	8	285°	$<10^{-3}$	286	36	15°	> 0.10 N.S.
49/3	15	270°	$<10^{-5}$	639	43		
49/10	11	4°	> 0.10	-	-		
		B. Ripple Mark					
34/1	15	95°(275°)	> 0.10	-	-		
		C. Current lineation					
49/7	7	49°(229°)	> 0.05	-	-		

Note. For explanation of symbols, see Table 2.

RAGGED RANGE (Figure 15)

Cambrian dolomitic quartz sandstone and siltstone and glauconitic dolomite (the Blatchford Formation) crop out in the Blatchford Escarpment of the Ragged Range; they overlie unconformably the Antrim Plateau Volcanics, and are overlain with angular unconformity, and in the southern part of the Ragged Range overlapped, by the Devonian Ragged Range Conglomerate.

Blatchford (1928), after whom we propose naming the west-facing Blatchford Escarpment of the Ragged Range, was the first geologist to record observations of the sandstone and conglomerate of the Range; failing to find fossils, he left open the question of the age of the conglomerate. Reeves (1948) found that the conglomerate is underlain by 'about 300 ft of red sandstone and sandy shale in which there are thin beds of grey siliceous limestone, containing the Lower Cambrian pteropod (Salterella hardmani). The red sandstone conglomerates overlying these 300 ft of sandstone and shale, we conclude are equivalent to the Mt. Elder Series, Middle Cambrian in age according to Teichert and Matheson.' Traves (1955) identified the shale and limestone as part of the Middle Cambrian Negri Group, and dated the overlying conglomerate as Middle Cambrian also, on the basis of its 'rapid transition from shales of the Negri Group'.

During visits to the Ragged Range in 1963, K.A. Plumb and J.J. Veevers discovered trilobites (subsequently dated by A.A. Öpik as possibly late Lower Cambrian) in brown siltstone overlying the Biconulites dolomite, an angular unconformity between the Cambrian dolomitic sandstone and the Ragged Range Conglomerate, and fossils in the Conglomerate that indicate Devonian, probably Upper Devonian.

Blatchford Formation (defined herein)

The Blatchford Formation is a sequence, at least 390 feet thick, of grey-green and brown dolomitic siltstone interbedded with fossiliferous glauconitic dolomite, overlain by cross-bedded fine-grained brown dolomitic quartz sandstone. The Formation unconformably overlies the amygdaloidal basalt of the Antrim Plateau Volcanics, and is overlain, with angular unconformity, by the Devonian Ragged Range Conglomerate.

The outcrop of the Formation (Fig. 15) extends 20 miles along the Blatchford Escarpment from a point four miles south of the confluence of Cabbage Tree Creek and the

Dunham River to a point nine miles north of Glenhill Homestead. Most of the outcropping Blatchford Formation dips gently eastward, but at locality L13(16°14½'S, 128°22'E) (Fig. 16), chosen as type locality, the Formation dips eastward as steeply as 25 degrees.

Two measured sections, L12 (columnar sections), situated immediately west of Conglomerate Hill, 12 miles south of L13, and L13 (columnar sections), show the range of lithology. The grey-green silty dolomite (sample L13/2) that occupies the interval 60-70 feet in section L13 consists of dolomite (70%) in a fine crystalline mosaic, angular quartz grains (25%) 20 to 100 microns across, and small amounts of glauconite, biotite, and muscovite, and is probably a dolomitized silty calcite mudstone. The glauconitic dolomite is a mosaic of fine-grained dolomite (95%), with rare patches of rhombs, with large grains (up to 3mm long) of glauconite (4%), possibly as replacements of echinoderms, and rare angular silt grains of quartz. The fine-grained dolomitic quartz sandstone (as represented by sample L14/1 from a nearby section) consists of fine angular sand grains of quartz (60%), some with secondary overgrowths, set in a mosaic of fine dolomite, and rare muscovite, and with narrow calcite veins along the bedding.

The only fossils found in section L13 are Biconulites and probable worm tracks, but at locality 51/1, five miles south-west of L13 (Fig.16), trilobites were found in brown siltstone that lies 20 feet above glauconitic dolomite with Biconulites. According to A.A. Öpik, these trilobites possibly indicate late Lower Cambrian, so that the Blatchford Formation is regarded as older than the Cambrian sedimentary succession of the Cambridge Gulf area to the north, and the Negri Group to the east and south-east.*

Upper and lower limits. The shape of the surface separating the Antrim Plateau Volcanics and the Blatchford Formation is not precisely known. That it is a structural unconformity is seen at locality 51 (Fig. 16), where faulted Volcanics are overlain by undeformed Blatchford Formation. Immediately south of locality L13, a fault with similar trend cuts all three formations, but,

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* Matheson & Teichert (1948) regarded the Negri Group as late Lower Cambrian; Öpik (in Traves, 1955) revised the age to Middle Cambrian.

as indicated by more intense deformation in the Volcanics, this fault was probably initiated before the deposition of the Blatchford Formation and Ragged Range Conglomerate, and was later re-activated. Evidence to show that this surface is also an erosional unconformity has yet to be found.

The discovery of pelecypods and gastropods, probably of Upper Devonian age, in the Ragged Range Conglomerate, and the recognition of an angular unconformity between the Blatchford Formation and the Ragged Range Conglomerate have led to the removal of the Conglomerate from the Cambrian, and point further to the possibility that at least part of the Elder Sandstone of the Hardman Basin, with which Reeves (1948) and Traves (1955) identified the Conglomerate, is itself Devonian. This possibility is recognised by Dow et. al. (1964) who have split off an upper unit from the Elder Sandstone.

Unless viewed from favourable points, such as the one from which the photographs of Plate 3A and Plate 4 were taken, the junction between the Blatchford Formation and the Ragged Range Conglomerate appears to be merely an erosional unconformity of low relief. In fact, despite the appearance of conglomerate immediately above the unconformity, first impressions lead one to group the lower part of the Conglomerate with the Blatchford Formation, and to subdivide the overlying part of the Conglomerate into various units separated by conspicuous erosional unconformities (in effect, large-scale cut-and-fill structure). About nine miles north of Glenhill Homestead, the Conglomerate overlaps the Blatchford Formation to rest direct on the Volcanics, and, east of the Ragged Range, near the south-west tip of the Carr Boyd Range, the Conglomerate rests direct on Precambrian rocks.

Ragged Range Conglomerate.

Devonian pebble, cobble, and boulder quartzite conglomerate and quartz sandstone, up to 1350 feet thick, crop out in the Ragged Range and a short distance to the south (Fig.15). The Conglomerate unconformably overlies Precambrian rocks in the south-east, and Antrim Plateau Volcanics and Blatchford Formation in the west. The north-east and south-west parts of the Conglomerate are faulted down against Precambrian rock.

As mentioned above Blatchford (1928) was the first geologist to record observations of the conglomerate and sandstone of the Ragged Range. He noted such salient features as the lateral passage of conglomerate through alternating conglomerate and sandstone to sandstone, the crumbly nature of the sandstone, the quartzite composition and perfect rounding of the phenoclasts, and, failing to find fossils, left open the question of age. As related above, Reeves (1948) and Traves (1955) regarded the Conglomerate as Cambrian.

The Ragged Range Conglomerate is a sequence up to 1350 feet thick of red pebble, cobble, and boulder quartzite conglomerate and yellow, pink, and red quartz sandstone. The length of outcrop is 36 miles, and its width ranges from 4 to 11 miles. The Ragged Range is a cuesta with gentle eastward dip; the north-east part of the Range is bounded by faults of the Ivanhoe Fault system, which continue south across the Range to the Glenhill Station area, where the faults mark the western limit of the Conglomerate. Between Flying Fox Bore and the southernmost outcrop, the Conglomerate is poorly exposed in a gentle north-east slope. The easternmost mapped outcrop of the Conglomerate is situated 5 miles north-east of Flying Fox Bore. Gentle dips prevail except in the central-eastern part of the Range, where dips of 25° are common, and locally along faults.

The proportions of conglomerate and sandstone change markedly from place to place, as seen by a comparison of sections L14-L15 (Fig. 16), which is dominantly sandstone, and section L12 at Conglomerate Hill (columnar sections), 13 miles southward, which is dominantly conglomerate. The variation in lithology is indicated in the air-photograph patterns (Plate 5); for example, in the composite section across the northern part of the Range (L14-L15)(Fig.16), the conglomeratic sandstone parts of the section (intervals 0-100 feet, 465-475 feet, 640-650 feet) underlie smooth barely dissected cuesta surfaces, and the sandstone parts underlie deeply and minutely etched hills criss-crossed with numerous joints. Traced southward, the conglomeratic sandstone thickens, and is dissected into smooth rounded spurs by a medium-textured trellis pattern of water-courses. South of locality 51, the minutely etched and jointed sandstone wedges out entirely to give way to a monotonous conglomeratic sandstone terrain in which the only variety is provided by the nearly vertical bluffs of conglomerate in the Conglomerate Hill area. These bluffs, which rise to heights of 700 feet above the underlying conglomeratic sandstone, are deeply dissected along joints into beehive shapes, with smoothly sculptured sides (Plate 3,B). In the southern part of the Conglomerate, south of Flying Fox Bore, the higher ground in the west underlain by small rounded hills of conglomeratic sandstone passes eastward into scree-covered foothills crosssed by broadly spaced tree-lined water-courses cut into alluvium.

Throughout mostof the outcrop, the phenoclasts in the conglomerate uniformly consist of quartzite and the matrix of quartz sandstone, to the virtual exclusion of other lithologies. Traves (1955) noted pebbles and boulders of strongly weathered granite in the north-west part of the Range, and samples from the southern part of the outcrop are fine pebble arkose conglomerates. The sandstone is everywhere crumbly; thin sections show a pressure solution fabric of quartz grains coated with a film of red-brown clay.

Pelecypods and gastropods were found at localities 52/1 and 53/2. The fossils are poorly preserved as impressions in medium to coarse laminated red and brown quartz sandstone. According to J.M. Dickins (pers. comm.), the pelecypods at 52/1 are Parallelodontidae gen.cf. *Leptodesma* sp., which is found also in the Cockatoo Sandstone of the Dillon Spring area and at Mount Cecil.

The dips of tabular cross-beds were measured at three localities, corrected stereographically for secondary tilt, and the corrected values analysed to determine the mean azimuth and its statistical significance. The results are given in Table 2. The method of analysis follows Curray (1956), abd the statistical significance of the difference between means was tested by Student's *t*-test. A significane level of 5% ($p < 0.05$) was adopted.

Since the probability that the value of θ at locality L2G could have arisen by chance from a random distribution exceeds 5%, this value is rejected as insignificant. The mean azimuth values from localities L14 and 53/1 are significant, and the differences between these means is also significant. In other words, at localities L14 and 53/1, which are situated only $\frac{3}{4}$-mile apart on the same bed, the directions of the depositing currents shifted from south-south-west to westward. Obviously many more measurements at numerous localities would be required to map the variable pattern of the depositing currents, but the present evidence nevertheless indicates that west or south-west currents were important depositing agents at least in the basal part of the conglomerate. These currents flowed across or counter to the local depositional slope, which, as indicated by the change from conglomerate to sandstone, contained a northward component.

TABLE 2.

Locality	n	$\bar{\theta}$ (o)	$P_{\bar{\theta}}$	s^2	$s^2_{\bar{\theta}}$	difference between means	significance (p)
L2G	10	278	> 0.05	-	-		
L14	12	268	< 0.02	3,464	287	68	< 0.01
53/1	12	200	$< 10^{-3}$	1,438	120		

n = number of dip measurements

θ = mean azimuth

$P_{\bar{\theta}}$ = probability that the mean azimuth could be obtained by chance from a random distribution

s = standard deviation of azimuth distribution

$s_{\bar{\theta}}$ = standard error of the mean azimuth

THE FORMATIONS

ANTRIM PLATEAU VOLCANICS (Traves, 1955)

The Antrim Plateau Volcanics are a discontinuous sheet of basalt and minor interbedded agglomerate and tuff, up to 3,000 feet thick, that covers large areas in north-western Australia. In the area described in this report, exposures are poor, and the basalt is generally strongly altered.

Along the south-western margin of the Bonaparte Gulf Basin (Figure 1), the Antrim Plateau Volcanics crop out intermittently between the Cambrian sediments, and disappear beneath Recent coastal deposits a few miles north-east of Mount Connection. Scattered outcrops of the Volcanics between Wyndham and Ragged Range lie at the base of the Palaeozoic outliers. Isolated outcrops of the Volcanics at Martin's Gap, at Kununurra and south-south-eastward, north of Cockatoo Spring, and south-south-east and north-north-east of Spirit Hill, are the only representatives of Cambrian rocks so far found on the southern and south-eastern margin of the Bonaparte Gulf Basin. Due to poor outcrop, the thickness of the Volcanics in the area studied was not measured, but it is estimated nowhere to exceed 500 feet; along the south-eastern margin of the Bonaparte Gulf, it is probably less than 100 feet thick.

Morgan (Appendix 4) studied a small suite of specimens, and found that they are sparsely porphyritic in plagioclase with minor augite, and have a groundmass with an intersertal and basaltic texture. Various specimens contain black iron oxide, interstitial chlorite vein quartz, and brown biotite. Devitrified glass and green smectite pseudo-morphing olivine were also seen. Most specimens are amygdaloidal, commonly in quartz, rarely with calcite, smectite, and chlorite. Xenoliths of sandstone were found in basalt from the area south-south-east of Spirit Hill. Morgan points out that the altered basalts resemble spilite, and that their general similarity to a relatively unaltered specimen of tholeitic basalt suggests that most of the basalt was altered after extrusion, possibly by a combination of metasomatism and diagenesis.

No trace of asphaltite, which is associated with the Antrim Plateau Volcanics in the Negri River area, was found.

A marked erosional and angular unconformity separates the Antrim Plateau Volcanics from the underlying Proterozoic rocks.

In the Ragged Range the Volcanics are overlain by the late Lower Cambrian Blatchford Formation at a low-angle unconformity indicated by certain faults in the Volcanics which do not affect the Blatchford Formation. Hence, at least in this area and probably elsewhere too, the Volcanics were deposited, weathered, and locally faulted before the late Lower Cambrian. In the Hardman Basin, Dow et al. (1964) have discovered thick profiles of deep weathering at the top of the Volcanics, which are overlain by early Middle Cambrian sediments. At Martin's Gap beds of basalt conglomerate in the sandstone and siltstone that overlies the Volcanics indicate local erosion of the Volcanics probably during the early Middle Cambrian.

Along the southern and south-eastern margins of the Bonaparte Gulf Basin, Volcanics are overlain at a low-angle unconformity by the Upper Devonian Cockatoo Sandstone. A few miles north of Cockatoo Spring (locality 81/7), the Volcanics are overlapped by the Cockatoo Sandstone, which rests direct on Proterozoic rocks.

BLATCHFORD FORMATION (defined herein).

The Blatchford Formation is a sequence, at least 390 feet thick, of grey-green and brown dolomitic siltstone interbedded with fossiliferous glauconitic dolomite, overlain by cross-bedded fine-grained brown dolomitic quartz sandstone. The Formation unconformably overlies the Antrim Plateau Volcanics, and is overlain, with angular unconformity, by the Devonian Ragged Range Conglomerate.

The outcrop of the Formation extends 20 miles along the Blatchford Escarpment of the Ragged Range. Most of the outcropping Formation dips gently eastward, but at Locality L13 (Lat. 16°14½'S, Long. 128°22'E), chosen as type section, the Formation dips eastward as steeply as 25 degrees.

The only fossils known in the Formation are metadoxidid trilobites, which possibly indicate late Lower Cambrian (Öpik, App.3), and <u>Biconulites.</u>

Further details are given under the description of the Ragged Range, which is the only known locality.

TARRARA FORMATION (defined herein)

The Tarrara Formation is a sequence, at least 700 feet thick and possibly as much as 1300 feet thick, of red micaceous silty quartz sandstone, green, chocolate and red shale and mudstone, and grey or red fossiliferous dolomite. The Formation overlies, apparently conformably, the Antrim Plateau Volcanics, and is conformably overlain by the Hart Spring Sandstone. The type section is the right bank of the Ord River at Tarrara Bar (section 278: Lat. 15°34'S, Long. 128°41'E). The only other known localities of the Formation are section 232, south of Clark Jump Up, and section 209, near Hart Spring. Section 232 contains an estimated 1300 feet of Tarrara Formation, half of which is obscured by sand. The upper part is represented by 680 feet of red laminated silty quartz sandstone with mud flakes, capped by 38 feet of grey-green fossiliferous sandy and oncolitic dolomite; and the lower part by a single outcrop only, of 40 feet of shale and mudstone. Hence the content, structure, and thickness of the lower part of the Tarrara Formation in this section are almost entirely unknown, and the only reliable estimate of thickness in this section is at least 700 feet. The Tarrara Formation in section 209, near Hart Spring, is 65 feet of red-grey fossiliferous dolomite overlain by 40 feet of red quartz sandstone interbedded with dolomite at the top. The dolomite at each of these localities contains fragments of an indeterminable species of <u>Redlichia</u> first recorded by Öpik (1957, p.83), which indicates Unit II (Öpik, App.3). Other fossils are fragmented brachiopods, stromatolites, and <u>Biconulites</u> cf. <u>hardmani</u>, which, at Tarrara Bar (locality 278/2) occurs also above the dolomite in silty shale.

<u>Biconulites</u> dolomite is also known in the outliers. In the Blatchford Formation of the Ragged Range, the <u>Biconulites</u> dolomite is overlain by siltstone containing metadoxidid trilobites, possibly indicating late Lower Cambrian (Öpik, App.3); in the Mount Rob and Dillon outliers no other fossils were found in association with <u>Biconulites</u>, and consequently the precise stratigraphical position of these <u>Biconulites</u> dolomites, whether Blatchford Formation or Tarrara Formation, which are lithologically similar, is unknown. For simplicity of presentation, and without

prejudice, we designate the unit at the base of the Cambrian sedimentary succession in the Mount Rob and Dillon outliers as Tarrara Formation, and the overlying red-brown sandstone as Hart Spring Sandstone, but remain aware that these rocks may alternatively be the Blatchford Formation. The same remarks apply to the 200 feet of barren shale and siltstone with interbedded volcanic conglomerate at Martin's Bluff.

The lateral variation of the Tarrara Formation is best seen in the dolomite. In thickness the dolomite ranges from 20 feet at Tarrara Bar through 38 feet in section 232 to 65 feet near Hart Spring. Associated with this thickening is an increase in the content of fragmental trilobites, and, from section 232 to Hart Spring, an increasing content of oncolites, which indicate deposition in very shallow water. Oolites occur also near Hart Spring. The lineation of <u>Biconulites</u> shells, in places telescoped into one another, also noted by Wade (1924, pl. IV) and by Teichert (1946) in the Negri Series of the Hardman Basin, indicates deposition in turbulent water.

The contact of the Tarrara Formation and the underlying Antrim Plateau Volcanics is everywhere poorly exposed; the dips in the two formations are roughly parallel, indicating essentially conformably structure. The base of the probable Tarrara Formation in the Mount Rob outlier (locality 273/12A) is a basalt breccia, and at Martin's Bluff (section 283) contains a conglomerate of basalt pebbles in a sandstone matrix, and similar conglomerate is interbedded higher in the section.

HART SPRING SANDSTONE (Traves, 1955)

Traves defined the Hart Spring Sandstone as 'the sandstone with some impure limestone and shale, which crops out in the vicinity of Hart Spring ...' The 'impure limestone and shale' have been named above as the Tarrara Formation, and the Hart Spring Sandstone is accordingly re-defined as the fine to medium red micaceous quartz sandstone that conformably overlies the Tarrara Formation and is conformably overlain by the Skewthorpe Formation. A complete section has not been measured. Strike faults interrupt the section at Hart Spring. The thickness of the measured section is 1,020 feet (1220 feet, if a covered interval estimated to represent 200 feet is included) in section 232, south of Clark

Jump-up. The Hart Spring Sandstone has also been seen at Mount [illegible], the northernmost known outcrop (section 275, 500 feet exposed); in several faulted sections in the Onslow Hills (sections 220, 221); along the south-west margin of the Pretlove Hills (section 240, locality 243); at Skewthorpe Ridge, locality 201; south-west of the fault at Clark Jump-up (section 231); south of the Pretlove Hills (section 245, 650 feet) and at Little Tarrara Bar (section 277, 510 feet). In the outliers the red sandstone overlying the Biconulites dolomite is either Hart Spring Sandstone or the upper part of the Blatchford Formation, and for simplicity of mapping, we have tentatively identified this red sandstone as Hart Spring Sandstone. An estimated 650 feet of red sandstone is preserved in the Dillon outlier, and 800 feet of red sandstone, conformably overlain by dolomite beds tentatively identified as Skewthorpe Formation, in the Mount Rob outlier.

The lithology is uniform reddish, fine-grained silty quartz sandstone which commonly contains mud pellets and flakes. Towards its top in some places, particularly in the northern outcrops (section 207, sample CG207/4,) it contains beds of white quartz sandstone with a calcareous or dolomitic cement, and rarely (in section 236) red silty shale bands. Glauconite grains are sparse, and are visible only under the microscope. Ripple marks, sun cracks, mud pellets, worm burrows, and sole and flute marking are common. It is prominently cross-bedded in the northern outcrops; tabular cross-bedding is common at Hart Spring (Traves, 1955, Fig.21), and large-scale trough cross-bedding at locality 276 about 3 miles to the south-east (Plate 1,C), which is very similar in scale (and lithology) to some of the cross-bedding structures of the Devonian Cockatoo Sandstone. All these sedimentary structures are common in shallow water deposits.* The red colour of the Hart Spring Sandstone is due to primary hematite, which coats the original grains, and to secondary hematite, which cements grains enlarged with quartz overgrowths. The only fossils

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* None of the observed sets of directional structures was clearly polarized, and current directions are consequently not known.

found in 1963 in the Hart Spring Sandstone are small phosphatic brachiopods from a loose rock in the valley north-east of Hart Spring (fossil locality CG209/6) and hyolithids, collected from many widely scattered outcrops. Traves also records a probable Billingsella. The fossil association and the position of the formation between the fossiliferous Skewthorpe and Tarrara Formations indicate that the Hart Spring is Middle Cambrian.

SKEWTHORPE FORMATION (Traves, 1955)

The Skewthorpe Formation is the name given by Traves to the sediments which crop out at Skewthorpe Ridge, where fossiliferous oolitic and sandy dolomite is interbedded with friable brown-red quartz sandstone.

The Skewthorpe Formation conformably overlies the Hart Spring Sandstone, and is conformably overlain by the Pretlove Sandstone.

From north to south the known localities of the Skewthorpe Formation are: locality 262, about 10 miles south-west of Bald Hill (the northernmost known outcrop); 285 (Mount Connection); 218 (= Traves' Locality 11); 219; 221; 226; 238; 236; 213; 214; 240; 201 (= Traves' Locality 13, Skewthorpe Ridge); 235 (Traves' locality 38); 245; 246; 277 (Little Tarrara Bar). Parts of sections 273 and 274, in the Mount Rob outlier, are tentatively identified as Skewthorpe Formation.

According to Öpik (App.3), trilobites and brachiopods found in this formation place its top in the Mindyallan stage of the Upper Cambrian (faunal unit V), and its base in the Middle-Upper Cambrian zone of passage (faunal unit IV, Fig.9).

LITHOLOGY

The Skewthorpe Formation consists of dolomite sandstone, and some shale, and is characterized by oolitic and, to a lesser extent, stromatolitic dolomite. Mud pellets, ripple-marks, cross-bedding and worm-burrows are found at most outcrops.

In the northern outcrops of the Skewthorpe Formation, (north of locality CG236, and Mount Connection) dolomite predominates, and quartz sandstone is a minor constituent. The sediments are arranged in rhythmic units consisting of quartz sandstone at the base, sandy dolomite with oolitic dolomite in the middle, and algal dolomite at the top (see descriptions of sections 236 and 238). Most of these northern outcrops crop out in cliffs or steep scarps, as at Mount Connection and at section 238 in the Onslow Hills (Fig. 17). The rythms are not so well developed, in some of the sections in the Onslow-Pretlove hills area; and in the sections south of the Pretlove Hills they appear to be absent, though more detailed mapping may reveal their presence in some other lithological form. The northern sections are abundantly fossiliferous. Stromatolitic dolomites predominate and are most abundant in the upper part of each rhythm; oolitic dolomites are present, but are not as abundant as in the central sections. Thus, the number of oolitic dolomite beds and algal dolomite beds, both of which predominate south of the Onslow Hills (214), and the abundance of trilobites and brachiopods decrease southward. A corresponding change is from grey dolomite in the north to red in the south; the northern outcrops usually contain a large proportion of detrital quartz sand (often up to 50%), but lack finer terrigenous material.

In the central parts of the Bonaparte Gulf Basin (the Onslow and Pretlove Hills, Figs. 3 and 5) the sandstone content increases southward at the expense of dolomite (sections 214, 240, 201, 235, 245, from north to south).

At Little Tarrara Bar, the Formation contains only 85 ft of reddish, sandy dolomite, with a few oolitic and rare algal dolomite beds, interbeds of quartz sandstone, and a distinctive dolomitic solution breccia (sample CG277/11, sse Appendix 2). A few crystalline glauconitic dolomite bands contain brachiopods. This is the southernmost outcrop that is positively identified as Skewthorpe Formation.

The part of the Mount Rob Section that is tentatively identified as Skewthorpe Formation is predominantly reddish-brown quartz sandstone with mud-pellets. The red colour is due to a primary hematite cement. The thin dolomite members consist of micro-granular, pink to reddish, silty, rarely glauconitic dolutites; dolomitic mudstones, and quartz sandstones with dolomitic cement (samples CG273/9, CG273/10B). No fossils have been found in them.

THICKNESS

At Little Tarrara Bar (section 277) the dolomite is 85 feet thick. Forty-five miles north-westward (sections 245, 246, 235, 201 and 240) the dolomite sequence is much thicker (140 to 235 ft), and is interrupted by two beds of quartz sandstone (Fig. 4). Farther to the north-west the dolomite contains only one major sandstone bed (sections 236, 226, 221), which disappears north-westwards and is not present in the dolomite beds of sections 218, 219 and 285 (Mount Connection).

Other variations in thickness are: (1) In the Bonaparte Gulf Basin itself, sections of the Skewthorpe Formation which lie near the north-east margin of the general area of Cambrian outcrop (sections 218, 240 ft; 219, 270 ft) show a greater thickness of dolomite than sections on the south-west margin (section 221, 135 ft; section 245, 140 ft). (2) The thickness of the dolomite sequence in a small area of the Onslow Hills (section 236, 130 ft; section 238, 150 ft; section 226, 180 ft.) and between Skewthorpe Ridge (section 201, 150 ft.) and near Clark Jump Up (section 235, 210 ft.) increases in a north-eastward direction.

The interpreted relationships between the major sandstone interbeds in the various measured sections of the Skewthorpe Formation are shown on the Correlation Chart (Fig. 9).

The inter-tongueing of the Skewthorpe Formation dolomite with quartz sandstone to the south and south-east, as shown on the Correlation Chart (Fig.9), as well as the thickening of the dolomite sequence northwards, suggest less terrigenous influence generally to the north-west and north.

Granted that the intervals shown in the two Mount Rob Sections 273 and 274 have been correctly assigned to the Skewthorpe Formation (see p.17), then the dolomitic sequence of the northern sections is at Mount Rob almost entirely represented by sandstone, at the top of which thin dolomite beds represent the climax of dolomitic deposition in the Formation.

The lithological and thickness differences from north to south of the Skewthorpe Formation are summarised in Table 3.

Speculations regarding the environment of deposition.

The Skewthorpe Formation was deposited in shallow water (cross-bedding, oolites, ripple marks), and probably in an intertidal environment (stromatolites; Cf. Logan, Rezak and Ginsburg 1964). To the north the terrigenous components of the Skewthorpe Formation decrease, even if the evidence from Mount Rob is disregarded. This, together with indications of oxidation (red colour) in southern sediments, indicates a strand-line environment to the south.

Two of the several possible explanations for the paucity of fossils in the south are that organic activity may have been inhibited due (1) to the dilution of the marine waters through the influence of continental drainage (sandstones and silty dolomites), or (2) to increased salinity due to evaporation, caused by a combination of shallowing and warm climate (Öpik, 1956).

There are no proved evaporites or similar deposits to indicate abnormal salinities in the south, but Sugden (1963), quoting Hedgpeth (1957) in his discussion of the relationship between biota and chlorinity in fossil faunas in the present-day Persian Gulf, asserts that "at chlorinities above about 44 gm/kg hardly any animals can survive, though gypsum precipitation does not commence in modern sea water until a chlorinity of about 60 g.kg is reached." That the climate was at least warm enough to allow evaporation in shallow areas is indicated by the presence of abundant oolitic beds and by the inference of warm oxidising conditions drawn from the colour and iron-oxide content of the sandstones and silts.

From these observations the Skewthorpe Formation sediments can be seen to correspond laterally to three palaegeographic zones of depositional environment within the shallow shelf province in which they were deposited:

(a) A relatively very shallow-water southern zone, where oxidising conditions prevailed and high salinities due to evaporation probably prevented organic population, and where terrigenous material predominated, possibly the result of continental drainage which may have diluted the marine waters just sufficiently to prevent the deposition of evaporites.

(b) A central zone, within the influence of marine currents, where the water was clearer, undiluted by continental drainage, and where conditions were favourable for oolite formation and protected enough to harbour a living population.

(c) The northern, "most marine", zone, where the clarity of the water and the supply of oxygen and nutrients by marine currents, and probably also by wave action, provided conditions suitable for the support of an abundant living population.

This threefold division of depositional environment is supported by evidence of the observed distribution of stromatolite types in the Skewthorpe Formation. In the central sections of the Bonaparte Gulf Basin only stromatolites of laterally-linked hemispheroid type (fig.23 and Appendix 1) have been found. This type of stromatolite, referred to in Logan, Rezak and Ginsburg (1964) as "type LLH", is probably characteristic of the"marine, intertidal mud-flat environment, mainly in protected locations of re-entrant bays and behind barrier islands and ridges where wave action is usually slight".

The northern sections of the Skewthorpe Formation contain stromatolites composed of discrete, vertically-stacked hemispheroids (type SH in Logan, et al., 1964), which are characteristic of "reef developments on exposed intertidal headlands and localities with moderate sea waves". Oncolites are known in the northern sections only. Logan et al. (1964) regard oncolites(their type SS) as characteristic of "agitated lower intertidal conditions." Plate 6A and Appendix 1).

THE RHYTHMS.

DESCRIPTION

The sedimentation rhythms of the Skewthorpe Formation are best exposed in section 238 (Fig. 18 and columnar sections), which contains thirteen complete rhythms.

The ideal rhythm (Figs. 17 and 18) consists of three units, in descending order:

C. Stromatolitic dolomite.
B. Sandy, crystalline, and oolitic dolomite.
A. Red, friable quartz sandstone.

Unit A (sample OG238/2a) is frequently eroded away, and locally contains dolomitic sandy shales in the lower part of the Formation. Unit B (sample OG238/2b) is progressively less siliceous and more dolomitic upwards: it passes from medium dolomitic sandstone at its base through current-bedded sandy dolomite to crystalline dolomite at its top. There are numerous oolitic beds in this unit. Unit C consists of dolomitic stromatolites (sample CG238/2c) with thin interbeds, lenses, and pockets of oolitic dolomite between the stromatolites. Frequently the stromatolites are capped by a breccia consisting of oval, rounded pebbles up to 4 inches long, locally imbricated, of the same stromatolites in a matrix of sandy and oolitic dolomite (Plates 6B,C).

Each rhythm is generally less siliceous and more dolomitic towards the top, as is the whole sequence: in the lower part of the Formation the quartz sandstone (unit A) forms a larger proportion of each rhythm; in the middle part, quartz sandstone beds are thin (Plate 7A, 7C) and in the upper part quartz sandstone is absent. The dolomite, sandy dolomite, and dolomitic sandstone of Unit B become proportionately thicker higher in the sequence. The dolomitic stromatolites of Unit C, with their characteristic domed, laminated and undulose structures, are absent in the lower part, and increase in number and thickness towards the top of the formation, where they are up to 5 feet thick. The dolomitic breccia capping the algal beds has the same distribution.

The rhythms progressively thin towards the top. They stand out well in outcrop, and the different units are easily distinguished: the top of most rhythms is a planed, undulating bench (Plate 7A, fig.23), and the base is frequently marked by a cleft where the weathered quartz sandstone of Unit A has been cut back.

DISCUSSION

The three units of the individual rhythm probably represent different depositional environments similar to the three broad zones (outlined above) which were represented by the southern, central and northern facies of the Skewthorpe Formation. Unit A probably represents terrigenous deposition near the shore; unit B (carbonate and oolite) was probably deposited in a clear-water lagoon in which trilobites and brachiopods flourished; unit C was probably deposited as a reef on the seaward side of the lagoon; mats of colonial algae trapped sediments (including oolites) and bound them into stromatolitic banks, providing a barrier against waves for the lagoon. That these stromatolites periodically emerged from the water is shown by the planed surface of almost every stromatolitic unit, (Fig. 23), and by the stromatolitic breccias which locally fill the troughs between the stromatolitic domes (Plate 7B, fig. 23).

In each rhythm, the terrigenous content decreases towards the top, probably indicating a shifting locus of deposition landward. Similarly, the terrigenous content progressively decreases upward in the Skewthorpe Formation, probably in response to a progressive advance of the sea.

This rhythmic succession can probably be best explained as the result of movement of the shoreline caused by fluctuations in the supply of sediment (Richards 1962), in conditions of uniform subsidence and major transgression. The primary condition is the subsidence of the basin or shelf. With the resulting marine transgression the environments represented by the rhythmic units A, B, and C (which will be called, for convenience, "Strand", "Lagoon" and "Reef") all migrated landward with the retreating shoreline, so that the Lagoon sediments advanced diachronously across the Strand sediments, and similarly Reef sediments across Lagoon deposits (Fig.18). When the algal Reef deposits had migrated shorewards over the Lagoon and Strand deposits and reached sea-level, it is possible that a temporary base-level of erosion in the hinterland may have been attained, causing the sediment supply to decrease, and allowing subsidence to overtake deposition, so that the sea could advance again. With the renewed relative subsidence, the rate of deposition accelerated, and on top of the planed Reef surface, sediments of the Strand facies were deposited renewing the cycle of sedimentation (Fig.18). According to this explanation, the deposition of the rhythms required a delicate balance between supply of sediment, relative sea-level, and subsidence of the basin floor.

PRETLOVE SANDSTONE (Traves, 1955)

Traves defined the Pretlove Sandstone as the Upper Cambrian white sandstone that crops out in the Pretlove Hills. He found no complete sequence, and did not designate a type section. During 1963, several complete sections of the Pretlove Sandstone were found and one of these, section 245, 4 miles south-west of Clark Jump Up, is designated type. Much of the area mapped by Traves as Pretlove Sandstone is now known, on palaeontological evidence, to be Devonian Cockatoo Sandstone.

The Pretlove Sandstone is the white, pink, and red fine to medium quartz sandstone that conformably overlies the Skewthorpe Formation and is conformably overlain by the Clark Sandstone. The type section, designated here, is section 245 (southern Pretlove Hills). Complete sections of the Sandstone range in thickness from 210 ft. at section 245 to 250 ft. at section 236; 830 ft. of sandstone are tentatively identified as Pretlove Sandstone at Mount Rob (see p. 17). The type section is 205 feet thick. The chief sections measured through the Sandstone are 218, 219, 226, 236, (Fig. 6), 240, 245, (Fig. 3); and, in the Mount Rob outlier, 273 and 274 (Fig. 12).

The correlation chart (Fig. 19) shows that the upper boundary of the Pretlove Sandstone with the Clark Sandstone is diachronous from the Mindyallan (faunal unit VI)in the north to the middle Franconian (top of faunal unit VII) in the south. There is possibly an overall corresponding increase in thickness towards the south, from 250 ft at section 236 in the Onslow Hills to 830 ft at section 274 near Mount Rob.

The sandstone varies little lithologically, within the Bonaparte Gulf Basin itself, where its lithology is as previously described. It is characterised by a meagre fauna and by numerous ferruginised ripple-marked planes (e.g. section 236). In the southernmost outlier of Mount Rob, however, where it has been tentatively identified, it resembles the Hart Spring Sandstone, and is darker, more ill-sorted and siltier than in the north. At Little Tarrara Bar it is siltier and darker than it is in the type section.

The Pretlove Sandstone is much thinner in sections 225, 226 and 226A (Fig. 6) than in section 236, only about a mile to the south (see Fig. 19). At section 226A fossils of faunal unit VII were not found; in faunal unit VII in section 226 a ferruginous pebble conglomerate (Appendix 3) is enclosed by sediments containing fossils of faunal unit V below and faunal unit VIII above. This conglomerate is present at the same horizon in section 225, where the Pretlove Sandstone is slightly thicker. These observations indicate conditions of partial non-deposition during the periods represented by faunal units VII and VI, which may be due to differential movements. The abruptness of the variation in thickness of the Pretlove Sandstone between sections 236 and 226 over the comparatively short distance of one mile suggests that the activity may have been locally expressed by faulting; in this locality the comparatively thick sediments of section 236 were probably deposited on the downthrown side, and the conglomerate, and the thin sediments of sections 226, 226A and 225 on the upthrown side, which also includes the area of non-deposition. That the movements did not affect sedimentation in the Skewthorpe Formation is shown by the uniform thickness of the Skewthorpe Formation in this area. These movements may be an extension of those reflected by the missing faunas of Queensland, (Öpik and Pritchard, 1960, pp. 108-109) which represent an equivalent age (Fig.19).

CLARK SANDSTONE (Traves 1955)

Traves defined the Clark Sandstone as "the sandstone which crops out on the eastern side of the fault at Clark Jump Up on the track from Carlton to Legune." At this locality (Traves' locality 36, our locality 231), dark-greenish to reddish medium-grained glauconitic sandstone and friable red sandstone contain, as elsewhere in the Sandstone, abundant trilobites, brachiopods and gastropods. The type section is isolated by faults and by sand; in section 245, four miles south-eastwards, the Clark Sandstone conformably overlies the Pretlove Sandstone, and is thought to be conformably overlain by the Pander Greensand. The Clark Sandstone has been identified in the following sections and localities (from north to south): CG262/1 (= Traves' Loc. 1), CG262/3 (Traves' Loc. 2) and 262/8, in the line of outcrops to the south of Bald Hill; 225, 226A, 226 and 236 (450 ft.) in the Onslow Hills; 240, north-west of Clark Jump Up, and 231 at Clark Jump Up; 202/4 in a ridge about one mile north-west of Pander Ridge; 245 (720 ft) in the south of the Pretlove Hills; 35 on the bank of the Ord River south of Little Tarrara Bar; 275 at Gap Point and 274 near Mount Rob. It crops out also in numerous isolated localities in the Pretlove and Onslow Hills. About seven miles south-west of Point Spring, at locality CG281, an isolated outcrop of Clark Sandstone is unconformably overlain by Devonian Cockatoo Sandstone: this is the easternmost outcrop of known fossiliferous Cambrian sediments in the Bonaparte Gulf Basin. Complete sections of the Clark Sandstone are exposed in localities 236 (Onslow Hills) and 245 (southern Pretlove Hills); the section at locality 274 (Mount Rob) is unconformably overlain by Devonian sandstone, and at Gap Point the base

TABLE 3

LITHOLOGICAL VARIATION IN THE SKEWTHORPE FORMATION

Area Lithological character	* Southern Mount Rob	 Little Tarrara Bar	Central	Northern
Presence of quartz as 'wedge' in Formation	Almost wholly	Almost wholly	2 1	none
Thickness (in feet) of dolomite member	10	85	210	270
Colour of dolomite	red	red grey	grey	grey
Silt content in dolomite	very abundant	abundant	rare	very rare
ss/dolomite proportion in dolomite member	as predominant	SS predominant	Dol ss	Dol predom
Oolite	not seen	rare	very abundant	abundant
current cross-bedding in dolomite beds	not seen	rare	present	abundant
Stromatolites	not seen	rare	present	predominant
Fossils	not seen	present	abundant	very abundant

* As pointed out in the text, the identification of the Skewthorpe Formation in the Mount Rob Section is tentative only.

Note: Glauconite occurs in all areas.

of the Clark Sandstone is not exposed. In section 236 the fossils, according to Öpik (Appendix 3), indicate that the top of the section has been eroded to a level slightly below that at which the Clark Sandstone is overlain by the Ordovician Pander Greensand at section 245 (Figs. 19 and 9). The scanty information on thickness indicates that the Clark Sandstone is at least as thick in the south as it is in the north (450 feet).

The lithology of the Clark Sandstone and its contrast with that of the Pretlove Sandstone have been more fully described in the discussion of sections 236, 245 and 275 (Gap Point). Little lateral lithological variation was seen.

The distinctive interbeds of reddish-grey, dark glauconitic felspathic sandstones with a crystalline dolomitic or calcareous cement at the type locality and at locality CG202/4 cannot be traced from one section to the next. They may represent brief periods of waning terrigenous influence during deposition, or they may be due to post depositional diagenetic changes (see Appendix 2).

These two sections are to the centre and east of the main Cambrian outcrop, where the possibility of embayment and flexure has already been pointed out (in connection with the Skewthorpe Formation) and where sedimentation may have been of more marine type.

The faunal break in the Clark Sandstone (between faunal units IX and X, see Figs. 19 and 9), which, together with very minor lithological variations, indicates an abrupt change of conditions of deposition at this time, has been discussed in the description of section 236.

In section 245 the faunal break and minor lithological differences similar to those of section 236 are found between two conformable sandstone beds (samples CG245/12 and CG245/13) containing fossils of equivalent age to those from localities CG236/13 and CG236/13½; the same break was found in two other sections, 274 near Mount Rob, and 202/4 at a low ridge about a mile north-west of Pander Ridge: in both localities it is accompanied by minor lithological differences (small quartz pebbles in the underlying white sandstone, and broken fossils in the overlying red sandstone). This break was detected in detailed sections only: it is not visible in the aerial photographs, and the contact is mappable by walking only. This was not practicable, and the sediments above and below the break have therefore been included in one formation - the Clark Sandstone. However, the break in the Upper Cambrian column has been noted where it occurs in the sections which have been measured, and more detailed work would possibly produce enough mappable information to warrant splitting the Clark Sandstone into two formations.

The fossils found in the Clark Sandstone place it within the Franconian and Trempealeauan stages of the Upper Cambrian, as shown in the Correlation Chart (Fig. 9).

The passage upward into the Ordovician Pander Greensand is obscured by sand cover in all the measured sections. According to Öpik (pers. comm.), the Cambrian-Ordovician contact is marked by a distinctive leached pipe-rock bed in an outcrop to the north of the Carlton-Nimbing track, north of Clark Jump Up.

PANDER GREENSAND (Noakes, Öpik, and Crespin 1952; defined Traves, 1955).

Traves defined the Pander Greensand as "the glauconitic sandstone which forms Pander Ridge". The poorly cemented, medium grained, highly glauconitic quartz sandstone contains numerous white, phosphatic fossil fragments. As previously described, "some of the glauconite grains have broken down to iron oxides, giving a red, green and white speckled appearance to the rock. In places where the glauconite is not altered to iron oxides, the rock has a dark green colour" (Traves, 1955). In other places there are interbeds and bands of medium grained iron-stained quartz sandstone with well-rounded grains. Glauconite commonly constitutes up to 60% of the rock, but rarely more.

The Greensand is thought to overlie the Clark Sandstone conformably and its top is everywhere eroded.

The Pander Greensand crops out in the following localities: CG249 (Traves' locality 37), where a 400 ft section was measured, the lower 50 ft of which may belong to the Clark Sandstone; a small ridge one mile north of this locality (Traves' locality 39); Pander Ridge (Locality CG233, Traves' locality 8;130 feet); CG245, (150 ft); and, tentatively, the top of section 275, at Gap Point; from this locality (CG275/5) a sample submitted for geochronological determination of K-argon in the glauconite indicated a minimum Lower Ordovician age (M. Bofinger, pers. comm.).

Öpik (in Traves, 1955) first recognised conodonts and other fossil fragments of Ordovician age from samples collected in 1949 from Pander Ridge, and he pointed out that the lithology is identical with that of the Upper Tremadocian Baltic "Glauconite Sandstone" from which Pander, more than a century ago, discovered and described the first known assemblage of conodonts. On the basis of the conodonts, the approximate position of the Cambrian-Ordovician boundary was determined in the field (see description of section 245). The tentative correlation of the three measured sections (233, 245, 249) of Ordovician sediments in the Bonaparte Gulf Basin is based on trilobites (Figs. 9 and 19; and Öpik, App. 3). This correlation, coupled with the position of the Pander Greensand above the Upper Cambrian Clark Sandstone, at locality CG245 in the southern Pretlove Hills, provides a basis for the estimate of 600 feet of the maximum preserved thickness of the Pander Greensand.

The Pander Greensand is the youngest exposed formation of the Cambrian and Ordovician sequence in the Bonaparte Gulf Basin and its outliers, and, as far as is known, represents the final deposit in the Lower Palaeozoic sea of the area.

STRUCTURE

The Cambrian and Ordovician rocks have been tilted, faulted, and uplifted. The only folds (observed in the overlying Devonian, but probably continued downward in the Cambrian and Ordovician rocks) are caused by reversals of dip in the graben at Mount Rob and Gap Point.

The outliers, the Tarrara Bar area, the Onslow Hills, and the area northward are cut by long faults with north to north-north-east strike. The Pretlove Hills are cut by strike faults with west-north-west strike. Precambrian, Cambrian, Ordovician, and Devonian rocks are affected alike by both sets of faults. The major faults have throws measured in thousands of feet; the fault zones are narrow (few exceed 100 yards, most are less than 10 yards wide), and most are heavily silicified. No drag (except the reversals of dip at Mount Rob and Gap Point) was seen along faults.

Detailed mapping in the Pretlove Hills (fig.20) reveals a set of horsts and graben bounded by high-angle normal faults.

Since Precambrian times, the following major diastrophic movements can be traced:

(1) Faulting, tilting and elevation of the Precambrian rocks prior to the outpouring of the Antrim Plateau Volcanics.

(2) Crustal adjustment after the deposition of the Antrim Plateau Volcanics, involving faulting and possibly warping.

(3) Subsidence of the basin during Lower Cambrian to Lower Ordovician.

(4) Uplift at an unknown period (probably at end of Lower Ordovician) during the interval between Lower Ordovician and Upper Devonian, and erosion to various levels.

(5) Subsidence and deposition in the Upper Devonian and early Lower Carboniferous, followed by

(6) Major faulting of early Lower Carboniferous and all older units, including Precambrian, Cambrian, Lower Ordovician, and Upper Devonian.

Minor movements during the Upper Cambrian are indicated, during the time of faunal unit VII (the conglomerate and non-deposition at section 226) and at the end of the time of faunal unit IX (the faunal and minor lithological break in the Clark Sandstone). Non-deposition (due to differential movement) may have been responsible for the missing fauna between faunal units VI and VII in the Upper Cambrian (Fig. 9).

DEPOSITIONAL HISTORY

At an unknown time during the late Proterozoic, the area was elevated to a land surface and dissected. In the Lower Cambrian, the Antrim Plateau Volcanics were extruded over this surface, locally faulted and warped, and, in the Ragged Range area, subsided in the late Lower Cambrian and were overlain by the marine Blatchford Formation. The area north of the Ragged Range was probably land or an area of marine non-deposition before the Middle Cambrian. In the early Middle Cambrian, marine deposition spread at least as far south-west as the

Mount Rob area, and as far south-east as the Hardman Basin, and in the area of the Bonaparte Basin and its outliers continued, with a few minor breaks only, at least to the end of the Lower Ordovician. The eastern limit of deposition is not known.

Sand and minor carbonates were deposited in a shallow, slowly subsiding basin. The two dolomite horizons indicate intervals of reduced terrigenous sand supply.

It is reasonable to infer that the dolomite and oolite of the Skewthorpe Formation indicate deposition in warm water. According to Öpik (1957, p.265), in the Cambrian, 'the climate of the western half of Australia was still arid, but to a lesser degree than in recent time, and the mean temperature of the air and sea was markedly lower'. In this general setting, the Skewthorpe Formation possibly represents a warm interlude.

There is no record of deposition in the interval between Lower Ordovician and Upper Devonian; during this time the Bonaparte Gulf Basin was probably a land surface, and in some places the whole column of sediments was eroded to various depths, locally to the Antrim Plateau Volcanics, before the Upper Devonian transgression.

ECONOMIC GEOLOGY.

Surface water. The area is drained by the lower parts of the Ord and Dunham Rivers, which carry enormous volumes of water in the wet season, and are reduced to a chain of water holes in the dry season. Tributary water-courses are almost completely dry in the dry season.

Numerous springs issue from faults that cut Cambrian sedimentary rocks south of Bald Hill, at Leichhardt Spring, and north-west of Hart Spring.

Underground water: To our knowledge, no bores or wells have been sunk into the rocks studied in this report.

Phosphate. Certain beds in the Pander Greensand contain concentrations of phosphatic brachiopods and conodonts. Two samples from Pander Ridge submitted for analysis contained less than 1% P_2C_5.

Petroleum: We concur with Traves (1955, p.104) in regarding the severely faulted outcropping Cambrian and Ordovician sedimentary rocks as poor prospects for petroleum. If, as is expected, less deformed equivalents of these rocks extend north-eastward under younger rocks, they would provide an attractive target for the drill. The only deep test yet made of the Bonaparte Gulf Basin was abandoned at a depth of 10,530 feet in Upper Devonian shale.

No trace of asphaltite, which is associated with Cambrian rocks in the Negri River area, was found.

Glauconite. The Pander Greensand locally contains up to 60% glauconite. The Clark Sandstone is glauconitic, particularly in the upper part; both the Pretlove Sandstone and the Skewthorpe Formation contain minor, though significant glauconite.

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APPENDIX 1

CALCAREOUS ALGAE FROM THE CAMBRIAN SKEWTHORPE FORMATION, WESTERN AUSTRALIA.

by

J. A. Kaulback

SUMMARY

Two distinct types of algae from the Skewthorpe Formation of the Bonaparte Gulf Basin are described and illustrated. They are distinguishable by diagnostic microstructures. Their stratigraphic position is indicated, and reference is made to their ecology and to the environment of the rocks in which they were deposited. Problems of taxonomic nomenclature are discussed.

INTRODUCTION

The specimens described here were collected during 1963 from dolomitic algal biostromes of the Cambrian Skewthorpe Formation in the Bonaparte Gulf Basin, Western Australia (Fig.1). They are associated with a fauna of brachiopods and trilobites which places the Skewthorpe Formation in the Middle to Upper Cambrian passage zone (Öpik, Appendix 3). Few algae have been described from the Cambrian of Australia: Chapman (1907) described *Girvanella* from the Silurian limestones of Victoria, and (1911) from the Upper Cambrian of Gippsland; Etheridge (1917) described *Girvanella* from the Cambrian of north-west Australia. More recently, attention has been paid to the description of Precambrian stromatolites (Robertson, 1960). This paper contains new information about previously undescribed Cambrian forms.

Algal stromatolites are found throughout the Skewthorpe Formation of the Bonaparte Gulf Basin, and are its predominant component in the more northern outcrops, at Mount Connection and in the Onslow Hills. The stromatolites occur in many types of external form, but only the two which have been found to contain microscopic structures are described. Because of the lack of comparable forms and the restricted nature of the samples, it is felt that a formal taxonomic nomenclature is inappropriate at this stage, and the two types are called Type A (field number CG213/15) and Type B (field number CG238/20).

LOCALITY AND STRATIGRAPHY

The stromatolites are found only in the Skewthorpe Formation, whose 200 feet of algal and oolitic dolomites are part of the almost wholly arenaceous 4,500 feet sequence of Cambrian and Ordovician rocks of the Bonaparte Gulf Basin (Fig. 2). Sample CG213/15 (Type A) was collected from measured section 213 (Fig.5)and columnar section 213) in the north-west Pretlove Hills, where stromatolites are prominent. Sample CG238/20 (Type B) was collected from measured section 238, in the Onslow Hills, where the largest stromatolites were found (Fig. 6)and columnar section 238). The stromatolites occur as the top members of the Skewthorpe Formation rhythmic units, which are most impressively exposed in a cliff face at locality 238. Each rhythm consists of lower quartz sandstone, overlain by sandy and oolitic dolomite and oolitic dolomite, overlain by the dolomitic stromatolites, which are frequently capped by a thin dolomitic breccia whose clasts vary in content from oolitic dolomite to stromatolite. The rhythmic layering is shown in Fig.17,which is the vertical section at locality 238 (it is more fully described in the main section of this paper).

ALTERATION

The stromatolites consist of aphanitic dolomite or ferroandolomite. It seems probable that they were originally deposited as dolomite, or as calcium carbonate with subordinate, but possibly high, magnesia content (Johnson, 1937; Johnson and Konishi, 1956; Schlanger et al. 1963), and were subsequently recrystallised (Anderson, 1950). The lack of porosity, the lack of any trace of calcite, and the fine grain-size of the rock indicate original deposition as dolomite, with recrystallisation which was penecontemporaneous with deposition, or early post-depositional. The fact that fine structures are preserved at all suggests that secondary recrystallisation took place molecule for molecule (there are no dolomite rhombs in the microstructures).

DESCRIPTION

TYPE A: (Sample CG213/15): distinguished by microscopic spherules along the laminae.

Handspecimen:

Structural formula: Discrete, vertically stacked hemispheroids composed of closely linked hemispheroidal laminae on a microscopic scale. (Fig. 21). The basal radius of the larger hemispheroid is variable.

($\frac{\text{SH-V}}{\text{LLH-C}}$: Logan, Rezak and Ginsburg (1964) formula).

Diameter of hemispheroids: range 1-3cm.
approximate average 2 cm.

Distance between centres of hemispheroids:
range 1-2.5 cm.
approximate average 2 cm.

Number of hemispheroids per 10 cm^2 40 - 70.

Thin Section: [illegible]

Diameter of spherules: average 45 µ
range 30-100 µ

Distance apart of spherules: average 50 µ

Vertical height of largest columnar aggregation of spherules: 200 µ approx.

Number of spherules per mm^2: 300 - 400.

Vertical distance apart of laminae: 200-300 µ

Observations

Frequently spherules occur in a roughly spherical colony (Fig.21) whose wall is made up of a thick network of smaller spherules; inside the wall, spherules are bigger and are arranged in clusters, which are separated by a matrix of microgranular or microcrystalline dolomite. The spherules are not distinct over a large enough area to enable an estimate of the variation of their number within a cluster or of the number of clusters within a colony. Spherules are of ferroandolomite, which appears darker than the dolomitic matrix; no signs of internal structure have been observed.

TYPE B (sample CG238/2c): distinguished by microscopic tubules along the laminae.

Handspecimen

Structural formula: Spheroidal, with small-scale component laminae of laterally linked hemispheroidal type, with close lateral linkage. (Fig. 22).

Diameter of spheroids: 8" - 24".

Thin Section (Fig. 22).

Vertical distance apart of laminae: average: 500 μ
range: 330-670 μ

Diameter of tubules: average 100-150 μ
range: 100-200 μ

Distance apart of tubule centres: average: 130 μ

Vertical length of tubules: range: 200-400 μ

Number of tubules per mm^2 : average: 76
range: 60-100

Observations

The tubules are approximately circular in section; there is a variation in diameter within and between the tubules. They are composed of microgranular dark ferroan-dolomite. No internal structures have been observed. Inter-tubule matrix is of clear microgranular or microcrystalline dolomite. There has been partial replacement of the tubules and matrix by a mosaic of finely crystalline dolomite. The tubules are frequently arranged (in horizontal section) in circular "colonies", which display alternate concentric rings of clear microcrystalline or microgranular dolomite and tubule-containing areas. This circular organisation is thought to be due to the angle at which the section is cut across the undulating laminae (Fig. 2).

THE ECOLOGY AND ENVIRONMENT OF THE SKEWTHORPE FORMATION

The ecology of the stromatolites can be deduced from a study of both recent and ancient algal deposits.

Controlling factors in algal growth are sufficient light for photosynthesis, clarity of water, and moderate water turbulence, where sedimentation is slow enough for them to avoid burial (Robertson, 1960, p.8). Algae grow in warm or cool, fresh or salt water (Twenhofel, 1919), and require a shallow shelf or lake environment (Cloud, 1942), though Recent blue-green algae have been found at great depths (Marshall, 1954).

The depositional environment of the Skewthorpe Formation is discussed in the main section of this paper: ripple-marks, cross-bedding, oolites and round-pebble breccias, all indicative of shallow conditions of deposition, are characteristic of the Skewthorpe Formation rhythms. Logan, Rezak and Ginsburg (1964) relate the varying external forms of the stromatolites to subdivisions of the inter-tidal or near-intertidal zones in which it is thought they were deposited: the laterally linked hemispherical stromatolites (type B) indicate a protected inter-tidal mudflat, and those exhibiting discrete hemispherpids indicate a more exposed inter-tidal headland (type A). However, this tentative allocation of environment only applies to the horizon in which the sample is found, and only to a restricted area within it, for differences in lithology and related micro-facies are abrupt and considerable both vertically and horizontally within the Skewthorpe Formation, and indeed in locality 238 (where type B was found) there is an abundance of spherical stromatolites, distributed vertically through the column, which indicates an overall increase in local agitation, and less protected, more permanently submerged conditions (Logan et al., 1964). Often the stromatolites exhibit a compound external form: the stromatolite from which CG238/20 (type B) was collected is of laterally-linked hemispheroid type, enclosed in a spherical structure. This is taken to indicate a change in conditions, from "protected intertidal mudflats" to "agitated lower intertidal". This corresponds to the observed indications of increasing marine influence upward within each rhythm (see under Skewthorpe Formation Rhythms, this paper).

There is a relation between the microstructures and the external structure of the stromatolites which may have a genetic significance. Type B, which has a primary external form of laterally-linked hemispheroids, contains delicate microscopic vertical tubules, which may be resonably supposed to require relatively protected conditions in order to survive. Type A, which has an external structure of discrete hemispheroids, contains no vertical tubules, and its spongy, matted microstructure appears admirably suited to withstand more exposed conditions. The fact that the microscopic structures are related to the external form may mean that the microscopic structures are themselves only an expression of adaptation to local conditions. This may be an argument for the abandonment of the generic nomenclature in favour of a nomenclature based on morphology, even in cases where microstructures are present. At this stage of knowledge, however, much more data is required before such speculations can carry any weight.

PROBLEMS OF TAXONOMIC NOMENCLATURE

The organised arrangement of microstructures in these stromatolites indicates that they are of organic, and probably of algal, origin. Modern studies on Recent stromatolite occurrences have highlighted the inconsistencies associated with a binomial nomenclature, which is based on external forms thought to be related only to physical environmental conditions (Black, 1933, Rezak 1957, Ginsburg and Lowenstram 1958, Logan 1961). Logan et al. (1964) have proposed a descriptive nomenclature based on external form; though this nomenclature is adequate for the expression of environmentally significant differences between modern stromatolite structures, it is not precise enough for stratigraphical use. Krylov (1963) in studies of Precambrian stromatolites of the Southern Urals has proposed a classification similarly based on external form; if external form is controlled by environmental conditions, this classification may not have stratigraphical significancebetween regions, though it has been found useful for local correlation. A binomial nomenclature, based on microstructures, is more suitable. However there have been too few descriptions of algal stromatolites from the Lower Palaeozoic and the Precambrian to give any indication of the presence of a diversity of micro-structures on which classification can be based.

This paucity of data is caused primarily by the widespread strong recrystallisation of carbonate rocks of this age, which obscures the microstructures, and partly by lack of co-ordinated fossil collection.

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APPENDIX 2

PETROGRAPHY OF THE CAMBRIAN AND LOWER ORDOVICIAN SEDIMENTS OF THE BONAPARTE GULF BASIN AND ITS OUTLIERS.

by

J.A. Kaulback

A note on nomenclature and methods of study

The descriptions of the selected samples are based on the study of 100 acetate peels and about 100 thin sections, chosen as representative, or in some way significant, from a larger number of handspecimens which were collected from the Bonaparte Gulf Basin in 1963 or by Traves and Öpik in 1949 or 1952.

The nomenclature of the carbonates is based on the descriptive classification of carbonates by Leighton and Pendexter (1962), but slightly modified, so that for example, a limestone with 50-90% detrital material and the rest micrite is a "micritic detrital limestone": under Leighton and Pendexter's classification this rock would be called a "detrital-micritic limestone". The modified classification is more in accordance with modern English usage, where the primary qualifying adjective is nearest to its noun.

Where reference is made to the size of carbonate crystals, (finely, medium or coarsely crystalline) the scale used in this report is that of Folk (1962).

The scale of Wentworth and Udden (1922) is used for detrital grain sizes.

Glovers' (1963) classification of diagenetic textures is used in the descriptions of these features (e.g. "reorganisation texture", "replacement texture").

Acetate peels were made of the carbonates, under the principles described by McCrone (1963), but modified to suit the comparatively insoluble dolomite. Samples were cut, polished and etched with dilute hydrochloric acid; acetone was then applied to the etched sample, and a piece of acetate paper (Kodatrace produced best results) quickly placed, matte side down, on the wet surface, with a rolling motion to eliminate air bubbles. The acetate paper with the impression of the etched rock on it was peeled off the sample after 15 minutes. An average etching time of 3-5 minutes with a 10% or 25% solution of HCl was necessary to produce a good peel of dolomite. The few limestone samples required only 1 minute's etching with 10% HCl. Etching time is a critical factor in making acetate peels, and the correct time and strength of the acid solution can only be found by experiment for each type of rock. Peels held between glass plates were used as negatives and projected through an enlarger onto photographic paper. All photographs of acetate peels made in this way are therefore negatives; a clear calcite crystal for instance appears black, while ferruginous dolomitic rings of ooliths appear white. Peels made in this way have proved very useful in petrography, and though they are not as valuable as thin sections for the determination of minerals other than carbonates, their chief advantages are that they are quickly made (about 20 minutes per peel) and much cheaper than thin sections; they cover a much wider area of the sample than a thin section (peels of carbonate rock surfaces of any convenient size can be made), and they contain fine detail.

In the differentiation of the carbonate minerals Alizarin Red S and K-ferricyanide were used as stains, after the technique of Warne (1962).

Samples of which an acetate peel or a thin section have been made are marked (P) or (TS) respectively.

Selected samples from the dolomitic members of the Tarrara Formation

Sample: CG208/1 (TS).

Locality: West of Hart Spring, at base of section 209.

Determination: Glauconitic recrystallised oolitic dolomite, with skeletal fragments.

Texture: Completely recrystallised in subhedral dolomite mosaic, which does not completely obscure the relict original skeletal and oolitic texture. Ooliths show cerebroid, radial and concentric structures.

Handspecimen: Red, fine grained, with prominent skeletal fragments.

Composition:

Dolomicrite: 90% in a subhedral dolomite mosaic.

Skeletal fragments: 10%: Similarly recrystallised.

Ooliths: Originally a skeletal oolite: now ooliths appear only as relict structures. Maximum size 0.2 mm.

Alteration: Cerebroid form of ooliths possibly may be due to shrinkage or compaction of an original calcite

Alteration (cont.)

matrix; mosaic is subhedral but not rhombic, suggesting that a secondary calcite mosaic, partially recrystallised from an original aphanocrystalline or granular matrix, was later replaced molecule for molecule by dolomite. There has been little reorganisation after the replacement by dolomite - hence the rarity of dolomite rhombs. The fact that the original oolitic and skeletal structures are so well preserved points to the preliminary partial recrystallisation of calcite prior to dolomite replacement.

Sample: CG273/11 (P).

Locality: Mount Rob outlier (probably Tarrara Formation).

Determination: Microgranular and microcrystalline dolomite and calcite.

Texture: Recrystallised; reorganisation and replacement texture.

Handspecimen: Very fine grained, dark and pale grey banded.

Composition: Alternate bands of dolomite and limestone, (Largest dolomite rhomb 200/u.

Alteration: Slightly silicified, partly de-silicified and de-dolomitised by weathering. A band of partly silicified ferroandolomite is sandwiched between calcite bands. The periphery of the ferroandolomite is de-silicified, and the dolomite has been dissolved from its lower part, enriching the residue with iron. The dissolved dolomite and iron have been carried down the vein below the dolomite band, while above it the vein contains mostly clear calcite. The right-hand vein is of clear quartz and calcite, and has leached the dolomite and silica from the dolomite band, leaving behind the original iron of the ferroandolomite.

Sample: CG T.E. (P).

Locality: The provenance of this rock is an unknown locality within the Lower or Middle Cambrian of the region. The description is included here because it resembles parts of the TARRARA Formation more closely than any other formation within the Bonaparte Gulf Basin. This sample is an erratic in the glacial Keep Inlet Beds (? Permian).

Determination: Skeletal micritic limestone.

Texture: Original; parts recrystallised to calcite mosaic.

Handspecimen: Grey, shelly, sparsely glauconitic, with prominent silicified Biconulites tests.

Composition: 70%; microgranular limestone with minute quantities of ferroandolomite.

Skeletal fragments: 25%; mostly Biconulites tests, which are often cone-in-cone. Abundant broken brachiopod fragments and some trilobite fragments. Some of the shell fragments are of calcite; most are silicified. Their interiors are filled with aphanitic dolomite.

Grains 5%: detrital, quartz.

Alteration: Skeletal fragments mostly silicified, in quartz crystalline mosaic.

Observations: A marked lineation of Biconulites shells.

Hart Spring Sandstone.

Sample: CG207/4 (TS).

Locality: West of Hart Spring, section 207.

Determination: Fine-to medium-grained quartz sandstone with dolomite cement.

Texture: Marked secondary outgrowths on both quartz and feldspar grains. Feldspar outgrowths are frequently moulded round quartz outgrowths, which were the first to form.

Intergranular spaces filled by euhedral dolomite rhombs and subhedral dolomite mosaic, which formed after the secondary overgrowths of the grains. Some mudstone lenses.

Handspecimen: White, friable.

Composition: Grains: 5-10% Feldspar (K, microcline mostly) and 60% quartz with 5% quartzite and chert. Range from 0.25 - 0.05 mm.

Dolomitic cement: 25-40%, as euhedral to subhedral mosaic.

Alteration: The dolomite mosaic probably replaced an original calcite matrix, of which a few scattered remnants remain.

Sample: CG235/1 (TS).

Locality: North-east of Clark Jump Up.

Determination: Quartz sandstone with abundant quartzite grains and iron oxide cement)
(probably hematite).

Texture: Secondary enlargement in both quartz and feldspars.

Handspecimen: Fine to medium grained, reddish-brown, friable.

Composition: Quartz grains: 60%. Well rounded prior to secondary enlargement.

K-Feldspar: 5% (microcline and orthoclase).

Quartzite: 30%.

Hematite and limonite cement 5%.

Accessory tourmaline, apatite and muscovite.

Alteration: Secondary overgrowths round and between the grains of feldspar and quartz. Original grains are coated with a film of hematite or limonite, and a thicker layer of iron oxide coats the overgrowths or intergranular cement, indicating two different periods of iron oxide deposition. The reddish colour of the Hart Spring Sandstone is threfore primary, from original ferruginous coatings on the grains, and secondary.

Skewthorpe Formation

(a) Oolites and pisolites

Sample: CG201/5 (P).

Locality: Skewthorpe Ridge.

Determination: Recrystallised pisolitic dolomite.

Texture: Originally oolitic and pisolitic, with microgranular matrix. Matrix and pisolites are partially recrystallised in fine rhombohedral texture, which does not obscure the original texture. Some of the groundmass is reorganised to medium crystalline rhombs. Pisolites grade from many-coated at the top to single-coated (psuedo-pisolites) at the base. Styolites occur preferentially in the many-coated pisolites. Many-coated pisolites have smaller nuclei than those with fewer coats.

Handspecimen: Buff-yellow pisolites protrude from a grey matrix.

Composition:

Pisoliths: 80%. 2.5 to 5 mm diameter. Ferroandolomite concentric coatings. Nuclei of micro-granular or shell fragment.

Cement: microcrystalline or microgranular. Some rhombs, with mean size 0.2mm.

Grains: Rare (0.05 - 0.15 mm): scattered in the matrix.

Alteration: Partial rhombic recrystallisation. Styolites were formed by solution of ferroan-dolomite.

Observations: The increase of iron content upwards suggests more oxidising conditions (and therefore possibly shallower), which suggestion is supported by the number of skeletal fragments which occur as nuclei of the pisolites with many rings, and by the gradual upward increase in the number of concentric rings per pisolite, which (Carozzi, 1960) indicates a relative increase in local agitation. This upward grading is exhibited in many oolitic and pisolitic beds of the Skewthorpe Formation and suggests that the inferred shallowing and increase of turbulence which it expresses within this bed was repeated within the other oolitic beds.

Sample: CG218/1 (P).

Locality: North-west of Pretlove Hills: section 218.

Determination: Glauconitic detrital pisolitic dolomite.

Texture: Partial rhombic recrystallisation texture (medium crystalline) in pisolitic nuclei. Otherwise original texture. Imbrication in oval pisolites.

Handspecimen: Protruding pisolites prominent. Grey-green.

Composition:

Pisolites: 50%; maximum 4 mm, of ferroan-dolomite. Many have skeletal nuclei.

Grains: 40%; detrital (probably quartz and feldapar, subrounded; 0.15 - 0.3 mm.

Cement: 5%; microgranular.

Glauconite: 5% pelletal.

Alteration: Partial rhombic recrystallisation of ferroan-dolomite in pisolitic nuclei.

Observations: Oval shape and imbrication of pisolites, together with the 40% detrital grains, indicate a more turbulent environment than that of CG201/5.

Sample: CG201/4G (P).

Locality: Skewthorpe Ridge.

Determination: Glauconitic, partially recrystallised oolitic dolomite.

Texture: Oolitic texture obscured partly by rhombohedral reorganisation texture.

Handspecimen: Grey-green: ooliths faintly visible.

Composition:

Ooliths: 60%; nuclei of dolomite and coatings of ferroandolomite to ankerite. Frequently flattened, and truncated by styolites parallel to bedding plane. Often nuclei are quite flattened, while outer rings are successively less so. The orientation of the axes of flattened nuclei is haphazard in relation to the bedding plane. This can be observed in both vertical and horizontal sections. Ooliths are frequently penetrated by quartz grains and by each other.

Grains: 25%; detrital quartz, 0.1 to 0.4 mm, well-rounded.

Cement: 15%; microgranular.

Alteration: Partial recrystallisation of dolomite to rhombs.

Observations: Flattening of oolitic nuclei was followed by further growth of concentric coatings, and by further movement, as shown by the haphazard orientation of axes of flattened oolith-nuclei. Inter-penetration also suggests re-working, as do twin and "triplet" ooliths, encased in one or more oolitic coatings.

Sample: CG285/4 (TS).

Locality: Mount Connection.

Determination: Aphanitic recrystallised dolomite (originally oolitic dolomite).

Texture: Complete recrystallisation into crystalline mosaic has taken place, but relict texture shows original ooliths. Crystals do not cross the original outer boundary of the individual ooliths. The outline of the original oolitic nucleus also survives in the same way, and within it the crystals are often comparatively small.

Handspecimen: Ooliths weather out clearly. Grey.

Composition:

Ooliths: 70%; maximum diameter 1.3 mm; of dolomite; well packed.

Groundmass: Subhedral mosaic cement of dolomite. Largest crystals reach 0.4 mm.

Grains: 8%; quartz, 0.05-0.2 mm.

Alteration: Dolomite crystals have replaced original fine structures of the ooliths in subhedral mosaic.

Sample: CG245/3

Locality: South of Pretlove Hills. Section 245.

Determination: Detrital oolitic dolomite.

Texture: Original oolitic texture completely replaced by rhombic dolomite; only circular arrangement of quartz grains round the original ooliths (1.1 mm. diam.) reveals the original texture. Typiclly there is a large dolomite rhomb (up to 0.5 mm.) in the centre of the oolith. Rhombs frequently zoned, with areas containing minute inclusions of ferruginous material alternating with areas without inclusions. Round the central large rhomb the subhedral mosaic is of smaller crystals, which cross the original external oolith boundary.

Handspecimen: Grey-buff.

Composition:

Dolomite: 75%; rhombic, and subhedral mosaic, with ferruginous inclusions and zones.

Grains: 25%; detrital quartz, subrounded before secondary outgrowths.

Alteration: Secondary quartz outgrowths on grains.

Observations: Ferruginous inclusions indicate an original primary cement of ? ferruginous clay or calcite.

Sample: CG201/4E (TS).

Locality: Skewthorpe Ridge.

Determination: Medium quartz sandstone, with ooliths, and dolomitic cement.

Texture: Ooliths and dolomitic cement partially recrystallised.

Handspecimen: Pinkish-grey.

Composition:

Grains: 60% detrital quartz, with some quartzite; attain 0.4 mm, and average 0.3 mm; poorly rounded.

Ooliths: 25%, of dolomite and ferroandolomite.

Cement: 15%, Aphanitic cement, with some rhombs.

Alteration: Ooliths have lost their original structure and have developed euhedral dolomite rhombs at their centres. These are frequently zoned, with the crystallorgaphic axes of successive zones unrelated in orientation to each other. Many rhombs contain ferruginous inclusions. The large central rhombs are in a matrix of cryptocrystalline dolomite with ferruginous inclusions, which is surrounded by a circular area of concentrated brown ferruginous pigment. At the periphery of the oolith is a circular band of small ferroandolomite rhombs with ferruginous inclusions. These rhombs are restricted within the circular outer boundary of the original oolith, which they never cross.

Detrital grains often are corroded by the dolomite matrix, which has partially replaced them along cracks and crevices.

Observations: The unrelated crystallographic axes of successive zones within the central dolomite zones of the ooliths suggest several periods of crystallisation, with varying composition of each zone. The concentrated ferruginous pigment round the central rhombs of the ooliths indicate a separation from an originally more disseminated form in the primary ferroandolomite composition of the oolith - a composition which all the unaltered oolitic dolomites display. (Cf CG201/5, 218/1, 201/4G).______________________

Sample: CG201/6 (TS)

Locality: Skewthorpe Ridge.

Determination: Aphanitic dolomite.

Texture: Completely replaced by subhedral dolomite mosaic. Relict ferruginous circular or oval line shows original oolitic texture.

Handspecimen: Grey-green, visibly crystalline.

Composition: Dolomite.

Alteration: Complete recrystallisation. Relict ooliths often have an inner concentric line within their external form. Rhombic and euhedral crystals frequently cut across the outer line, but never the inner line, within which they are smaller. The inner ring of the photomicrograph of sample CG201/6 shows an elongated off-centred shell-fragment as a nucleus. There is a bipartite division of the inner ring; crystals in one division are relatively smaller than those in the other.

Observations: The inner ring may represent a pause in oolith formation, during which an oxidised coating formed. After renewed oolitisation round the inner ring, crystallisation took place separately inside and outside the inner ring (sphere), possibly at different times. The bipartite division of the inner ring may be due to a fortuitous alignment of dolomite crystal faces, or to some phase-difference during crystallisation when the oolith may have been stationary. (Choquette, 1955, has shown that gravity is the cause for segregation of the crystal sizes in siliceous ooliths).

Discussion of diagenesis in the oolitic beds of the Skewthorpe Formation.

The ooliths in beds unaffected by recrystallisation are frequently composed of aphanitic or microgranular dolomite, which argues for a primary dolomitic composition, or a very early replacement of an originally magnesium-rich calcite by dolomite (Schlanger et al 1963) and ferroandolomite. Diagenesis in the form of reorganisation to rhombic crystals or a ehuedral mosaic took place at a later stage. There is no evidence of any compaction, which would have taken place in the event of an original cement or matrix being dissolved away before the influx of dolomite-rich solutions; there was therefore probably no overall change in volume, and recrystallisation was purely a process of reorganisation of existing material: the aphanitic and microgranular dolomite and ferroandolomite of both matrix and ooliths were recrystallised into rhombs in which the more ferruginous material remained as inclusions or was concentrated in zones. The unrelated axial orientation of the different concentric zones of the rhombs displayed in some oolites may indicate that there was still some motion of the ooliths during recrystallisation, which was therefore probably a syn-depositional or early post-depositional process. In some samples (CG201/4E), where the iron content of the primary ferroandolomite in the ooliths was so high as to be unstable, the dolomite became separated from the excess iron and formed large rhombs, around which the iron oxides were concentrated in a granular mass. This process would have taken place before consolidation of the rock, as post-consolidation reorganisation would probably result in rhombs of ankerite rather than a separation of the dolomitic and ferruginous components of the primary composition, which would have been more feasible in a relatively fluid medium.

The fact that some oolitic dolomite beds are recrystallised, while others of practically identical lithological and chemical composition are not, also argues for an early and possibly pre-consolidation recrystallisation. If diagenesis were due to some late post-consolidation process there is little reason to suppose that beds of a similar chemical and lithological composition would not have been similarly affected by it.

(b) Sandstones

Sample: CG238/2 (TS).

Locality: Onslow Hills.

Determination: Medium-grained quartz sandstone with dolomite cement.

Texture: Secondary outgrowth of quartz grains. Cement is fine subhedral mosaic of rhombic dolomite. Circular grouping of grains suggest relict outlines of ooliths, completely recrystallised.

Handspecimen: Friable, grey-buff.

Composition:

Grains: 60% Quartz. Subrounded.
10% Quartzite and rare K-feldspars.
0.2-0.25 mm.

Cement: 30% dolomite.

Alteration: Secondary quartz outgrowths. Recrystallised cement.

Similar rocks: CG240/2 which has laminae and bands of crystalline dolomite. CG262/1, which has no dolomitic cement but a ferruginous cement.

Sample: CG277/1 (P).

Locality: Little Tarrara Bar.

Determination: Oolitic solution breccia.

Texture: Angular clasts of finely-bedded oolite (3 mm to 25 cm or more) in fine ferruginous sandstone and rock. Top and base of brecciated beds are straight. Brecciation extends along whole of bed; interbedded with non-brecciated beds. No ooliths in non-brecciated beds. Complete recrystallisation of ooliths, which are distinguishable only by circular arrangement of grains round their original outline. Clasts are corroded and dissolved round their edges.

Handspecimen: Purplish-grey. Clasts difficult to distinguish from matrix.

Composition:

Clasts: Glauconitic detrital oolitic ferroan-dolomite, layered. Grains are quartz and quartzite (fine to medium, subrounded). (Ooliths 40%, Glauconite 8%, microgranular cement 22%, Grains 30%).

Matrix: Detrital quartz and quartzite grains (fine to medium.) Subrounded 30%, rock-flour 40%, and fine ferruginous material 30%.

Alteration: The ferroandolomite of the recrystallised ooliths in the clasts has dissolved, to leave a ferruginous residue in the matrix, as well as a higher concentration of detrital quartz grains and iron oxides.

Observations: The solution of the ferroandolomite in oolitic beds is the probable cause of brecciation: non-oolitic solution-resistent beds did not dissolve, but were brecciated into the voids left by the dissolved beds. This mechanical action ground up the brecciated rocks against each other, producing rock-flour. Glauconite (absent from the matrix) was probably altered to iron oxides. Relative insolubility of resistant beds was probably due to primary compositional differences.

A similar solution breccia is described by Middleton (1961).

(b) Algal stromatolites

Sample: OG214/13.

Locality: South Onslow Hills.

Determination: Fine to medium grained quartz sandstone, with dolomitic cement.

Texture: Subangular grains. Cement is euhedral and often rhombic. Scattered ooliths and spherical algal pellets.

Handspecimen: Grey-green-brown.

Composition:

Grains: 50% Quartz, with secondary outgrowths, K-feldspar (10%) with secondary outgrowths, and quartzite (5%).

Accessory tourmaline.

Cement: dolomite, whose crystals have grown round the secondary outgrowths of the grains.

Ooliths: scattered; showing radial and concentric structure.

Algal pellets: scattered, consisting of aggragations of small quartz grains and dolomite rhombs bound together by fine ferruginous threads and branching filaments. Algal pellets often act as nuclei for ooliths.

Similar rocks: CG214/6, which is essentially similar, except that it has a high enough content of algal structures to be a stromatolite with scattered detrital grains. The algal stromatolite binding the sediment is in the form of crenulated horizontal branching threads, which are frequently gathered up in spheres, which may be unattached in areas where detrital grains are most numerous.

Logan, Rezak and Ginsburg (1964) relate spherical shape of algal structures to a more turbulent depositional environment than that of horizontally layered or hemispherical structures.

(c) Dolomitic breccias

Sample: CG262 E (F).

Locality: North of the Onslow Hills.

Determination: Dolomitic breccia.

Texture: Rounded, oval clasts from a few mm. to 3 inches, in a matrix of medium grained quartz sandstone with dolomitic cement. The matrix contains scattered ooliths. Oval clasts show imbrication.

Handspecimen: Grey-green, with prominent clasts.

Composition:

Matrix: Grains (70%) are quartz and feldspar, subangular in a euhedral mosaic cement of dolomite. There are scattered ooliths, composed of ferroandolomite or ankerite.

Clasts: Composed of ferruginous oolitic quartz sandstones with ferroandolomite cement; of ferruginised algal stromatolitic dolomite, and of oolitic dolomite.

Similar rocks: CG214/15, CG262.

Observations: The dolomitic breccias mark the transition between the more continental and the marine parts of the Skewthorpe Formation sedimentary rhythms, and indicate very shallow (beach) deposition.

Upper Cambrian and Ordovician Sandstones

Sample: CG226/3 (TS).

Locality: Section 226, Onslow Hills.

Age: Clark Sandstone, Upper Cambrian.

Determination: Medium-grained feldpathic quartz sandstone, with weak ferruginous cement.

Texture: Well-developed secondary enlargement of the originally well-rounded feldspar and quartz grains.

Handspecimen: Reddish-brown, friable. Contains trilobites and brachiopods.

Composition:

Grains: Quartz - 50%.
K-feldspars - 35%.
Glauconite - 10%, pelletal, green.
Accessory chert, quartzite and tourmaline.

Grain size: 0.05 - 0.2 mm.

Cement: Hematite - very little.

Alteration: Secondary enlargement (see Texture); many secondary overgrowths of feldspar have straight crystal faces.

Sample: O & T (TS).

Locality: A few hundred yards north-west of Clark Jump Up.

Age: Ordovician (Pander greensand).

Determination: Medium-grained glauconitic quartz feldspathic sandstone with dolomitic cement.

Texture and alteration: Poorly sorted, well rounded grains. Secondary growth prominent in feldspars, with authigenic rims in both quartz and feldspars frequently moulded on glauconite grains against which they abut. Some of the glauconite has been altered to iron oxide at points of greater pressure due to the compressive effect of authigenic quartz and feldspar. Partial replacement of authigenic veins by dolomite cement.

Handspecimen: Green and red speckled.

Composition:

Grains: K-feldspars - 25%.
Quartz - 20%.
Quartzite - 5%.
Glauconite (pellets) - 25%.

Cement: Dolomite (25%).

Observations: Authigenic feldspar formed after the glauconite pellets. Dolomite formed last, as it has partially replaced the authigenic veins.

Sample: CG233A (TS).

Locality: Pander Ridge.

Age: Ordovician (Pander Greensand).

Determination: Medium-grained glauconitic quartz sandstone, with hematite cement.

Texture and alteration: Quartz and feldspar grains have secondary outgrowths. Glauconite pellets are fresh, but often mechanically compressed and distorted by compaction, and frequently altered to iron oxide at pressure points.

Handspecimen: Dark-red to purple, with green and white specks.

Composition:

Grains: Quartz 50%
Quartzite and chert 10%
Feldspar 5%
Phosphatic shell fragments 3%
20% Glauconite (pelletal)

Cement: Hematite. Often as coating round original grains, between the grain and its authigenic vein.

Similar rocks: CG233G, Pander Greensand (TS) has well-developed secondary outgrowth of quartz, with a hematite coating round the original grain as well as in intergranular spaces.

CG233D Pander Greensand, (TS); some of the glauconite pellets altered to iron oxide at pressure points.

CG231A, Clark Sandstone (TS); some of the glauconite pellets have yielded to pressure from secondary outgrowth of grains by splitting along micro-faults within the pellets. One glauconite grain shows parallel cleavage, similar to that of biotite. CF Hodgson, (1962).

CG202/3A, Clark Sandstone (TS): authigenic growth of quartz has stopped where the quartz grain penetrates a glauconite pellet, which show that quartz secondary outgrowth was subsequent to compaction.

CG202/4D, Clark Sandstone (TS): many glauconite pellets are completely replaced by a rhombic mosaic of dolomite, in which only the relict outline and a few green traces of pigment remain.

CG202/41, Clark Sandstone (TS): Quartz grains are corroded and partly replaced by dolomite, which is rhombic and has ferruginous inclusions, indicating a probable original matrix of ferruginous material - ? clay or silt.

CG202/3A. Clark Sandstone (TS): glauconitic pellets contain relict ghosts of rhombic dolomite, from which the dolomite has been dissolved, together with the dolomitic cement, of which no trace is left except for indirect evidence of etched quartz grains.

Discussion:

The history of the formation of the Upper Cambrian and Lower Ordovician sandstones is summarised as follows:

1. Deposition of feldspathic quartz sandstone in a matrix of ferruginous silt or clay, and formation of glauconite pellets.
2. Authigenic growth of secondary quartz and feldspar.
3. Replacement of the original matrix by a crystalline dolomitic cement.
4. Solution of the dolomitic cement and alteration of glauconite to iron oxide.

REFERENCES - See References for this Record.

APPENDIX 3.

THE CAMBRIAN AND ORDOVICIAN SEQUENCE, CAMBRIDGE GULF AREA, WESTERN AUSTRALIA

by
A.A. Öpik

INTRODUCTION

The geographic designation 'Cambridge Gulf Sequence' is applied here for sense of continuity with the earlier published accounts (Öpik, 1956; 1957) regarding the same sequence and region. Other designations are Joseph Bonaparte Gulf and the colloquial 'Bonaparte Gulf' (for example, in Noakes, Öpik and Crespin, 1952).

The collection in hand (by J.J. Veevers and Party, 1963) is rather voluminous. The extraction of all fossils and their adequate study is a project of several years; hence, the present account is based on a preliminary study of selected material.

The larger part of the earlier collection by D.M. Traves and A.A. Öpik was destroyed in a fire before it could be examined in the laboratory, and the account by Öpik (1956) refers essentially to palaeontological field observations.

Friable sandstone prevails as matrix of the fossils, and tests of trilobites and calcareous brachiopods are not preserved. Special care is therefore needed in extracting and conservation of the specimens; furthermore, large numbers of specimens are needed for an adequate description of species, and even genera to ensure that features approaching the size of sand grains and interspaces between the grains may not escape observation and conservation.

STRATIGRAPHIC DESIGNATIONS AND PALAEONTOLOGICAL NOMENCLATURE.

Twelve stratigraphic entities can be recognized in the Cambrian and Ordovician sequences of the Cambridge Gulf area; they are enumerated by Roman numerals I to XII, in ascending order. These entities are based on fossils, and on trilobites in the first place. The entity III, covering the larger part of the Middle Cambrian is, however, unfossiliferous on available evidence, but its age is evident from the interpolation between the divisions II (below) and IV (above). The division X is composite, with XA (below) and XB (above); these subdivisions are apparent from the distribution of different species of common genera, and even of different genera of common subfamilies.

The names of trilobites used in the description of the stratigraphic subdivisions are given in a form not affecting the existing taxonomic nomenclature. Designations like 'Metadoxidids' and 'Kaolishaniid' are references to the 'nearest family' in the sense of current classifications; the formal names of families (e.g. Saukiidae, Parabolinoididae) and of genera (*Prosaukia*, *Ptychaspis*, *Paramansuyella*) are used in their definite taxonomic meaning.

CORRECTIONS

The corrections that follow below (in ascending order) are needed to maintain the continuity passing from the earlier publications (Traves, 1955; Öpik, 1956, 1957) to the present account. Amplified discussion of the corrected stratigraphic and palaeontological data are given in the next part (The faunal sequence).

(1) The limestone - siltstone sequence in Ragged Range (Traves, 1955, p.47, text-fig.20) designated as 'Negri Group' belongs to a different unit probably older than the Negri Group.

(2) The fossiliferous part of the Skewthorpe Formation dated by Öpik (1956, 1957, p.53) as *nathorsti* or *Leiopyge laevigata* Zone is even younger than that (Middle Cambrian - Upper Cambrian passage and early Upper Cambrian).

(3) The 'not yet properly correlated locality containing '*Idahoia*' associated with dikelocephalids and a probably olenid trilobite' (Öpik, loc.cit) represents the division VII. Dikelocephalids, however, are absent and the 'Olenids' belong now to the Parabolinoididae (this family was established in 1956).

(4) The 'middle Dresbachian' sandstone with *Crepicephalus* (loc. cit) represents the division IX. This '*Crepicephalus*' is a kaolishaniid (probably a new genus).

THE FAUNAL SEQUENCE

I. This division contains *Biconulites* and a Metadoxidid trilobite; *Redlichia* is absent, but follows above. *Biconulites* occurs in the early Middle, and apparently in the late Lower Cambrian, and the Metadoxididae are believed Lower Cambrian in age. This sequence is therefore regarded as of a possible late Lower Cambrian age.

II. (Redlichia). The Redlichia is known from fragments only and cannot be determined specifically; it is associated with Biconulites cf. hardmani. The age is early Middle Cambrian, and, probably, older than the Xystridura-bearing upper part of the Negri Group.

III. This part of the sequence is unfossiliferous, but represents the larger part of the Middle Cambrian.

IV. The fossils in this part of the Skewthorpe Formation are the agnostids Peronopsis, Grandagnostus, and Ptchyagnostus and the polymerid trilobite hitherto regarded, and referred to, as Solenoparia; it belongs, however, to a new and apparently local genus of the Ptychopariacea of an unknown family affiliation. The above mentioned agnostids were formerly believed to occur in the Middle Cambrian only, but are now known to pass into the early Upper Cambrian in Queensland as well. In the same division (IV) fragments of the Damesellidae (but not of Damesella!) have been recorded, which are even better represented higher up in this division. These trilobites belong to Blackwelderia, and another unpublished genus, both known from the early Upper Cambrian Mindyallan Stage (Öpik, 1963) of Queensland. Hence, the division IV represents the Middle Cambrian-Upper Cambrian passage and also the earliest part of the Upper Cambrian, which, however, are inseparable from each other in the collections from the Cambridge Gulf area.

V. Mindyallan: Mindyallan is the initial Upper Cambrian stage (Öpik, 1963): in the lower (in parts dolomitic - calcareous) levels of this division the 'Solenoparia' (see under IV) and the unpublished form of the Damesellidae are well represented; in sandstone that follows above sinistral gastropods occur; undescribed as yet, these are recorded in the Mindyallan faunas of Queensland and Central Australia. Hence, the division V wholly belongs to the Mindyallan Stage, and it is correlated with the Kushanian of China and the lower Dresbachian of North America.

VI. Idamean: The part of the sequence referable to the Idamean Stage of the Upper Cambrian (Öpik, op.cit.) is poor in fossils. Gastropods and phosphatic brachiopods occur sparodically; trilobites referable to the Aphelaspidinae are present in the sample 245/7, but are inconclusive as regards their position within the stage.

Owing to the scarcity of fossils the Idamean and the Mindyallan parts of the sequence cannot be separated from each other. Furthermore, even more obscure is the upper extent of the Idamean because a fauna is missing which should intervene between the Idamean and the division VII (Parabolinoididae). The missing fauna is expected to correspond to the zone of *Irvingella tropica* and *Agnostotos inconstans* of the Queensland scale of zones (below) followed above by an equivalent of the American *Elvinia* Zone. Of course, it is possible that in the Cambridge Gulf sequence the Parabolinoididae appeared already in the *Elvinia* time, i.e. one zone earlier than in America. It should be noted also that in Queensland (Öpik, 1963, p.22) a barren sequence covers the interval between the *Irvingella tropica* - *Agnostotes* Zone of the Idamean and the strata containing *Paramansuyella.* Consequently, equivalents of the *Elvinia* fauna and of the division VII (Parabolinoididae) are not evident in Queensland.

The three following faunal divisions, beginning below with VII (Parabolinoididae), VIII (Parabolinoididae and *Paramansuyella*) and ending above with IX (Kaolishaniid) cannot be separated sharply from each other because the Parabolinoididae extend apparently even into the base of the division IX: nevertheless the faunal contrast between the earliest (VII) and the latest (IX) divisions prevents any confusion, and *Paramansuyella*: (of VIII) and the Kaolishaniid (of IX) have notbeen found as yet together.

VII. (Parabolinoididae): Three genera of Parabolinoididae Loohman, 1956, occur in the Cambridge Gulf sequence. *Parabolinoides* itself is absent, but affiliates of *Taenicephalus* and, apparently, of *Croixana* (forms with obsolete or partly obsolete frontal marginal cranidial furrow) are present.

VIII. (Parabolinoididae and *Paramansuyella*), The Parabolinoididae in the division VIII are referable to the genera of the earlier division VII; the species of *Paramansuyella*, however, is continued to the division VIII. It is very close to the undescribed species from the Chatsworth Limestone of Queensland (Öpik, 1960, p.107; 1963, locality D124, p.22).

IX. (Kaolishaniid): The trilobite in question is recognisable from the pygidium, cranidium and free cheeks and belongs to an undescribed genus tentatively placed in the family Kaolishaniidae. The division IX with the Kaolishaniid is a valuable stratigraphic marker. Above it, and quite abruptly, a different fauna, beginning with *Ptychaspis* gains with the advance in time in diversity and abundance of forms.

X. *Ptychaspis* - *Prosaukia*: This unit is divisible into a lower (X.A.) and an upper (X.B.) part. The lower part contains, among other trilobites, *Tsinania* and an asaphiseid which has been compared with *Maryvillia* (Öpik, 1956, p.53); these disappear in the subdivision XB in which a saukiid appears distinguished by a long frontal spike.

As a whole, the unit X. contains several undescribed and some known genera of the Saukiidae. *Prosaukia* is represented by some three species and *Sinosaukia* probably by two. *Ptychaspis* is also well represented and a form intermediate between a *Saukia* and a *Ptychaspis* occurs frequently. Deserving of mention also is an affiliate of *Prosaukia* whose cranidia are some 3 cm. long and are distinguished by very long (transversely) postero-lateral limbs.

XI. (*Tellerina*) : Only one collection (275/4) is referable to this division. It contains a *Tellerina* like pygidium and fragmentary cranidia of Saukiidae reminiscent of *Saukia* and/or *Saukiella*. The occurrence of cranidia cf. *Tellerina* was mentioned by Öpik (1956, p.53).

The unit XI represents the top of the Upper Cambrian (i.e. of the Cambrian:) and should be examined in the field once more.

XII. (Ordovician): Within the section 249, the bed 249/9 contains fragments of asaphids and cystid plates with porerhombs. Above it, Richardsonellidae, Leiostegiidae and protopliomerids indicate a late Tremadocian to early Arenigian age of the bed 249/11.

PROVINCIAL AFFINITIES AND ZONE CORRELATION.

The fossil record in the Cambridge Gulf sequence is continuous beginning with the unit VII whose Parabolinoididae indicate marine connexion with North America (e.g. Minnesota), whereas *Paramansuyella* and the Kaolishaniid are of a S.E. Asian affinity. The units VII to IX together can be correlated roughly with the *Conaspis* Zone of the Franconian of North America. The fauna of the unit X is also a blend of North American and S.E. Asian forms on a background of a probably endemic Australian population of trilobites. It correlates well with the American Upper Franconian Zones with Ptychaspis and Prosaukia. The unit XI finally repreents the Trempealeauan Stage.

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APPENDIX 4.

The Petrography of some Specimens of the Antrim Plateau Volcanics and Associated Rocks from the Bonaparte Gulf Basin and Outliers.

by

W.R. Morgan

Introduction:

The specimens described are listed below, with their localities.

Registered Number	Field No.	Locality
R 15308	302	Ord River, 1 mile west of Kimberley Research Station
R 15320	27/1A	8 miles south-east of 8-mile Creek Bore
R 15352	MG1	Martin's Gap
R 15353	MG2	Martin's Gap
R 15865	62/1	Ord River, near Tarrara Bar
R 15866	62/3	Ord River, near Tarrara Bar
R 15867	62/4	Ord River, near Tarrara Bar
R 15876	58/1	5 miles south of 8-mile Creek Bore
R 16901	273/12A	5 miles south-south-east of Mount Rob.
R 16915	283/1	Martin's Gap.
R 16951	83/1A	7 miles north-north-east of Dillon Spring.
R 16952	83/1B	
R 16956	85/1	Northern tip of Carlton Range.
R 16988	L13/1	Northern part of Ragged Range.
TS.14,440	86/1A	Martin's Bluff.
TS.14,441	86/1M	Martin's Bluff.
TS.14,442	76/1B	4 miles north of Nigli Gap.
TS.14,443	79/1	8 miles south of Spirit Hill.
TS.14,444	79/2	
TS.14,445	121/1	9 miles north-east of Spirit Hill.

All the specimens represent the Antrim Plateau Volcanics except R 16901, 86/1A, and 86/IM TS 14,440, and TS 14,441 which are specimens of conglomeratic and brecciated material which directly overlie the volcanics.

Antrim Plateau Volcanics:

All of the specimens, except R 16952, TS 14,443 and TS 14,444 are strongly altered. The fresh specimens will be described first, and the altered ones second.

R 16952 is a moderately porphyritic basalt; about 10% of the rock consists of phenocrysts whose diameters range between 0.3 and 2.8 mm. Most of the phenocrysts are formed of tabular, commonly clustered crystals of fairly strongly sericitized plagioclase, with a composition of about An_{55} to An_{60}. One or two small porphyritic crystals of augite are present. A few small phenocrysts consisting of green smectite and ferruginous material may possibly represent pseudomorphed olivine. TS. 144443 and TS 14444 are very sparsely porphyritic rocks, in which the plagioclase phenocrysts range up to about 1 mm. diameter, and form less than 1% of the specimens.

In all three specimens, the groundmass has an intersertal, basaltic texture. Plagioclase forms a meshwork of laths, the crystals having an average size of 0.1 mm. long by 0.03 mm. wide. In R 16952, it is strongly sericitized, but in the others it is only slightly altered to sericite. Plagioclase composition is about An_{50}. Augite is slightly chloritized in R 16952; in TS 14444 and TS 14445, it is somewhat ferruginized and partly altered to smectite. In all rocks, augite forms granular to prismatic crystals 0.03 in diameter. Black iron oxide crystals, 0.02 to 0.1 mm. across, are octahedral. Interstitial chlorite, and, in R 16952, probable glass that is now devitrified, are present. Some vein quartz is present in R 16952 and R14445. Small amounts of fox-brown biotite form poikilitic flakes, about 0.1 mm. diameter in TS 14444.

The strongly altered specimens are, in general, very similarrto each other texturally and mineralogically. All are sparsely porphyritic, the phenocrysts forming less than 1% of most rocks; R 15876 contains about 5% phenocrysts. The porphyritic crystals commonly range up to about 1 mm. length, although in R 15865 and R 15876, they are about 3 mm. long. The phenocrysts are mostly composed of tabular crystals of moderately to strongly sericitized albite. In R 16951, the only phenocryst present consists of pseudomorphed pyroxene; it is now composed of calcite. In R 15867, in addition to plagioclase, a few chloritized phenocrysts of pyroxene, and a pseudomorph of serpentine and ferruginous material after olivine are present.

In all except three of the specimens, the groundmass consists of a meshwork of moderately to strongly sericitized plagioclase laths, together with ferruginous chlorite pseudomorphs after pyroxene, enclosed in high ferruginous chlorite pseudomorphs after pyroxene, enclosed in high ferruginous and chloritic material, much of which possibly represents altered glass. Probable pseudomorphs after olivine are present in specimens R 15308, R 15320, R 15866, and R 15867. The average grain-sizes measured range between 0.01 and 0.2 mm. Three specimens R 15353, R 16951 and TS 14445 appear to consist mostly of highly ferruginized, strongly altered glass.

Most of the specimens are amygdaloidal; the amygdales commonly contain quartz; in one or two specimens, a thin rim of chlorite forms an outer zone in the amygdales. R 16988 contains calcite as well as quartz. In R 15867, the amygdales are filled with smectite and chlorite; in R 15320, clay minerals, and TS 14445, smectite and chalcedony.

TS 14442 contains some xenoliths formed of somewhat inequigranular, fine-grained sandstone, in which the grain-sizes range from 0.03 mm. to 0.15 mm. The grains are angular to sub-rounded; they consist mostly of quartz, but chert, albite,microcline and ferruginous material are also present. The ferruginous material is much more common close to the xenolith margins, and appears to have been introduced from the basalt - whether this is due to weathering or metasomatic action is not clear. The very abundant matrix in the xenoliths is formed of apparent zeolitic material and crystalline quartz; again, the origin of this is not clear; zeolites can result from incipient regional metamorphism.

Conglomeratic and Brecciated Rocks:

The two specimens of conglomeratic rocks, TS 14,440 and TS 14,441, consist of rounded granules and pebbles which range up to 6 mm. diameter in the thin section. These consist of heavily ferruginized, chloritized, and carbonated basalt, apparently similar to that described in the previous part. The granules and pebbles are embedded in a matrix composed of crystalline calcite that encloses a few clastic quartz grains.

The breccia (R 16901) consists of angular to sub-rounded fragments ranging up to about 7 mm. diameter. The fragments are mostly of ferruginous siltstone and sandstones and some slightly feldspathic sandstones; a few consist of layered ferruginous siltstone/sandstone. One fragment has a texture that suggests it is a strongly silicified acid tuff.

The matrix is a somewhat feldspathic sandstone; a few grains of sodic plagioclase and microcline are present; the grain shape and general appearance of the plagioclase is unlike that in the basalts. In some places, however, the matrix contains a few grains of strongly altered basalt similar in appearance to that in the underlying basalt flows. The matrix grains are enclosed in a silica cement; some cavities are filled with crystalline calcite.

Remarks

The altered basalts are, mineralogically and in general appearance, like spilites. Most writers nowadays prefer to believe that spilitic rocks are alteration products of more normal igneous rocks after emplacement - e.g. Hopgood (1962), Dickinson (1962), Nicols (1958). Some believe that autometasomatism is responsible for the alteration (e.g., Nicols, op.cit). Others believe that diagenesis and possibly burial metamorphism cause alteration (e.g., Dickinson, op.cit). A.J.R. White (pers. comm.) believes that many spliitic rocks in strongly folded, geosynclinal regions are basalts, dacites, etc., that have been metamorphosed, producing green schist facies mineral assemblages.

In general appearance, the spilite-like rocks of the Antrim Plateau Volcanics are very similar to the relatively unaltered specimen (R 16952) which is probably a tholeitic basalt. This suggests that they were altered after extrusion. The cause of the alteration is not easy to find. Obviously, they are not products of regional metamorphism, because, in the field they are only slightly folded. The answer to the problem is possibly that a combination of autometasomatism and diagenesis was responsible.

The relatively unaltered basalts, in general characteristics, are fairly similar to those described from the Antrim Plateau Volcanics by Glover (in Traves, 1955), except that they are far less porphyritic. The specimens, however, do not exactly correspond with any of the groups described by Edwards (in Edwards and Clarke 1940), although, again, in general characteristics, they are similar.

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PLATE 1, A

Plates 1A, 1B, 1C missing from original.

Shale and mudstone of the Tarrara Formation, Section 232. The white veins are travertine.

PLATE 1, B

Aerial view of the Skewthorpe Formation overlying the Hart Spring Sandstone at locality 245; looking to the south-west, with the Precambrian Cave Range in the background.

PLATE 1, C

Hart Spring Sandstone; large-scale trough cross-bedding at locality OG276, 3 miles south-east of Hart Spring.

PLATE 2

Plate 2 missing from original.

A view of the Cambrian section at locality 236, looking south-west from the top of locality 238. Fossil localities are shown.

PLATE 3, A

Plates 3A, 3B missing from original.

Looking north-east at the unconformity between the Blatchford Formation (Clb) and the Ragged Range Conglomerate (Dr.). For location, see Fig.16.

PLATE 3, B

Looking north-east from locality L12 at the Ragged Range Conglomerate: the upper unit of red conglomerate shows weak layering and deep joints, and overlies less boldly exposed conglomeratic sandstone. The Blatchford Formation underlies the lower part of the slope.

PLATE 4

Plate 4 missing from original.

Conglomerate Hill, from a point two miles westward (point L11), showing horizontal Ragged Range Conglomerate (Dr) unconformably overlying broadly folded Blatchford Formation (Ꞓlb) and Antrim Plateau Volcanics (Ꞓla).

PLATE 5

Plate 5 missing from original.

Air photograph of the northern part of the Ragged Range Conglomerate and conglomeratic sandstone passing northward into closely jointed sandstone. For details, see Figure 16. North is upward. Scale approximately 1:50,000.

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PLATE 6, A

Plates 6A, 6B, 6C missing from original.

Planed stromatolite bed (Unit C) in rhythmic beds of Skewthorpe Formation. Locality CG238.

PLATE 6, B

Dolomitic algal breccia round stromatolites in Skewthorpe Formation. Locality CG238.

PLATE 6, C

Imbrication in dolomitic algal breccia overlying stromatolite bed: Skewthorpe Formation. Locality CG238.

PLATE 7, A

A typical sedimentation rhythm in the upper part of the Skewthorpe Formation, where the lower sandstone Unit A is very thin. Locality CG238.

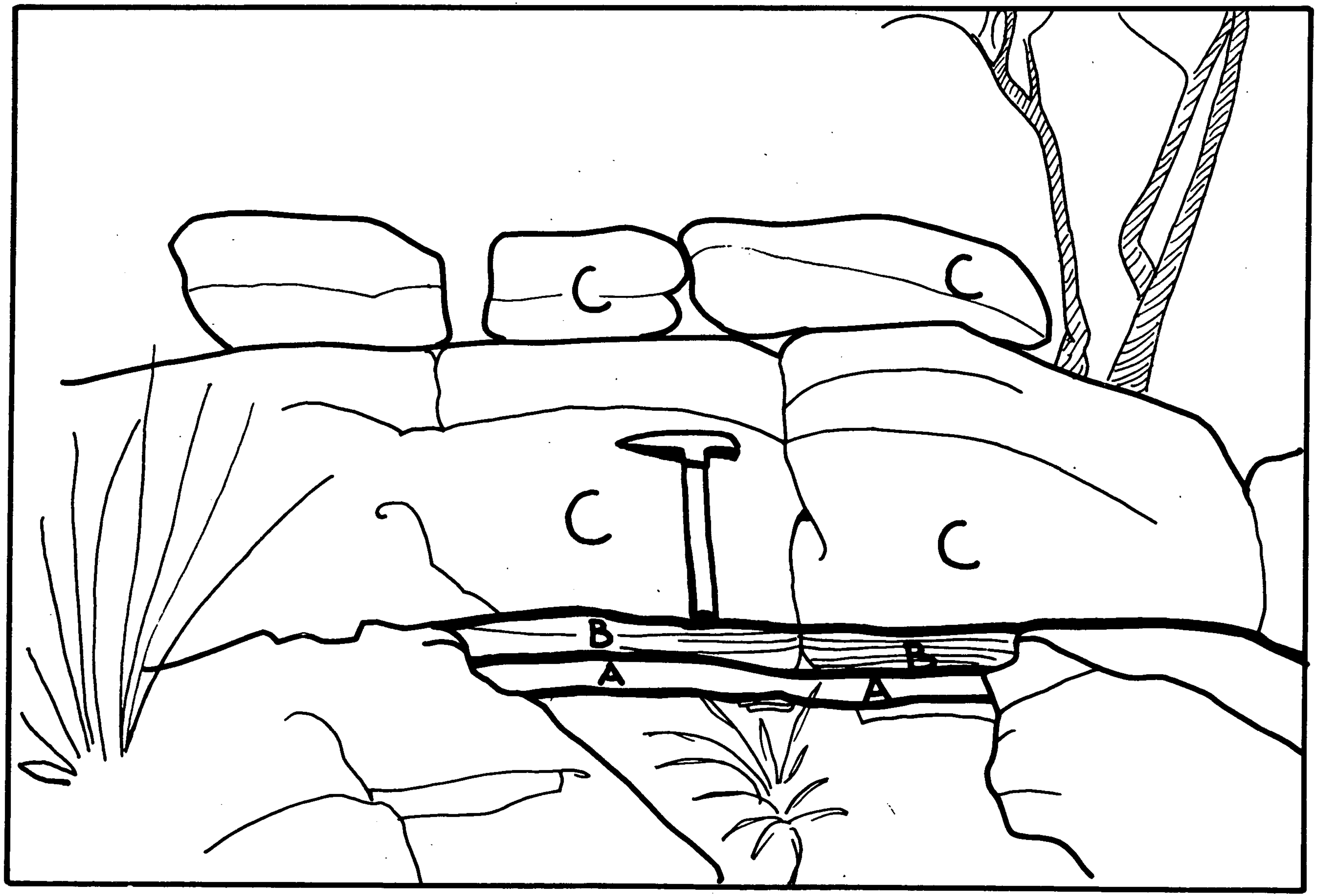
PLATE 7, B

Plate 7B missing from original.

Upwardly-convex stromatolite hemispheroid in Skewthorpe Formation (Locality CG238) with younger beds deposited round it. This is in the upper rhythmic beds of Section 238, and the algal unit (C) is overlain directly by sandy, cross-bedded dolomite (Unit B), without intervening quartz sandstone (Unit A), present in lower rhythms.

PLATE 7, C

An exposure at locality CG238, showing a typical sedimentation rhythm in the Skewthorpe Formation. The sandstone (Unit A) is cut deeply back.



A typical sedimentation rhythm in the upper part of the Skewthorpe Formation, where the lower sandstone (unit A) is very thin.

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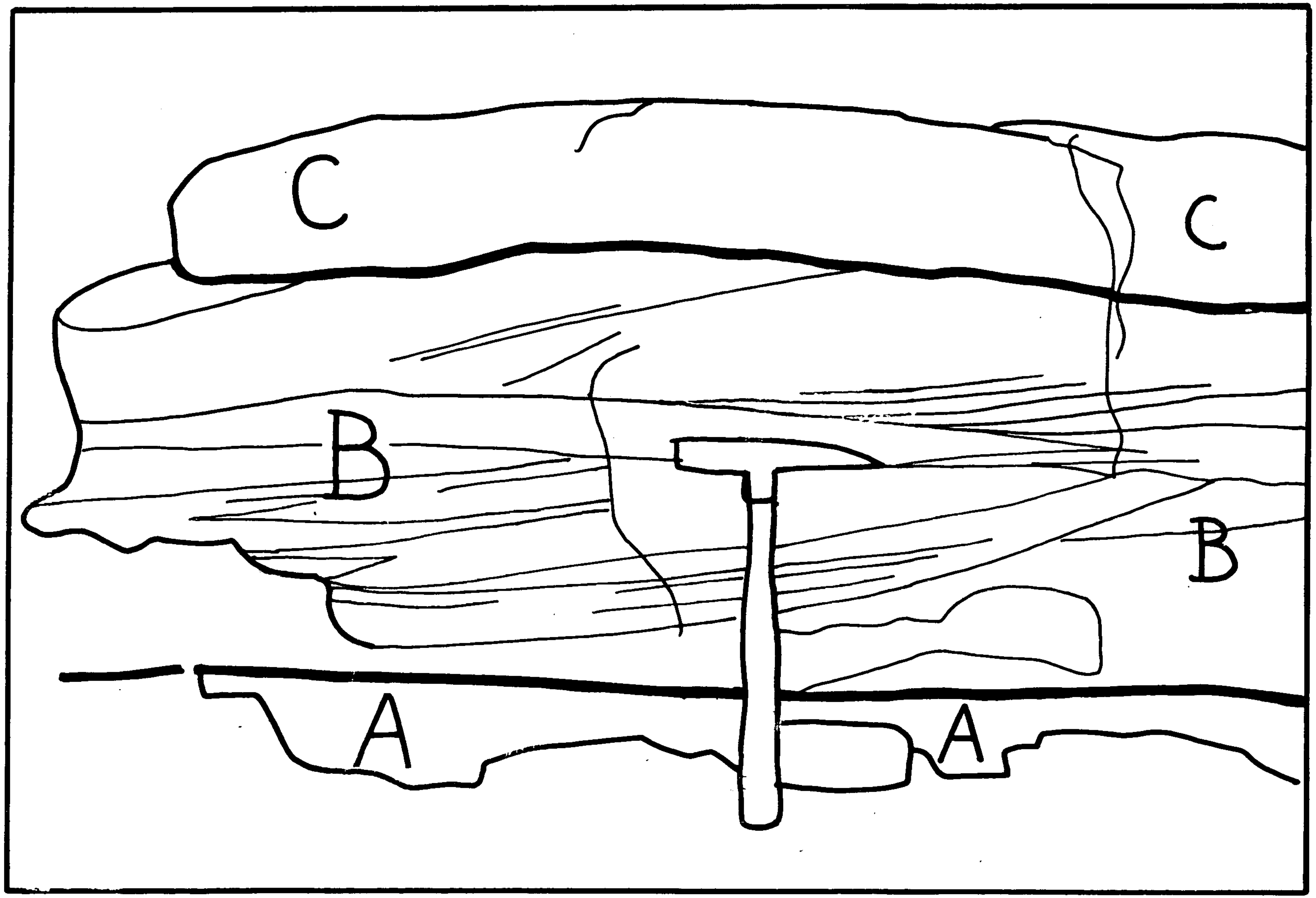
PLATE 7 C



An exposure at locality CQ 238, showing a typical sedimentation rhythm in the Skenthorpe Formation. The sandstone unit A is cut deeply back.

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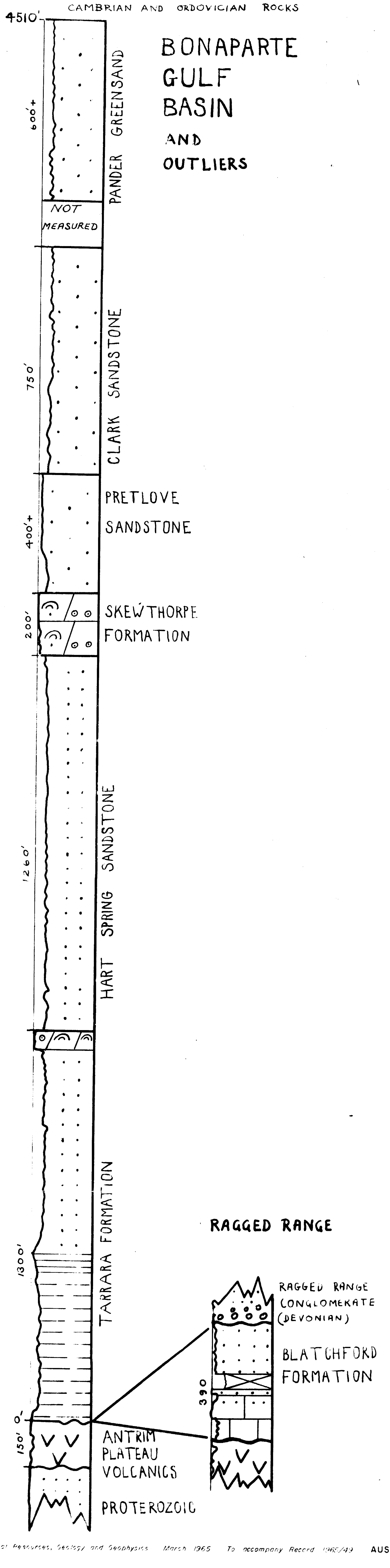
FIG. 2.

COMPOSITE SECTION

CAMBRIAN AND ORDOVICIAN ROCKS



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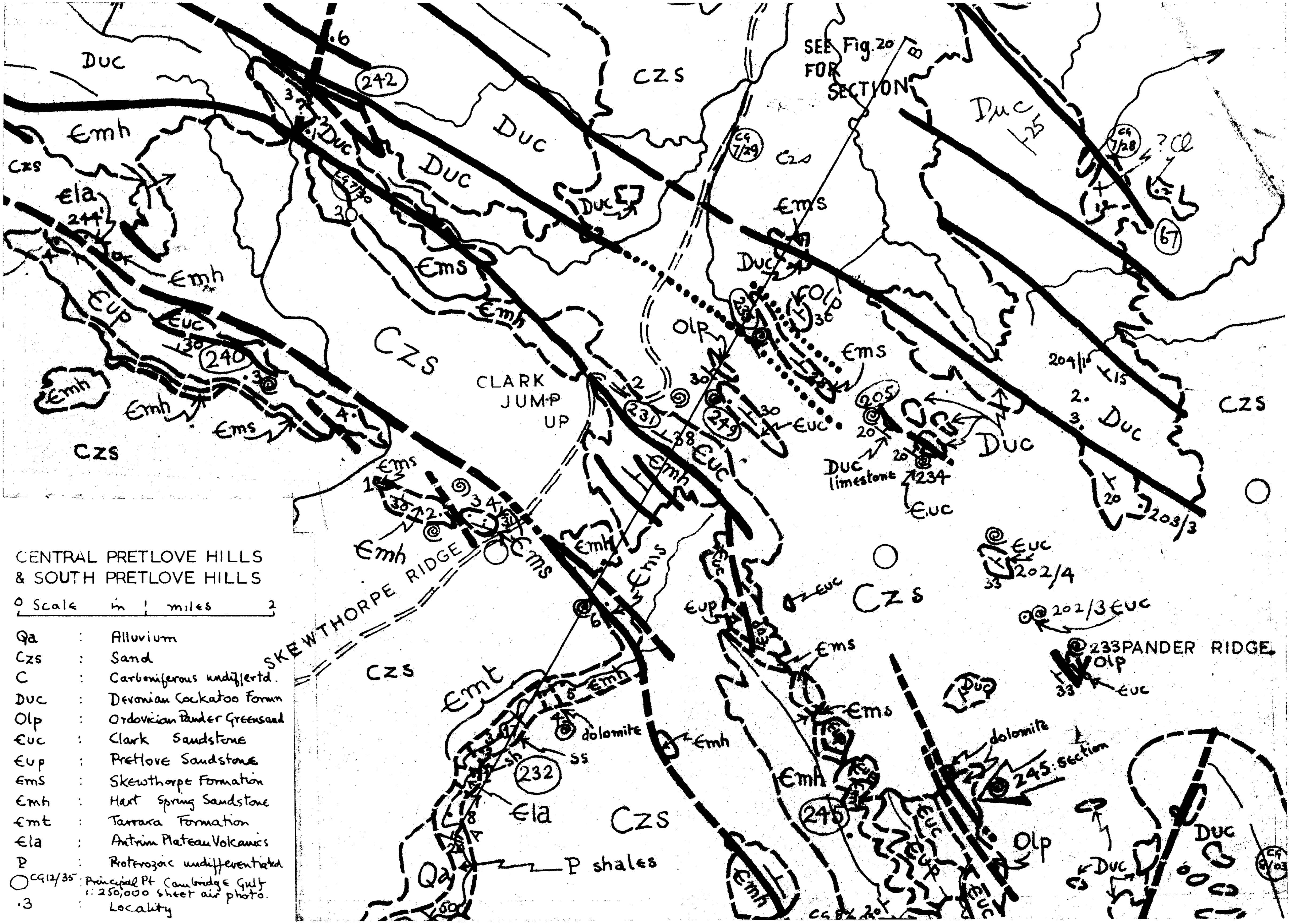
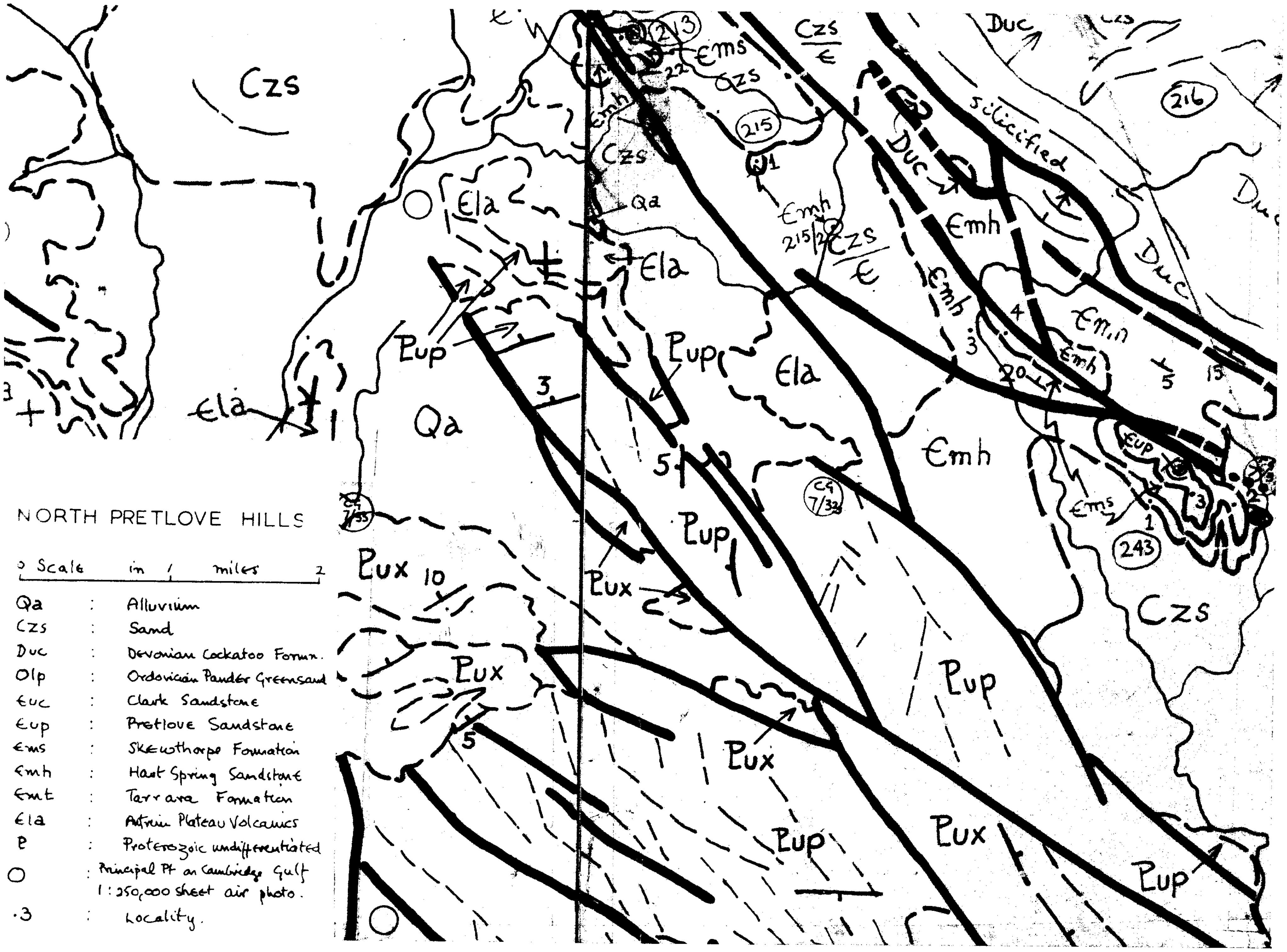


CENTRAL PRETLOVE HILLS
& SOUTH PRETLOVE HILLS

0 Scale in 1 miles 2

Qa : Alluvium
Czs : Sand
C : Carboniferous undiffertd.
DUC : Devonian Cockatoo Formn
Olp : Ordovician Pander Greensand
Ꞓuc : Clark Sandstone
Ꞓup : Pretlove Sandstone
Ꞓms : Skewthorpe Formation
Ꞓmh : Hart Spring Sandstone
Ꞓmt : Tarrara Formation
Ꞓla : Antrim Plateau Volcanics
P : Proterozoic undifferentiated
○CG12/35 : Principal Pt Cambridge Gulf 1:250,000 sheet air photo.
·3 : Locality

FIG 5



NORTH PRETLOVE HILLS

0 Scale in 1 miles 2

Qa : Alluvium
Czs : Sand
Duc : Devonian Cockatoo Formn.
Olp : Ordovician Pander Greensand
Єuc : Clark Sandstone
Єup : Pretlove Sandstone
Єms : Skewthorpe Formation
Єmh : Hart Spring Sandstone
Єmt : Tarrara Formation
Єla : Antrim Plateau Volcanics
Ᵽ : Proterozoic undifferentiated
○ : Principal Pt on Cambridge Gulf 1:250,000 sheet air photo.
·3 : Locality.

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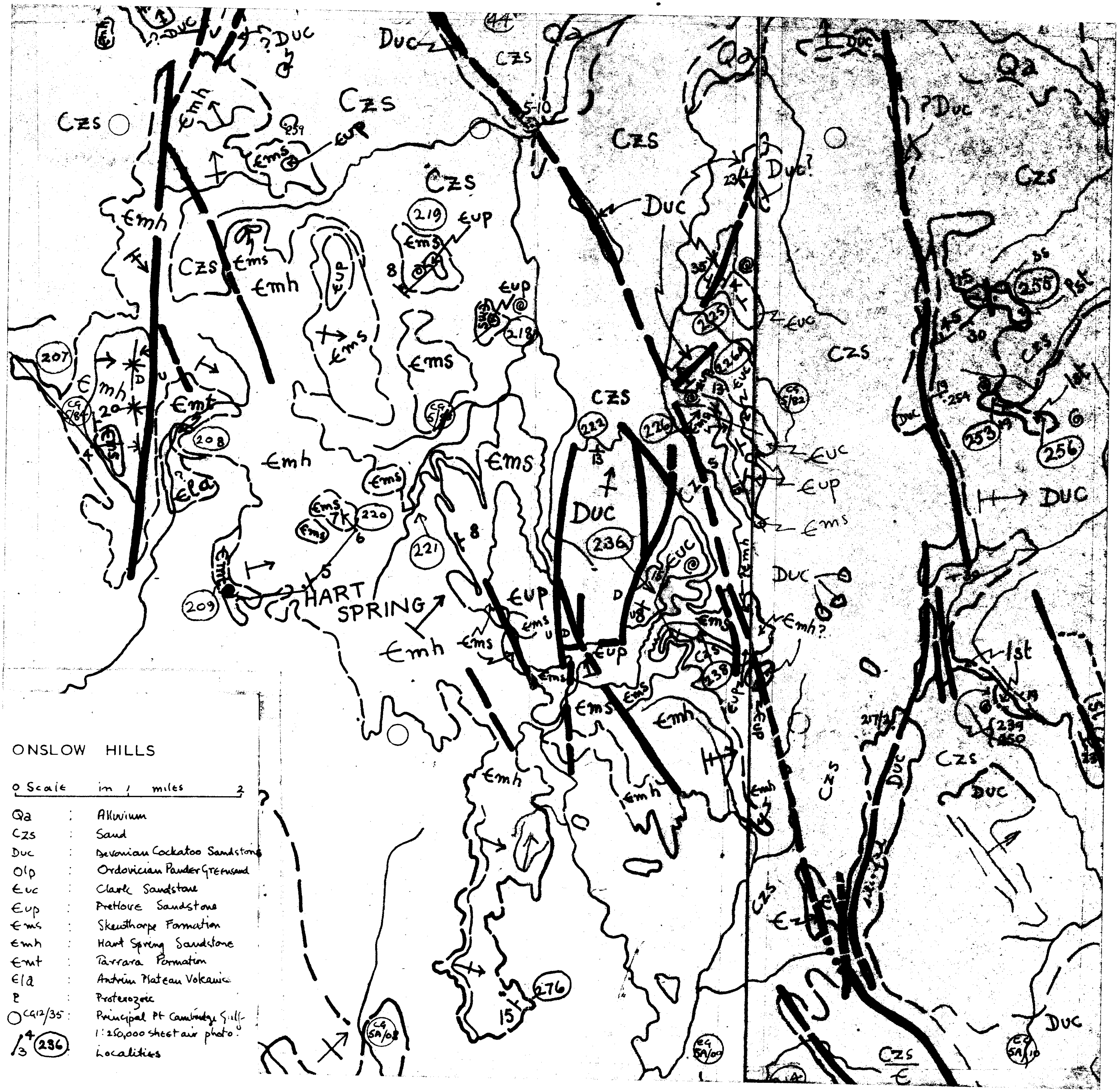
AUS/1/45

FIG. 6



ONSLOW HILLS

0 Scale in miles 2

Qa : Alluvium
Czs : Sand
Duc : Devonian Cockatoo Sandstone
Olp : Ordovician Pander Greensand
Єuc : Clark Sandstone
Єup : Pretlove Sandstone
Єms : Skewthorpe Formation
Єmh : Hart Spring Sandstone
Єmt : Tarrara Formation
Єla : Antrim Plateau Volcanics
P : Proterozoic
○ CG12/35 : Principal Pt Cambridge Gulf 1:250,000 sheet air photo
4/3 (236) Localities

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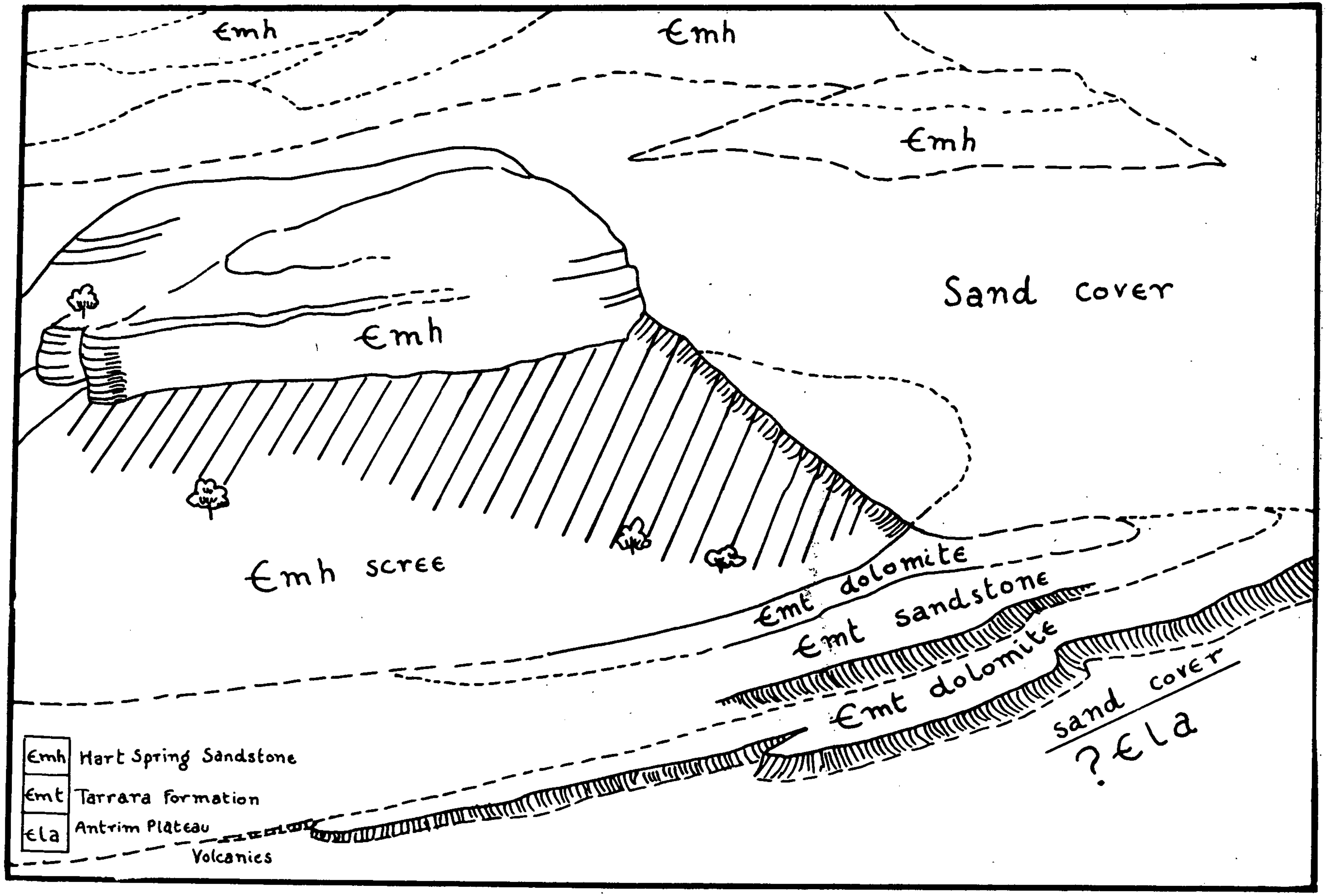
AUS /1/46

FIG. 7.



An aerial view of the base of section 209, showing the two benches of dolomite (Tarrara Formation) underlying the Hart Spring Sandstone. Drawn from a photograph.

AUS/1/47

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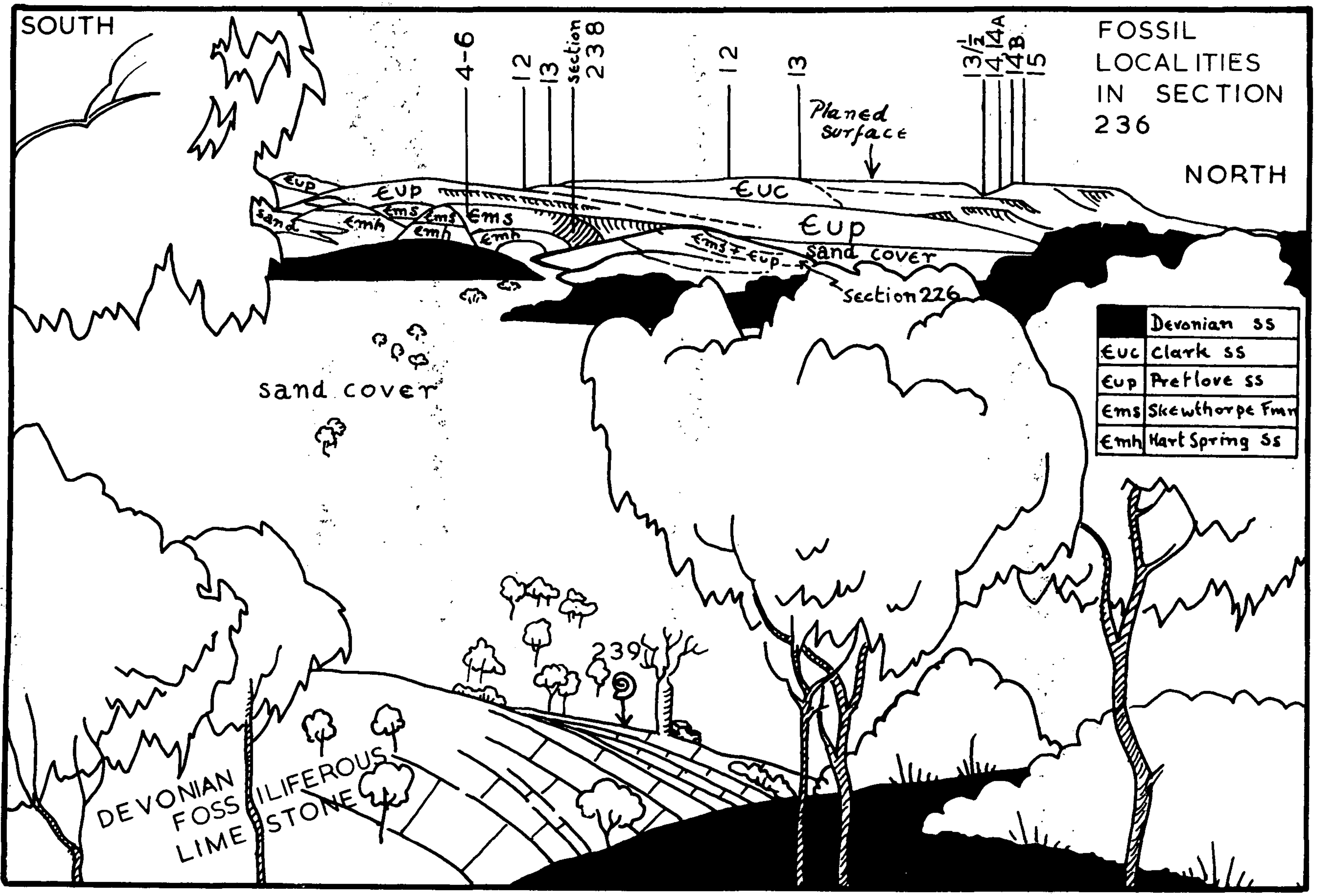
March 1965. To accompany Record 1965/49

FIG. 8:



A view of the Cambrian section at locality 236, in the Onslow Hills, looking west from the top of the Devonian sandstone scarp above locality 239. Cambrian fossil localities in section 236 are shown. (Drawn from a photograph).

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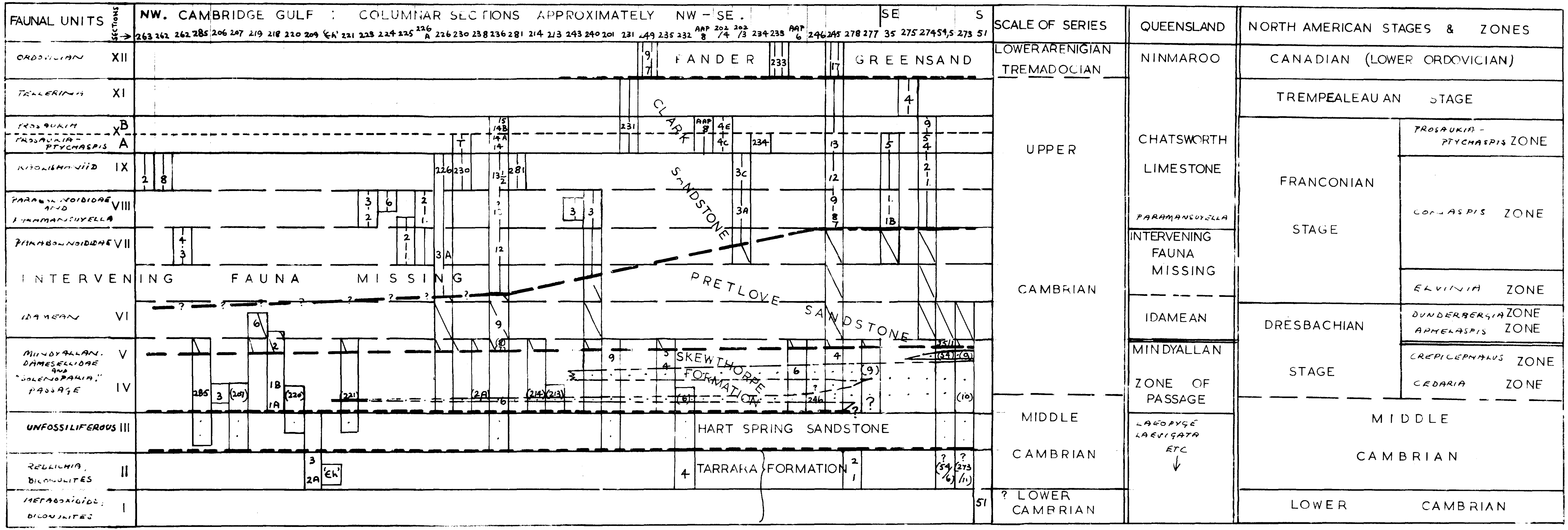
FIG. 9.

CORRELATION CHART CAMBRIAN AND ORDOVICIAN



Note: Thicknesses and time intervals not to scale.
Columnar sections show fossil locality numbers

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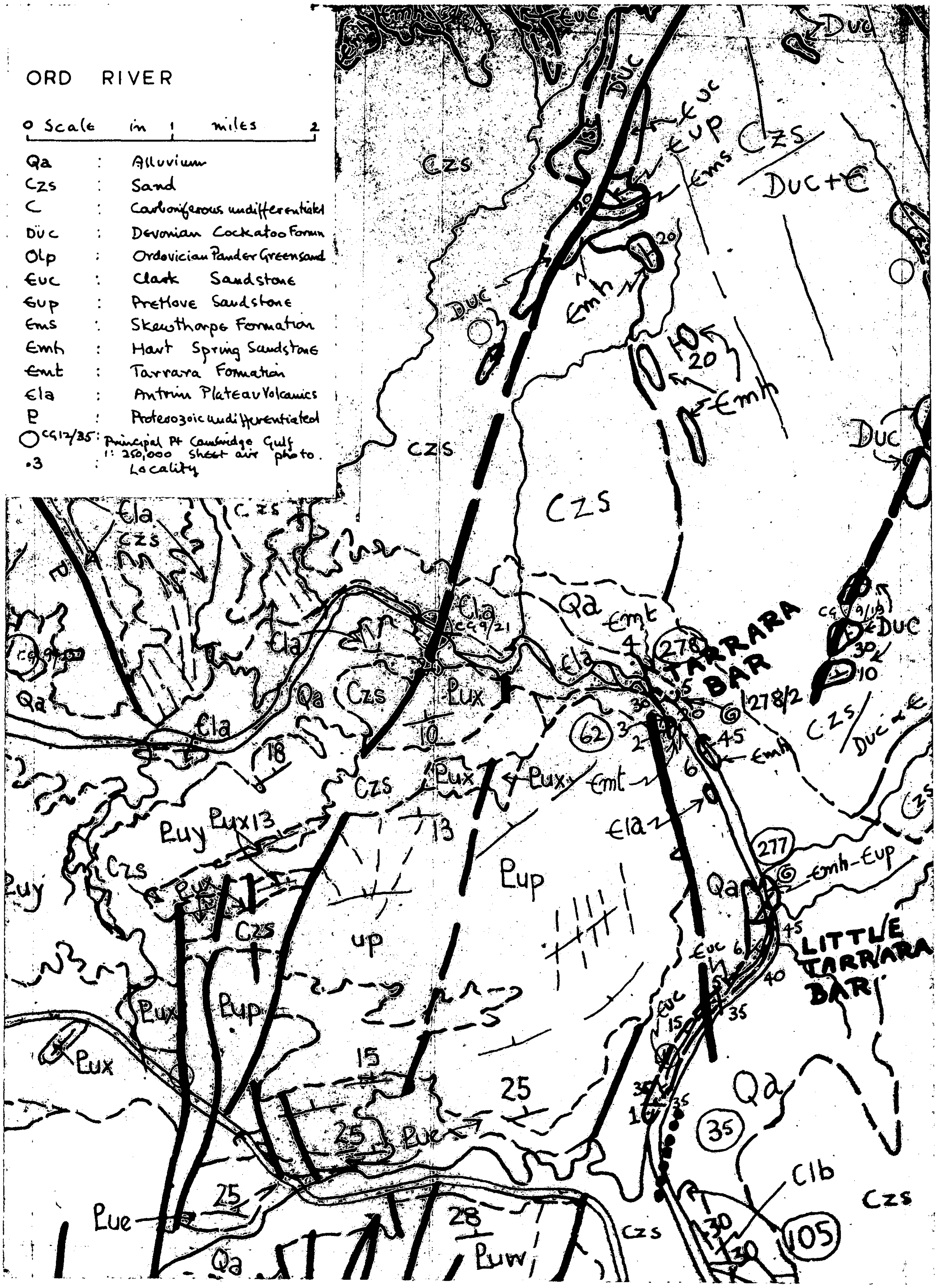
AUS /1/49

FIG. 10



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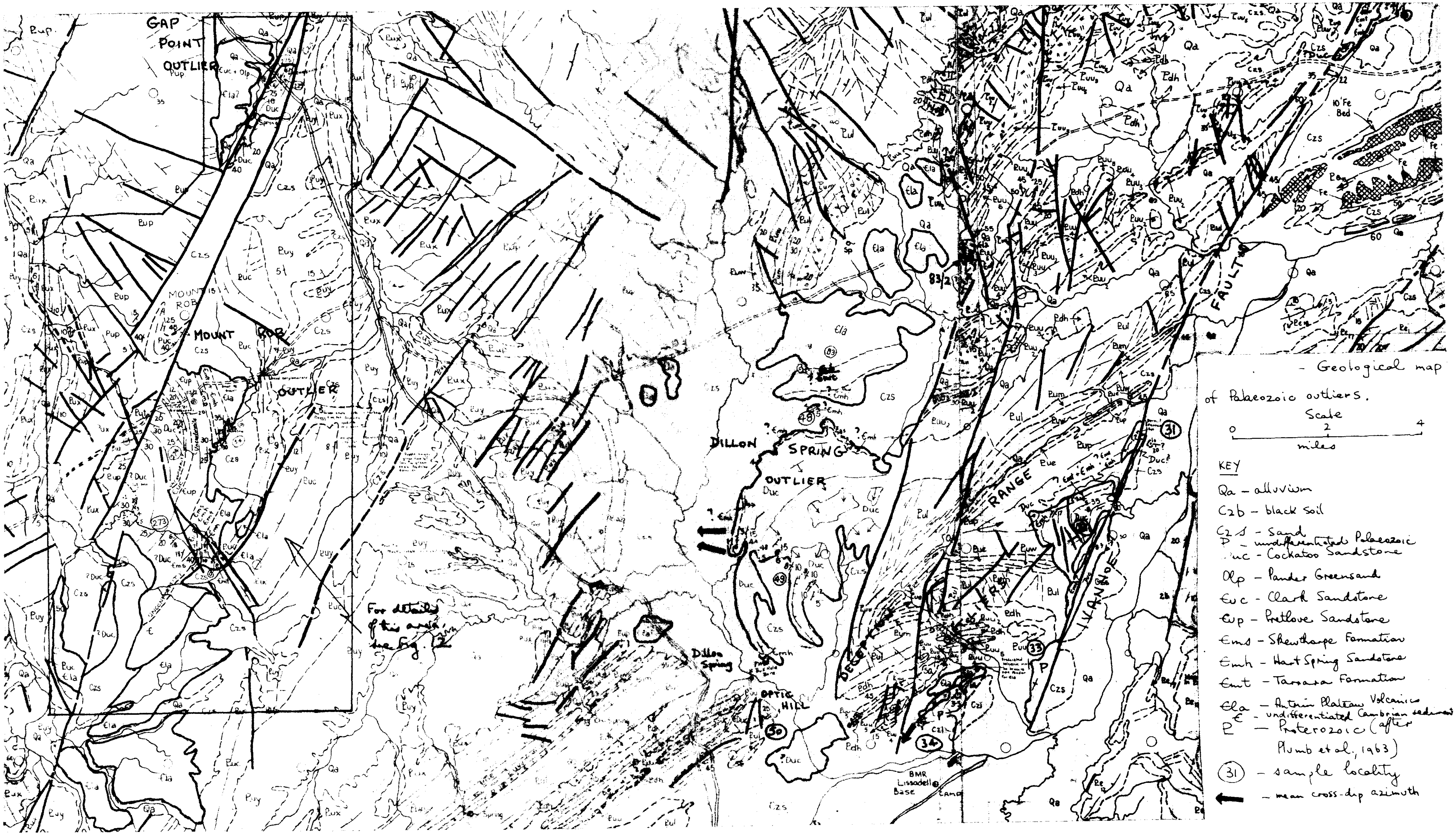
AUS/1/50

FIG. II.



– Geological map of Palaeozoic outliers.

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AUS/1/51

FIG. 12

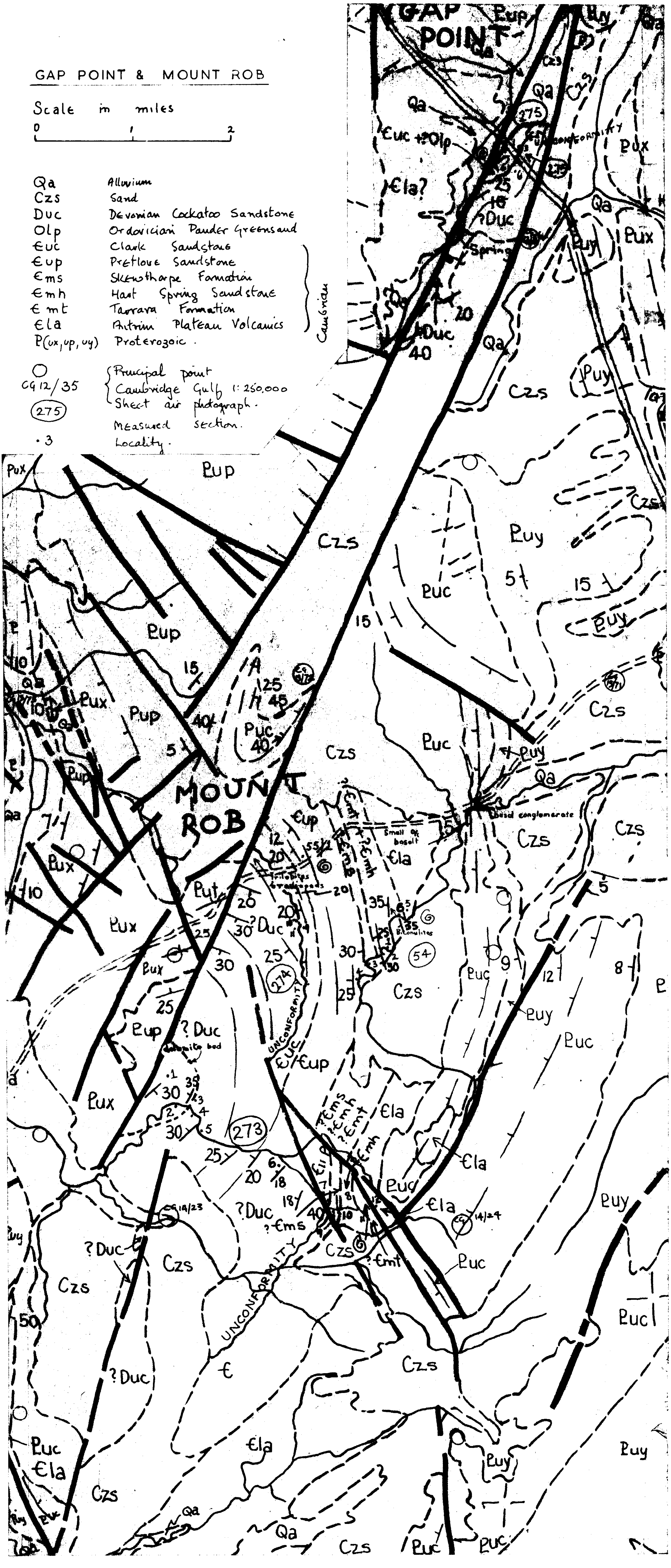

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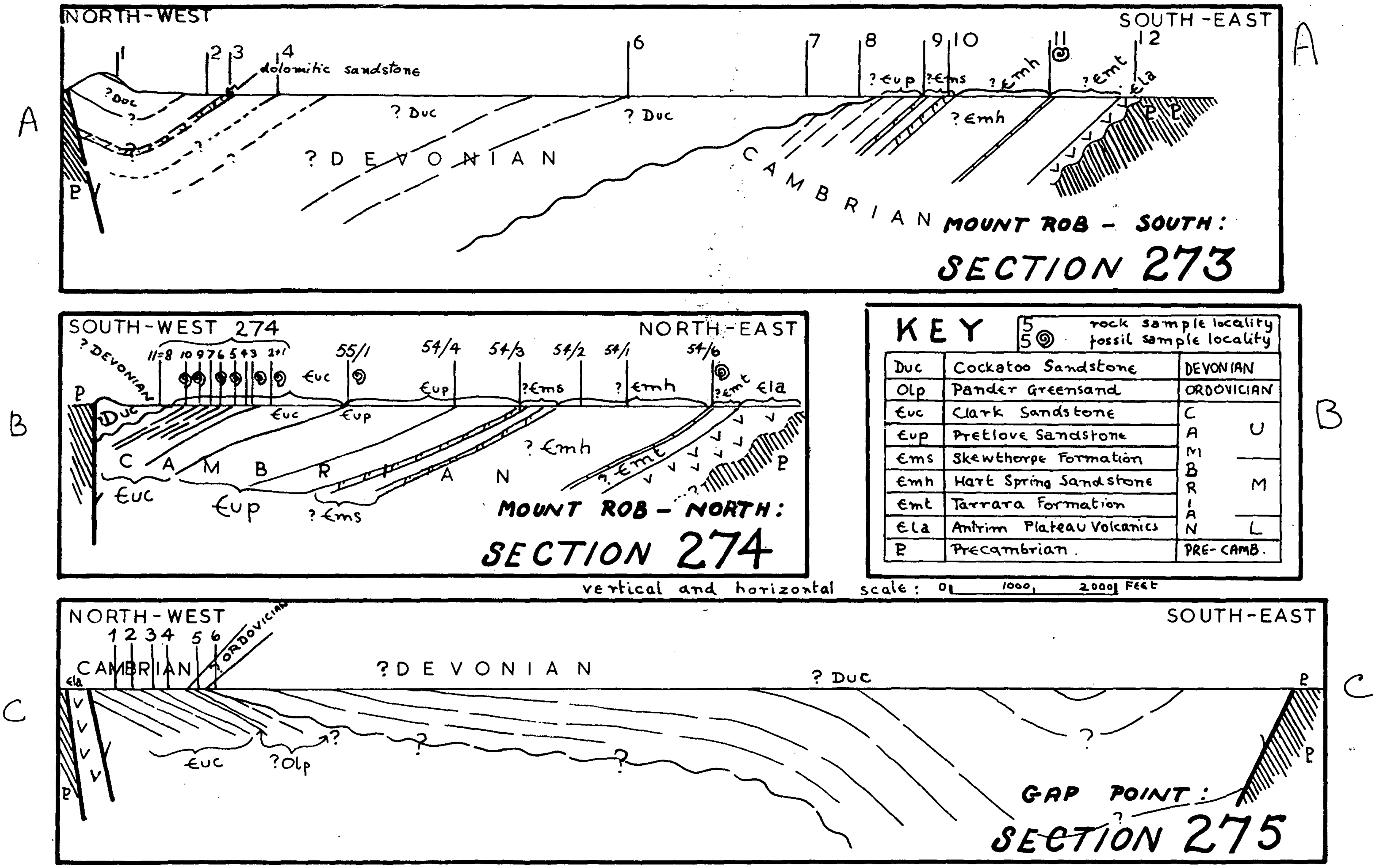
FIG. 13



Cross - sections of Cambrian, ?Ordovician and ?Devonian sediments in the outliers of Gap Point and Mount Rob.

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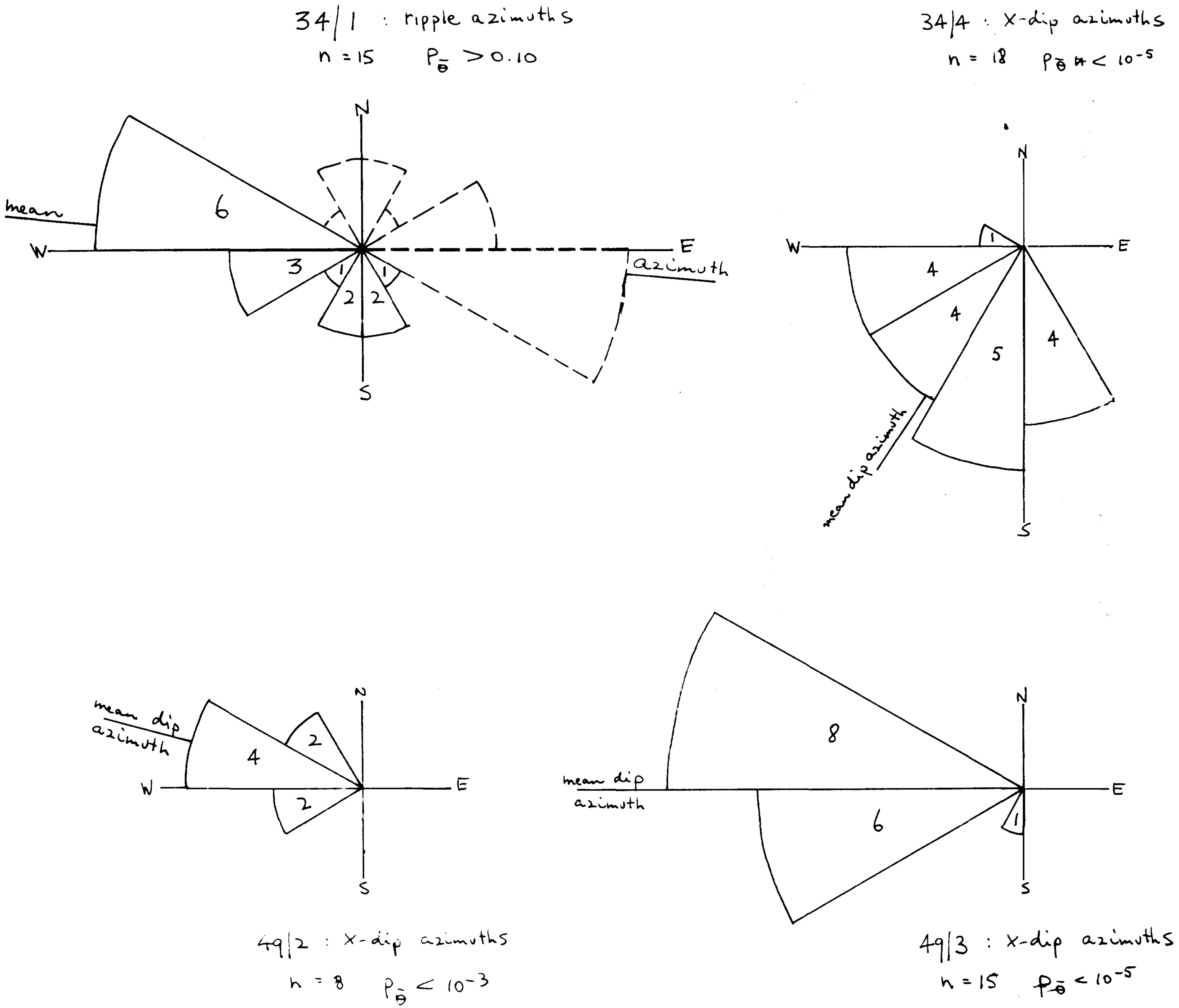
AUS/1/53

FIG. 14.



Cross-dip and ripple-mark azimuth frequency distributions, divided into 30° classes.

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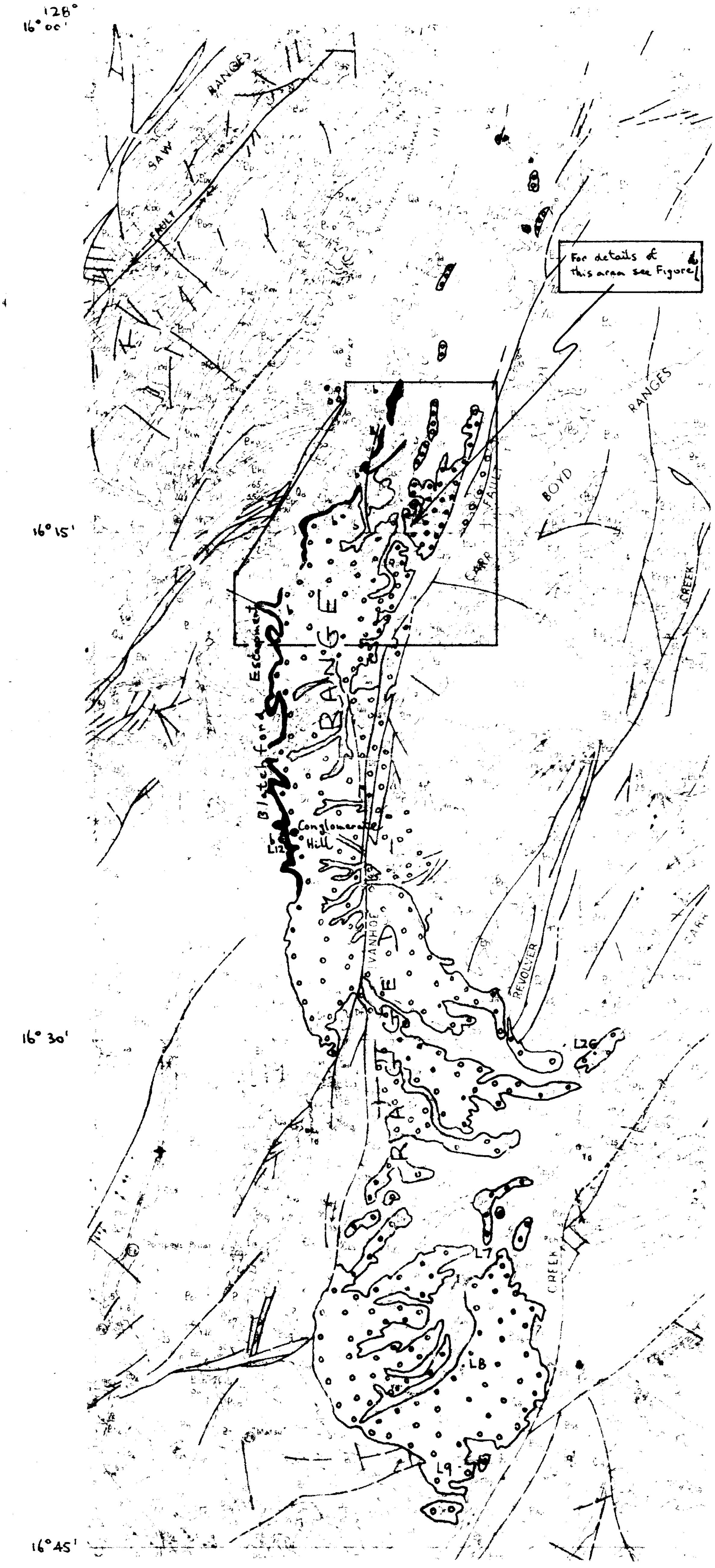
FIG. 15



Geological map of Ragged Range, W.A.
(after Plumb et al.)

Scale in miles
5 0 5

KEY
Qa alluvium
Czs sand
Dr Ragged Range Conglomerate
Єlb Blatchford Formation
Єla Antrim Plateau Volcanics
Ꝑ Proterozoic
L2G Sample locality

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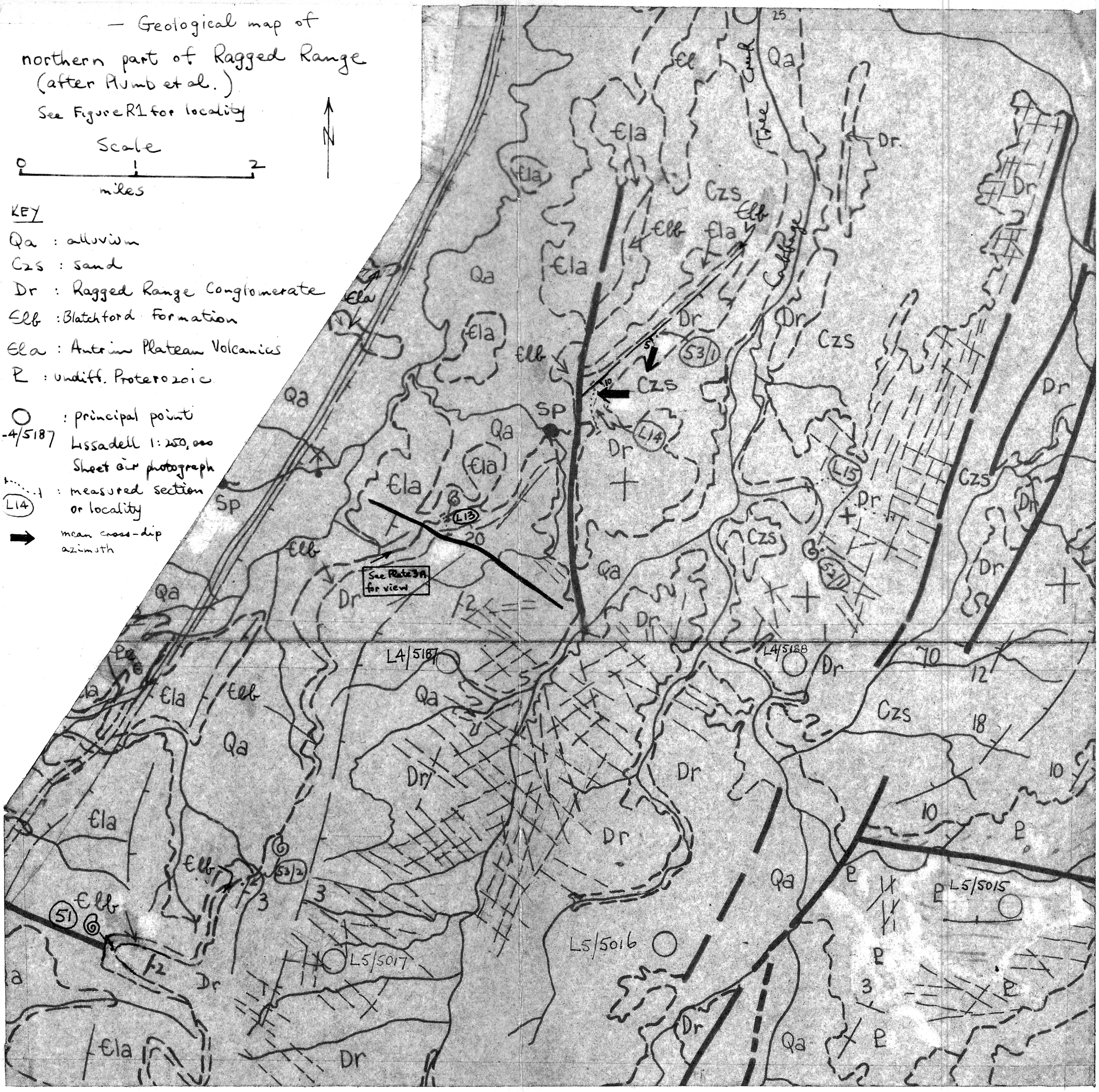
FIG. 16

— Geological map of northern part of Ragged Range (after Plumb et al.)

See Figure R1 for locality



KEY

Qa : alluvium

Czs : sand

Dr : Ragged Range Conglomerate

Єlb : Blatchford Formation

Єla : Antrim Plateau Volcanics

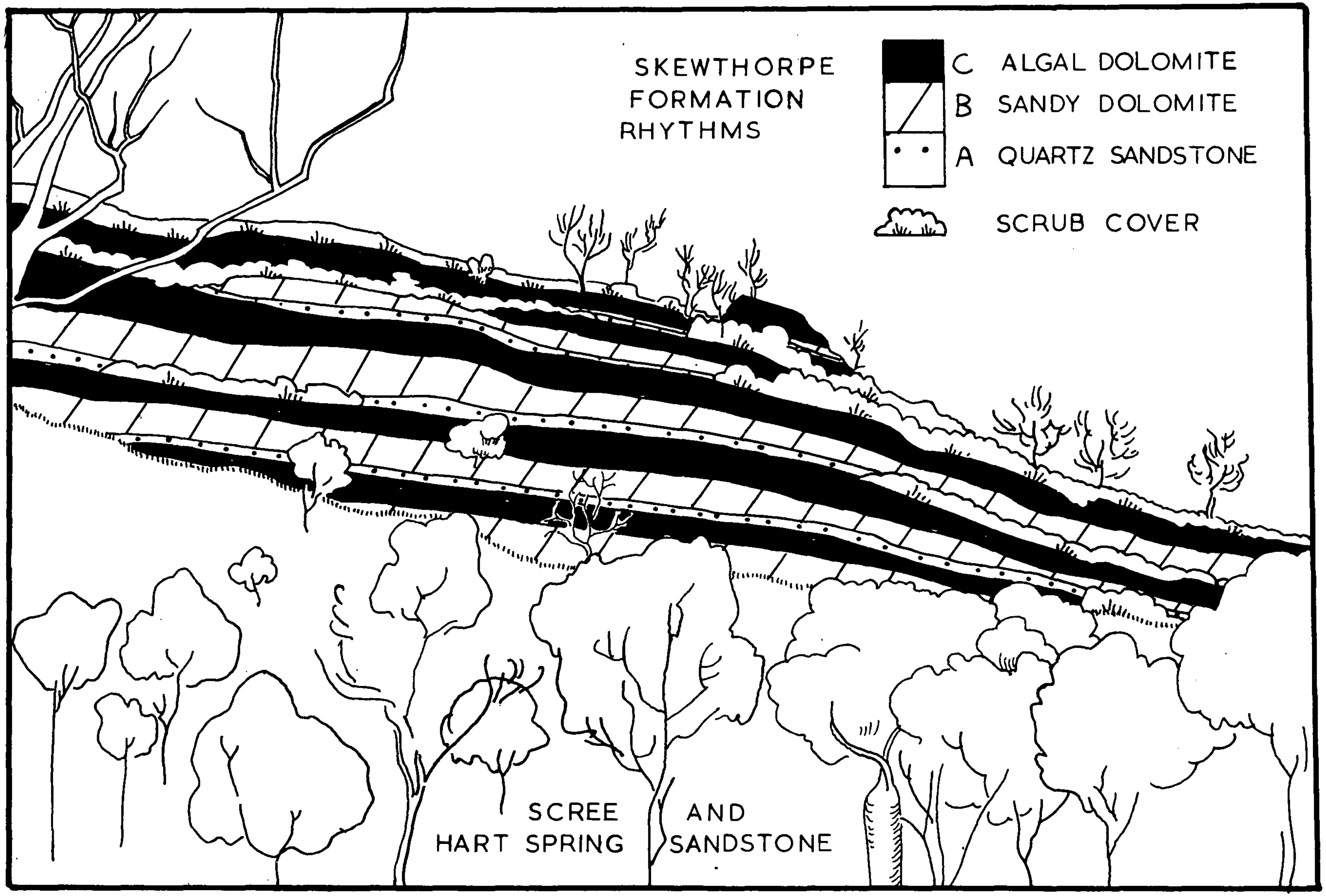
Ꝑ : undiff. Proterozoic

○ -4/5187 : principal point Lissadell 1:250,000 Sheet air photograph

.... L14 : measured section or locality

➡ mean cross-dip azimuth

FIG. 17.



An outcrop of the Skewthorpe Formation at section 138, in the Onslow Hills, showing rhythmic layers: taken from a photograph.

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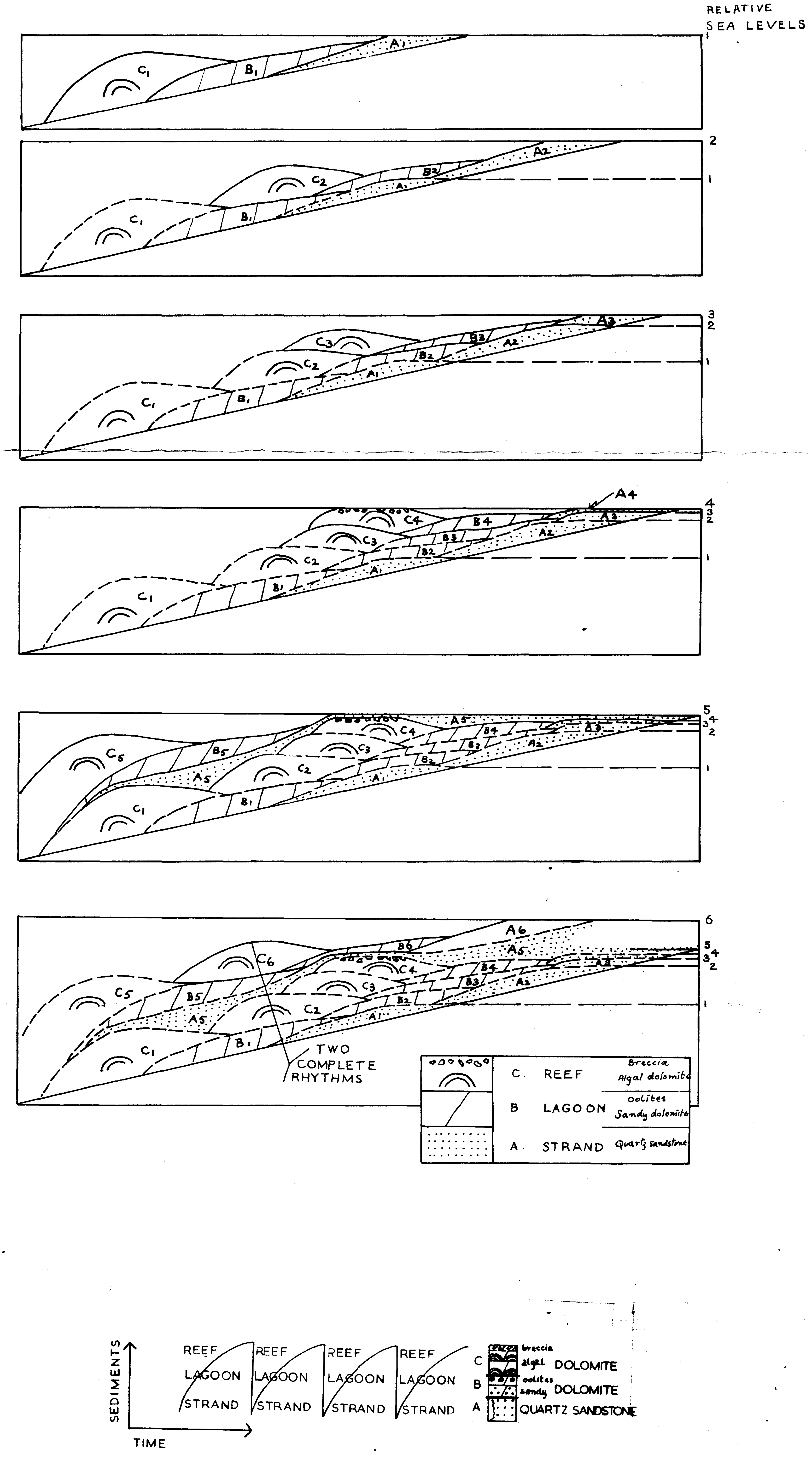
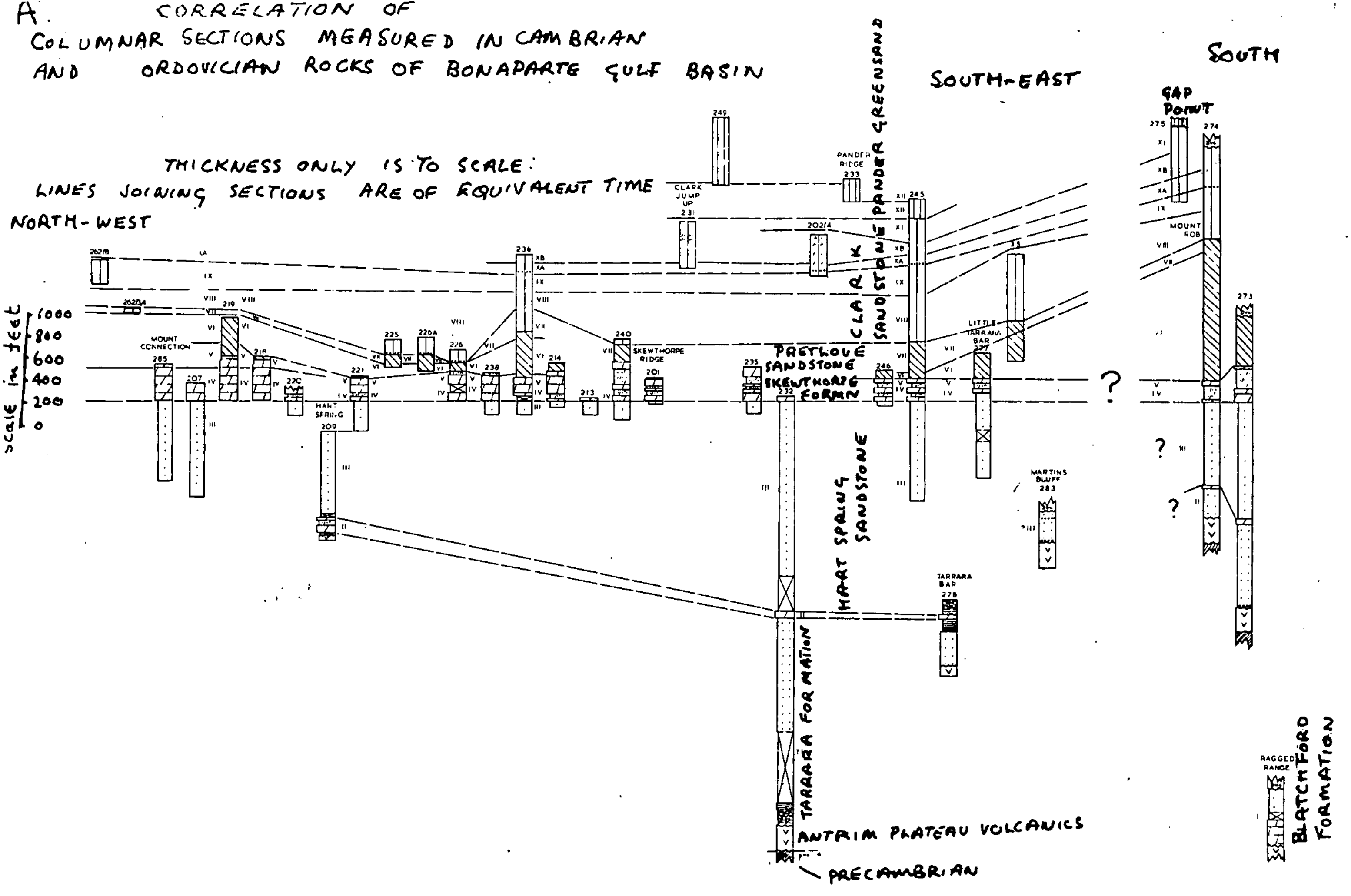
FIG. 18.

DIAGRAMMATIC INTERPRETATION OF RHYTHMIC SEDIMENTATION

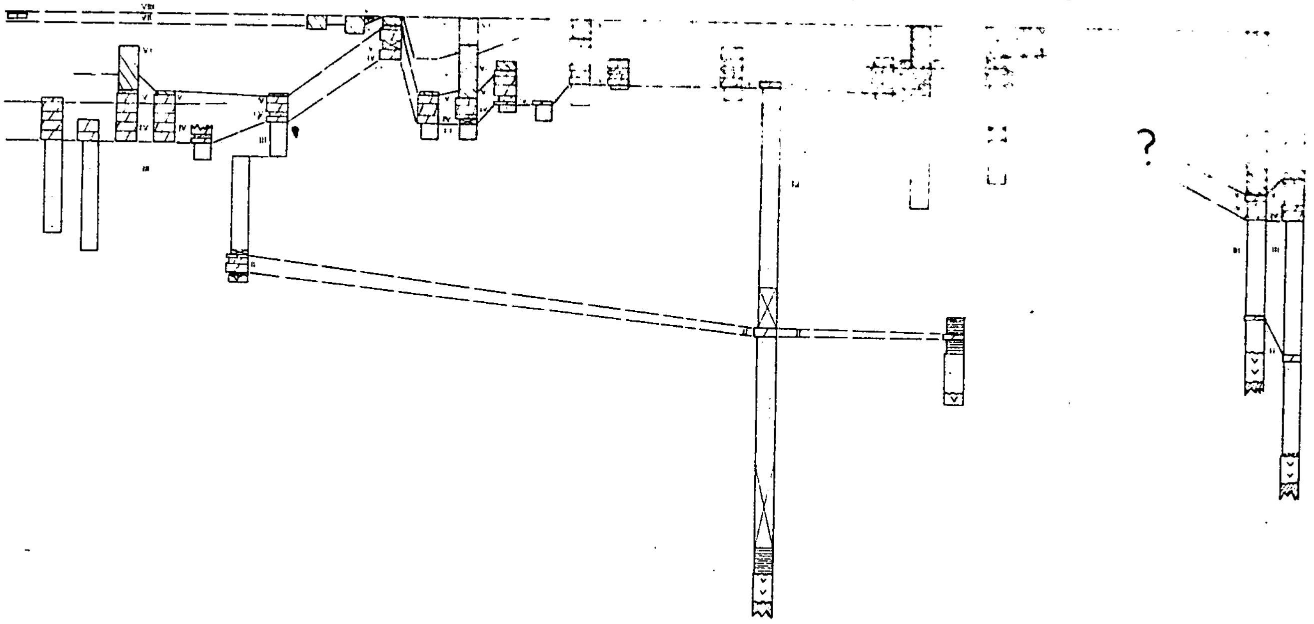


Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/58

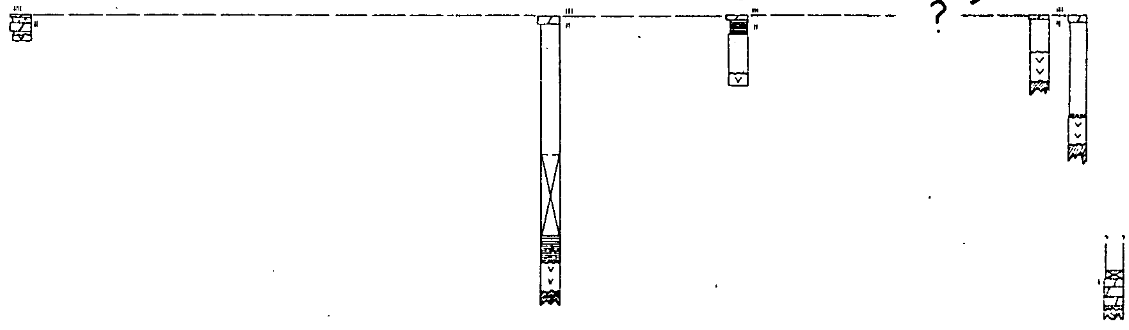
A. CORRELATION OF COLUMNAR SECTIONS MEASURED IN CAMBRIAN AND ORDOVICIAN ROCKS OF BONAPARTE GULF BASIN



B. SEDIMENTATION UP TO THE TIME OF FAUNAL UNIT VIII (paramansuyella)



C. SEDIMENTATION UP TO END OF TARRARA FORMATION (FAUNAL UNIT II)



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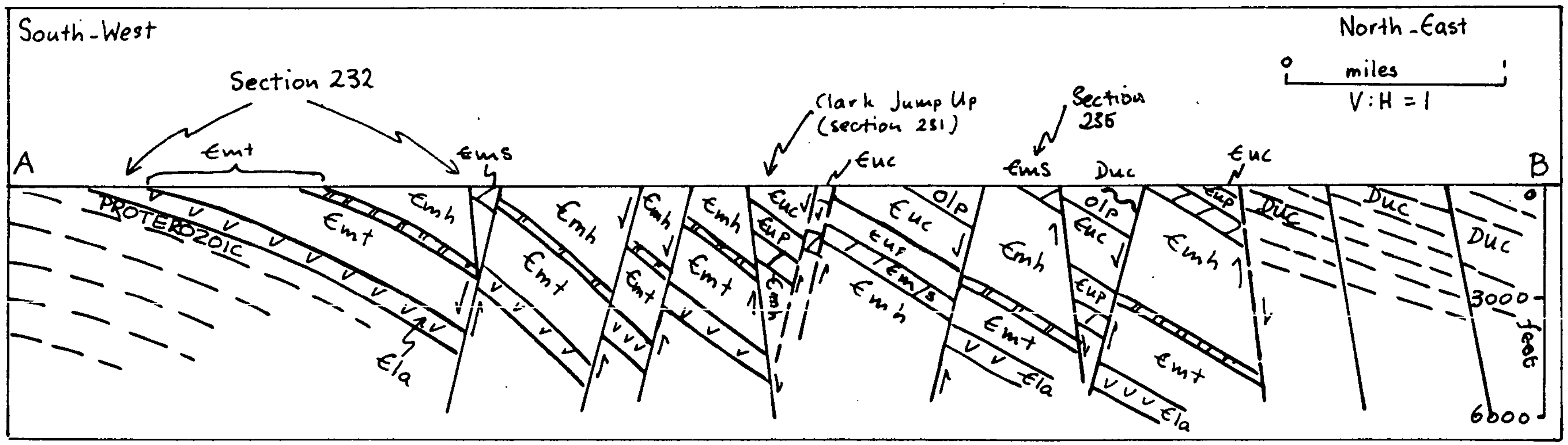
AUS/1/59

FIG. 20



Diagrammatic cross-section of solid geology along line of section drawn on Fig. 3, in the Pretlove Hills, showing strike-faulting. Topography is ignored, and only major faults are drawn. Dips of faults are inferred from trace on airphotographs and at localities 231 and 235 from visible dip.

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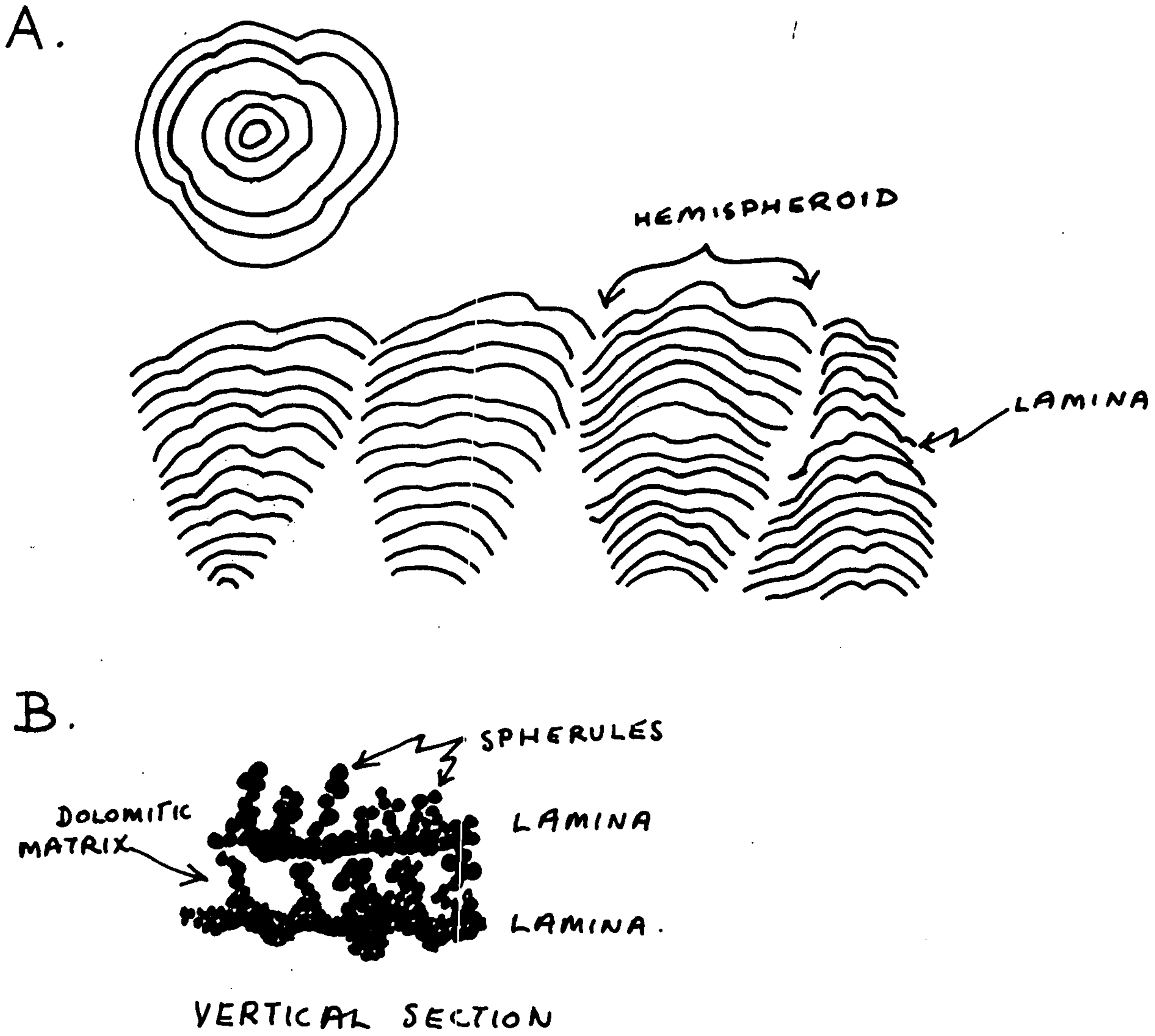
FIG. 21.

Type A.



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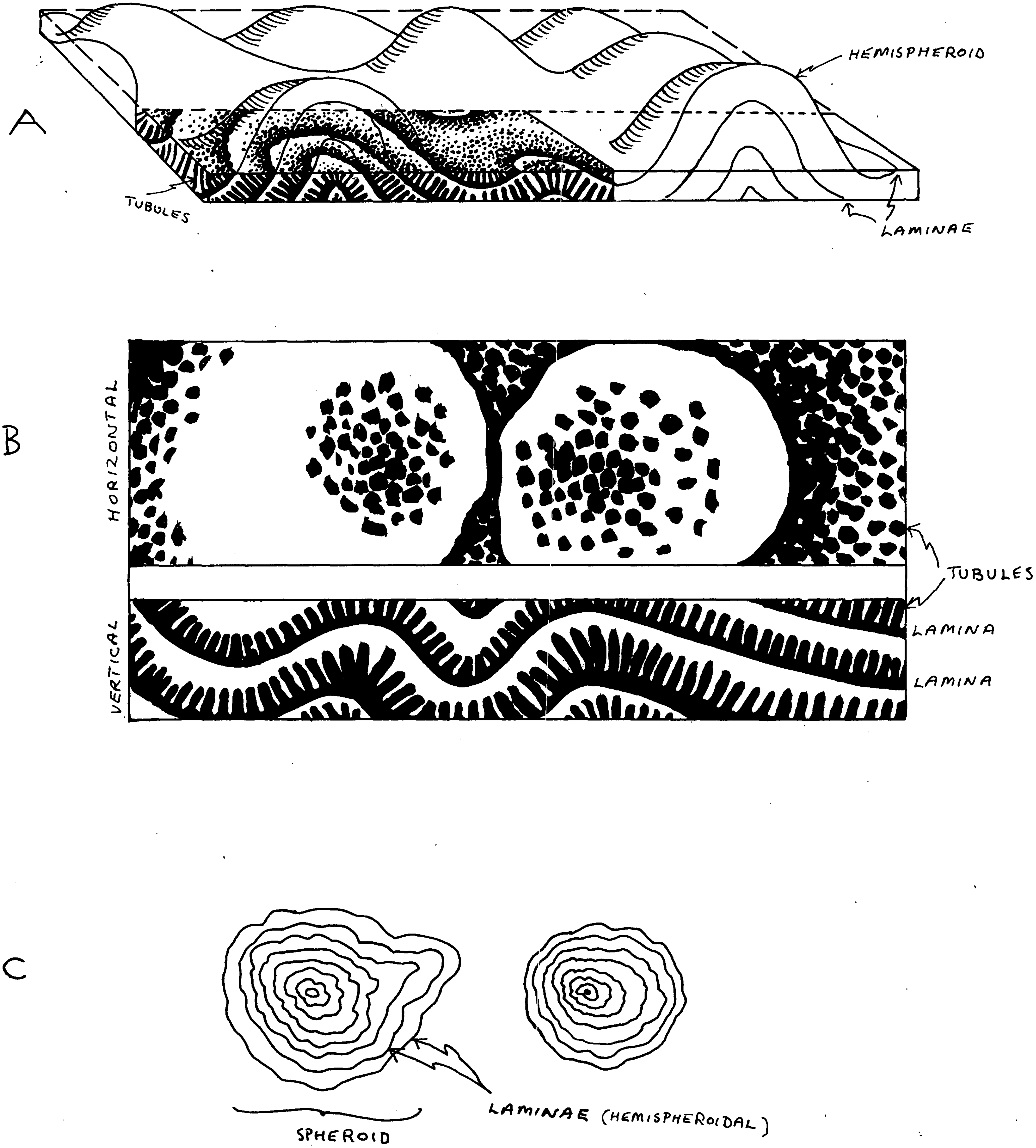
To accompany Record 1965/49

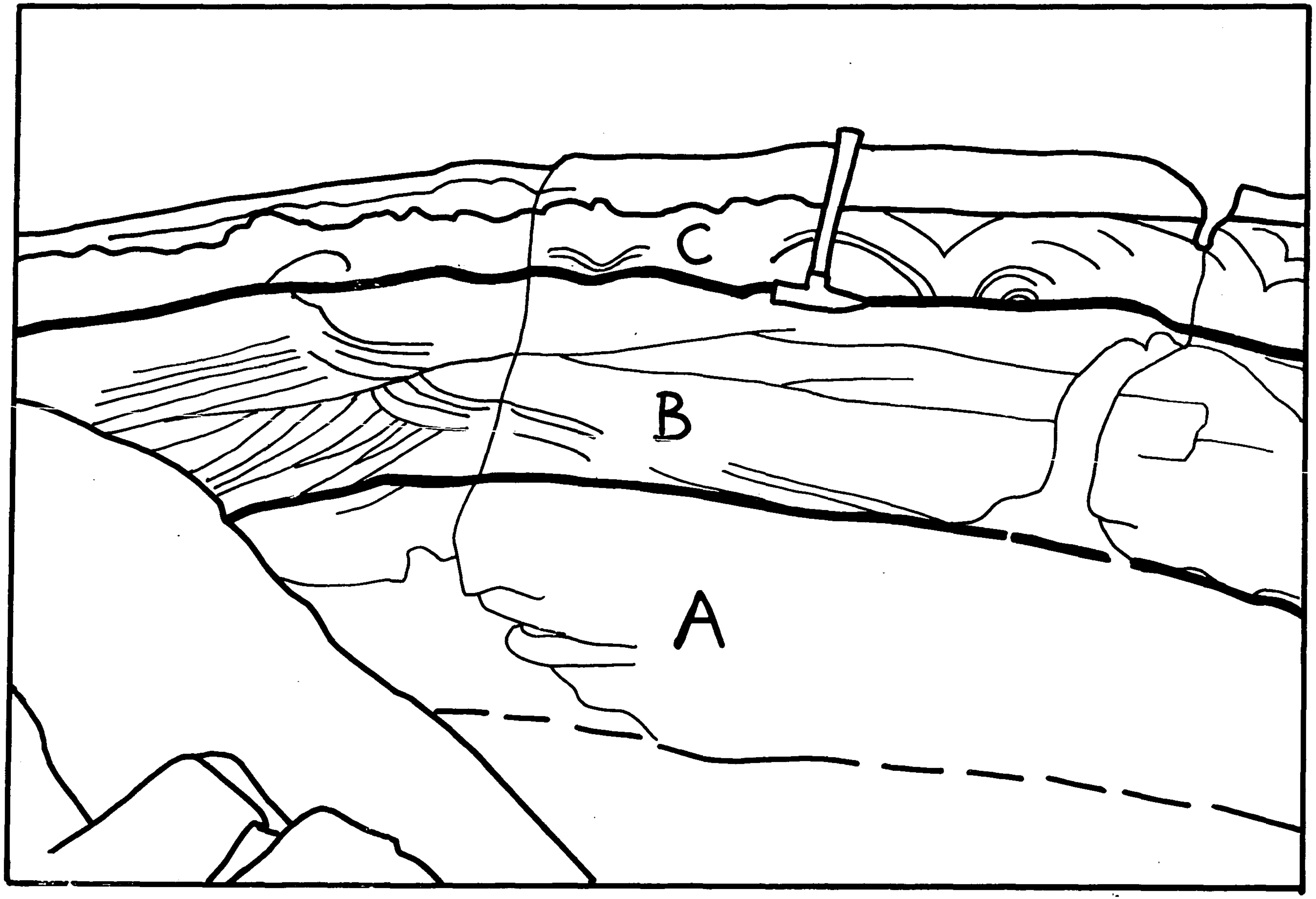
AUS /1/61

FIG. 22
Type B.



Bureau of Mineral Resources, Geology and Geophysics. March 1965. To accompany Record 1965/49 AUS/1/62

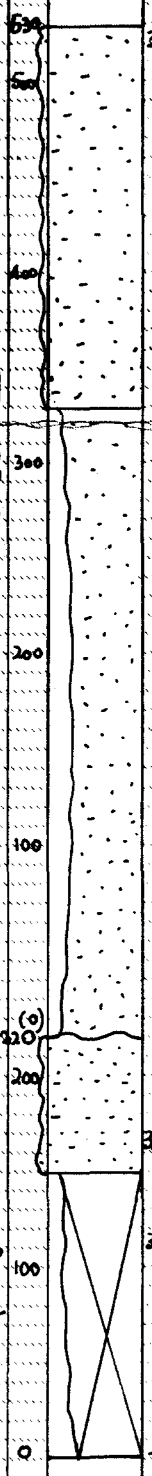
FIG. 23



A typical sedimentation rhythm in the lower part of the Skewthorpe Formation, where the lower sandstone (unit A) is comparatively thick. The top unit C is truncated by a dolomitic breccia bed, as it shown by the planed algal domes to the right of the hammer.

Bureau of Mineral Resources Geology and Geophysics. March 1965 To accompany Record 1965/49 AUS/1/63

Section	CG 32	SECTION	CG 32
Locality	Deception Range	SCALE	1" : 100'
Air Photograph	CG 14/5129	MAP	Fig. 11
Topography	Scarp and dip-slope	DATE	6.10.64
Outcrop	Moderately strong, scree at base		
Notebook	BP63 JJV pp. 25, 26		
Method	Abney traverse with Jacob staff		

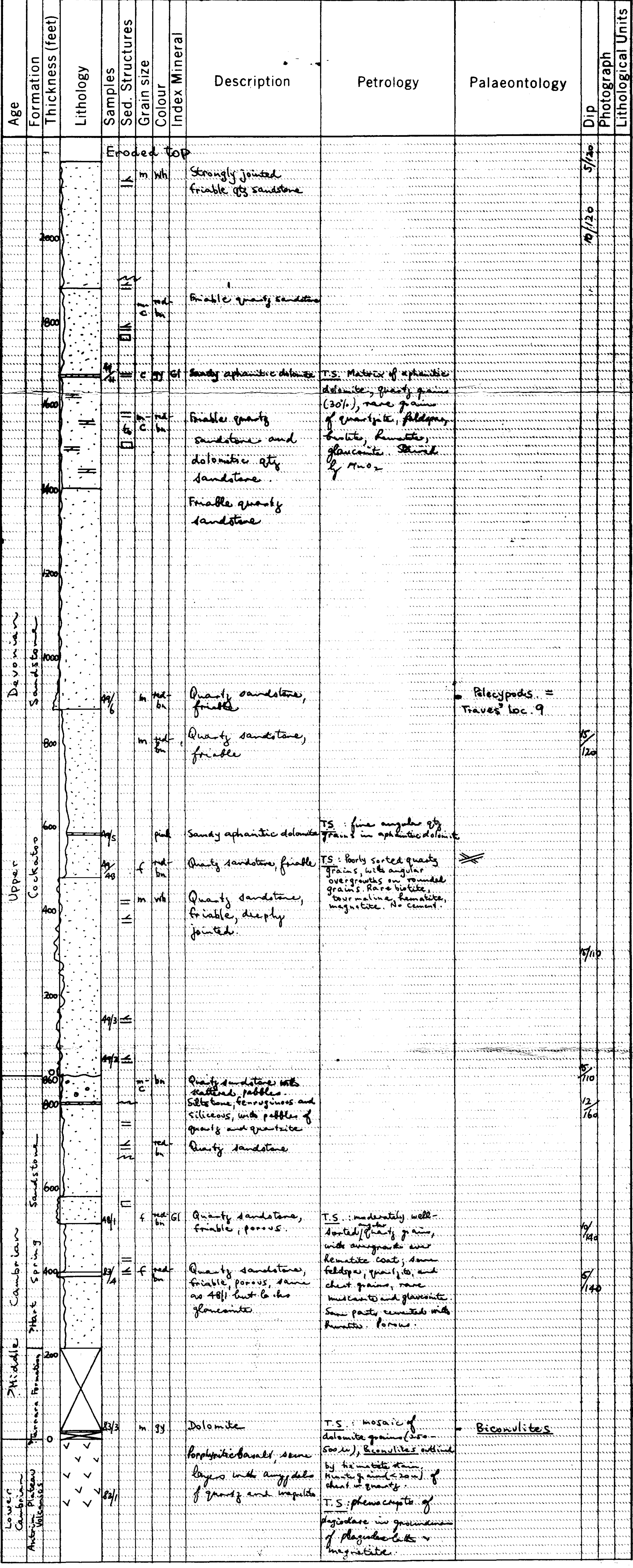


exposed top

Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
? Upper Devonian	? Cockatoo Sandstone	630		32/6		m	wh		Quartz sandstone, bedding obscured by tight jointing.	T.S. : poorly sorted well-rounded grains with angular overgrowths in a tightly packed mosaic. Patches of chalcedony cement.		0 25/140		
					=	c	wh		Quartz sandstone, friable, except where locally silicified.			25/140		
? Middle Cambrian	? Hart Spring Sandstone	220		32/3	≡	c	red and gy		Quartz sandstone	T.S. : poorly sorted quartz grains with angular overgrowths producing a mosaic; patches of chalcedony cement, iron oxide stains.		20/140		
				32/2		f	gy-gn		Chalcedonic quartz sandstone	T.S. : well-sorted sub-angular quartz grains (30%), rare biotite & muscovite, set in chalcedonic matrix.				

floor of valley

Section	CG 83-48-49	SECTION	CG 83-48-49
Locality	north-east of Dillon Spring	SCALE	1" : 200'
Air Photograph	CG 14/5127	MAP	Fig. 11
Topography	scarp and dip slope, plain	DATE	6.10.64
Outcrop	Poor at base, excellent above		
Notebook	BP63 JJV, pp. 37-39, 64		
Method	basal and top parts estimated from air photographs, middle part by abney traverse.		



Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
				Eroded top								5/120		
						m	Wh		Strongly jointed friable qtz sandstone					
		2000										10/120		
		1800				m-c	red-bn		Friable quartz sandstone					
				49/44		c	gy	Gl	Sandy aphanitic dolomite	T.S. Matrix of aphanitic dolomite, quartz grains (30%), rare grains of quartzite, feldspar, biotite, hematite, glauconite. Stained by MnO_2				
		1600				m-c	red-bn		Friable quartz sandstone and dolomitic qtz sandstone.					
		1400							Friable quartz sandstone					
		1200												
Upper Devonian	Cockatoo Sandstone	1000												
				49/6		m	red-bn		Quartz sandstone, friable		Pelecypods = Traves' loc. 9			
		800				m	red-bn		Quartz sandstone, friable			15/120		
		600		49/5			pink		Sandy aphanitic dolomite	TS: fine angular qtz grains in aphanitic dolomite				
				49/48		f	red-bn		Quartz sandstone, friable	TS: Poorly sorted quartz grains, with angular overgrowths on rounded grains. Rare biotite, tourmaline, hematite, magnetite. No cement.				
		400				m	wh		Quartz sandstone, friable, deeply jointed.					
												15/110		
		200		49/3										
		0		49/2								15/110		
		860				m-c	bn		Quartz sandstone with scattered pebbles.					
		800							Siltstone, ferruginous and siliceous, with pebbles of quartz and quartzite			12/160		
							red-bn		Quartz sandstone					
		600												
				48/1		f	red-bn	Gl	Quartz sandstone, friable, porous.	T.S.: moderately well-sorted angular quartz grains, with overgrowths over hematite coat; some feldspar, quartzite, and chert grains, rare muscovite and glauconite. Some parts cemented with hematite. Porous.		10/140		
?Middle Cambrian	?Hart Spring Sandstone	400		83/4		f	red-bn		Quartz sandstone, friable, porous, same as 48/1 but lacks glauconite			5/140		
	Tarrara Formation	200												
				83/3		m	gy		Dolomite	T.S: mosaic of dolomite grains (250-500 µ), Biconulites outlined by hematite stain. Hematite grains (<20 µ) of chert or quartz.	Biconulites			
Lower Cambrian	Antrim Plateau Volcanics	0		83/1					Porphyritic basalt, some layers with amygdales of quartz and [illegible]	T.S: phenocrysts of plagioclase in groundmass of plagioclase laths & magnetite.				

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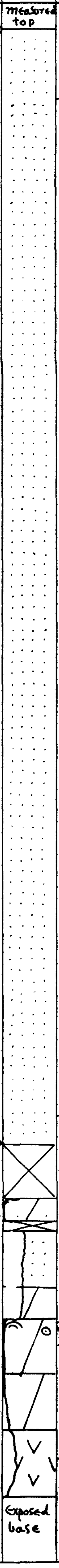
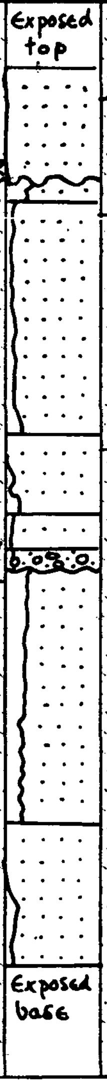
Section	CG 209	SECTION	**209**
Locality	Hart Spring and Onslow Hills.	SCALE	1" : 50'
Air Photograph	CG 5/83		
Topography	SS hills sloping N.E.	MAP	Fig. 6
Outcrop	Generally Good		
Notebook	BP 63 JAK p 5. 6.	DATE	29 . 6 . 64
Method	Abney traverse in €mt : distance & dip above		



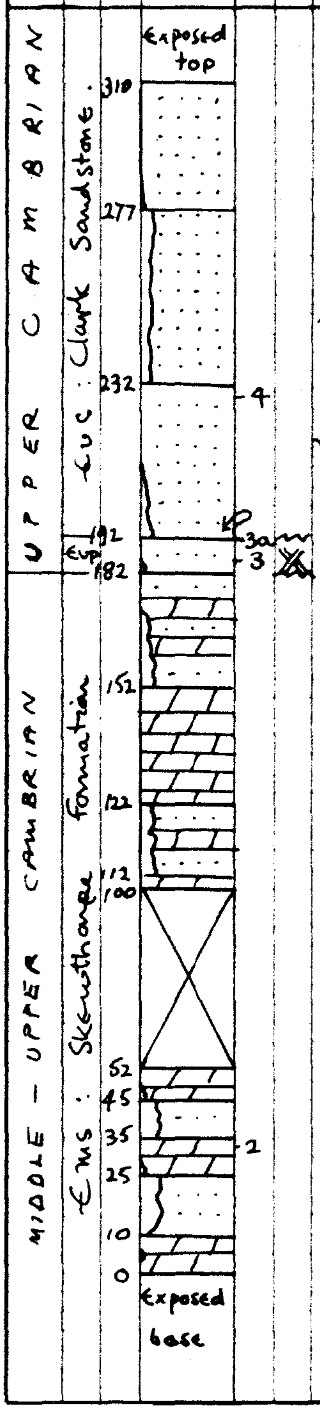
Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
M I D D L E C A M B R I A N	€mh : Hart Spring Sandstone.	660	measured top											
		630		6							— Floater : medium white quartz sandstone with brachiopods and hyolithids.			
												5/35 5/50		
						m f	Red		micaceous quartz sandstone.				K1 17, 18, 19	
				5					medium-fine quartz sandstone	— T.S. CG 209/5 (CG 207/4)				
		160							No outcrop.					
	€mt. Tarrara Formation	135					Red		Dolomite, silty, + Red	TS — CG 208/1				
		125							No outcrop.				K29 3-15	
		120				m-f	Red		Quartz sandstone					
		95							Fine calcilutite and lutitic dolomite.	Peels: CG 208/1	— CG 209/3 stromatolitic dolomite + biconulites & trilobite fragments Faunal unit II			
		80		3 2a			Red Gy		hard flaggy dolomite, partly silicified. Broken trilobite fragments.	CG 208/1a CG 208/1b CG 208/1d	CG 209/2a --- Trilobite fragment (= Redlichia)			
									Poor exposure at base.	CG 208/2				
LOWER CAMBRIAN	€la : Antrim Plateau Volcs.	30		1					?Amygdaloidal Basalt Obscure outcrop.					
		0	Exposed base											

Section	CG 226 A	SECTION	**226A**
Locality	NE Onslow Hills	SCALE	1" : 50'
Air Photograph	CG 5/83		
Topography	Fault-bounded hill in Sdy. plain.	MAP	Fig. 6
Outcrop	Good in scarp.		
Notebook	BP 63 JAK p 19, 20	DATE	29 . 6 . 64
Method	Abney traverse		

Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
Probably U. Devonian	Cockatoo Sandstone Dvc		 Exposed top											
				4		m	wh		qtz sandstone.	T.S. CG 226 A4				
		20												
UPPER CAMBRIAN	Єuc: Clark Sandstone	197		2							CG 226 A2 Trilobites: Faunal Unit VIII			
						m	Red	Gl	qtz sandstone					
		137		1							CG 226 A1 Trilobites: Faunal Unit VIII			
		117							Poor exposure.					
		107												
		102					Red	Fe	Ferruginous pebble conglom with sandstone matrix					
	Єue: Pretlove Sandstone											13/350		
						m	Red		Poor exposure: Some friable quartz sandstone.					
		37			~									
						m	Pk		flaggy qtz sandstone micaceous with phosphatic brachiopod shell fragmts.					
		0	Exposed base											

Bureau of Mineral Resources, Geology and Geophysics. March 1965 To accompany Record 1965/49 **AUS /1/71**

Section	CG 226	SECTION	**226**
Locality	Onslow Hills	SCALE	1" : 50'
Air Photograph	CG 5/83		
Topography	Fault-bounded hill in sandy plain	MAP	Fig. 6
Outcrop	Fairly good in scarp		
Notebook	BP 63 JAK p 21, 24	DATE	29 . 6 . 64
Method	Abney traverse.		



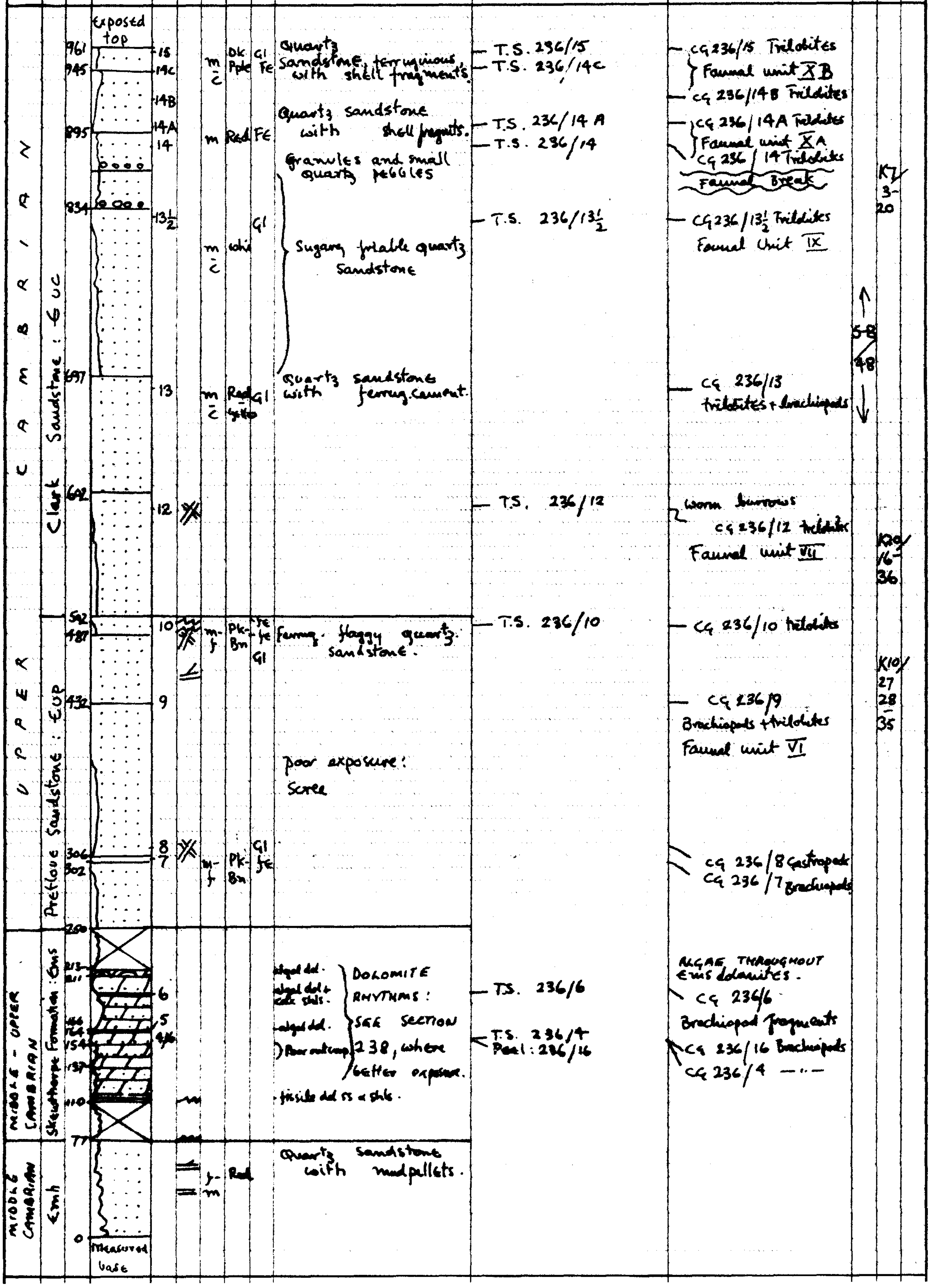
Thickness (feet)	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip
277	m	Red	gl	qtz ss			
	m	Red	gl	qtz ss			
232	m	Red	gl	Micaceous qtz ss with shell fragmts & trilobites		CG 226/4 gastropods.	
192				ferruginous plane		CG 226/3a shell fragmts + trilobites FAUNAL UNIT VIII	13/75
182	m	Red	Fe	qtz ss, flaggy	T.S. CG 226/3	CG 226/3 phosphatic brachiopod fragments.	
				Poor outcrop: Sandy dolomite & dol ss with micac. qtz ss.			
152				Dolomites in rhythmic succession + dol ss + qtz ss. (qtz ss beds are fossiliferous).			
122				Poor exposure dol (sandy) bed.			
52				Dolomite		ALGAL STROMATOLITES abundant in dolomite rhythms. = FAUNAL UNIT V (trilobites)	
45				Poor exp: ? red qtz ss.			
35				Rhythmic dolomites: algal dol/ Sandy dol + oolites/ dol ss/ qtz ss.			
10		gy		Sandy dolomite + m qtz ss bands; poor outcrop. thin oolitic dolomites.			

Section	CG 232	SECTION	**232**
Locality	South of Clark Jumpup, in Creek.	SCALE	1" : 100'
Air Photograph	CG 8/01		
Topography	Creek bed in sandy plain	MAP	Fig. 3
Outcrop	Fair to poor; locally no outcrop		
Notebook	BP 63 JAK p 27	DATE	24/ 6 / 64
Method	Along traverse, and dip and distance on air photo		

measured top (Continued in section 245)

Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
6							Brachiopods 232/6			
		f-m	Bn Rd		Silty Quartz sandstone with mudflakes: fair to good exposure.			30/35 31/56		
5					No outcrop.					
4			Gy Gn		Dolomite: algal and sandy, with silicified fossils.	Peel	232/4 Biconulites Brachiopod and Redlichia fragments. Algal stromatolites. Faunal Unit II	17/30		
		f	Rd		Silty laminated quartz sandstone with mudflakes: Fair outcrop.			17/26		
3					No outcrop: Probably shale or f. silty sandstone: thickness calculated on basis of dip & distance.					
					Extremely poor outcrop: shale inferred.					
X 2					Good outcrop of shale, mudstone with travertine bands.				K7 1, 2	
					Extremely poor exposure: shale inferred.					
1 B 7					Basalt, amygdaloidal, flaggy.			14/62		
					Qtz sandstone, indurated. Precambrian sediments continue ↓ at least 300' to base of section (0')			20/50		

Section	C.G. 236	SECTION	**236**
Locality	Onslow Hills	SCALE	1" : 100
Air Photograph	CG 5/83	MAP	Fig. 6
Topography	Hill bounded by N/S fault.	DATE	26 . 6 . 64
Outcrop	Good except in scree-covered areas		
Notebook	BP 63 JAK pp 32 - 34		
Method	Abney traverse.		



Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
UPPER CAMBRIAN	Clark Sandstone : Ꞓuc		Exposed top											
		961		15		m-c	Dk Pple	Gl Fe	Quartz sandstone, ferruginous, with shell fragments.	T.S. 236/15	CG 236/15 Trilobites Faunal unit XB			
		945		14C						T.S. 236/14C				
				14B							CG 236/14B Trilobites			
				14A					Quartz sandstone with shell fragmts.	T.S. 236/14 A	CG 236/14A Trilobites Faunal unit XA			
		895		14		m	Red	Fe	Granules and small quartz pebbles	T.S. 236/14	CG 236/14 Trilobites Faunal Break		K7 3-20	
		834		13½		m-c	whi	Gl	Sugary friable quartz sandstone	T.S. 236/13½	CG 236/13½ Trilobites Faunal Unit IX	↑ 58 48 ↓		
		697		13		m-c	Red yello	Gl	Quartz sandstone with ferrug. cement.		CG 236/13 trilobites + brachiopods			
		602		12						T.S. 236/12	worm burrows CG 236/12 trilobites Faunal unit VII		K10 16-36	
	Pretlove Sandstone : Ꞓup	542		10		m-f	Pk-Bn	fe fe Gl	ferrug. flaggy quartz sandstone.	T.S. 236/10	CG 236/10 trilobites		K10 27 28 35	
		487												
		432		9					poor exposure: Scree		CG 236/9 Brachiopods + trilobites Faunal unit VI			
		306		8				Gl			CG 236/8 Gastropods			
		302		7		m-f	Pk-Bn	fe			CG 236/7 Brachiopods			
MIDDLE - UPPER CAMBRIAN	Skewthorpe Formation : Ꞓms	260												
		213							algal dol. DOLOMITE RHYTHMS: SEE SECTION 238, where better exposure.		ALGAE THROUGHOUT Ꞓms dolomites.			
		211		6					algal dol + calc shls.	T.S. 236/6	CG 236/6 Brachiopod fragments			
		166		5					algal dol.					
		164												
		154		4/16					Poor outcrop	T.S. 236/4 Peel: 236/16	CG 236/16 Brachiopods CG 236/4 —"—			
		137												
		110							fissile dol ss & shls.					
MIDDLE CAMBRIAN	Ꞓmh	77				j-m	Red		Quartz sandstone with mudpellets.					
		0	Measured base											

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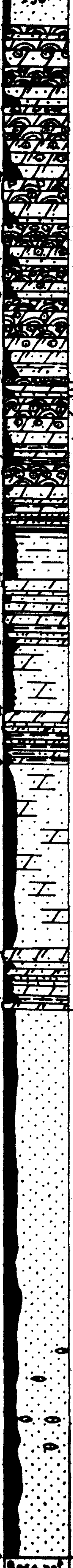
Section	C.G. 238	SECTION	238
Locality	Onslow Hills		
Air Photograph	C.G. 5/83	SCALE	1" : 20'
Topography	Scarp		
Outcrop	Good	MAP	Fig. 6
Notebook	BP 63 JAK p 35-36		
Method	Abney and tape-measure	DATE	16 . 10. 64



Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
UPPER CAMBRIAN	Pretlove Sandstone		Continued in section 236 ↑			fm	Pk-Br Wh	fE	Quartz ss + flaggy partg.	Ferruginised b.p.s.				
MIDDLE TO UPPER CAMBRIAN PASSAGE	Skewthorpe Formation	231 229 225 219 208 201 195 190 178 175 165 155 148 138 128 120 92 84		238/1 ABC 238/2		m m m m m m f f m f m m f f m m f	Gy-Gn Gg-Gn Rd-Bx-Wh Gg-Gn Rd-Bn-Wh Gy-Gn	Gl Gl Gl Gl Gl Gl Gl Gl Gl Gl Gl Gl Gl poor outcrop Gl poor outcrop Gl poor outcrop Gl	Dolomitic & oolitic beds + algal dolomites: Rhythmic units each consist of basal m qtz ss, friable and often eroded overlain by m dolomitic ss, m x-bedded sandy dolomite, m glauconitic 'dolarenite,' algal dolomite + interbedded oolitic dolomite beds & oolitic lenses and pockets, capped by a dolomitic breccia whose clasts vary from algal dolomite to dolomite to oolitic dolomite. Each rhythmic unit becomes less siliceous and more dolomitic towards the top, as does the whole sequence: in the lower rhythms the siliceous sandst. beds form a larger proportion of the rhythm, while in middle and upper rhythms qtz ss beds are thin or absent. Dolomite, sandy 'dolarenites' and dolomitic ss beds become thicker - proportionately to rhythm - in the upper beds. Dolomitic breccias are absent from lower rhythms in the sequence and become more numerous higher up. Rhythms decrease in size towards the top in gradual progressive manner. Some dolomitic sandy shales occur as interbeds within qtz ss or dolomitic ss members of the lower rhythms, but are absent from the upper part of the sequence. Glauconite grains are abundant throughout sequence, especially in 'dolarenites' and sandy dolomite beds. Thirteen complete rhythms are present. ← lowermost dolomitic bed.	T.S. C.G 238/2B gn size 0.2-0.25 mm. friable grey-buff qtz ss with dol cement. T.S. CG 238/1 m-c glauconitic qtz ss with dolomitic cement. Relict dolomitised ooliths & algal structure. Peel : CG 238/2 : v.f detrital aphanitic dol. with rhombohedral mosaic in aphanitic cement. Peel : CG 238/1a : m-f qtz glauconitic ss with dolomitic (rexlsd) cmt. Peel : CG 238/1: friable m qtz ss, ankeritic matrix.	CG 238/2 Trilobites C Brachiopods B Algae A CG 238/1 Brachiopods	5/48	K 20: 16-36	13 12 11 10 9 8 7 6 5 4 3 2 1
MIDDLE CAMBRIAN	Hart Spring Sandstone	83 0	Base not seen			f-m	Rd Bn	Gl	Quartz sandstone with mud pellets (rounded, up to ½") and some shaly siltstone towards the top. Scattered ferruginous nodules. Scree slope: poor exposure.					

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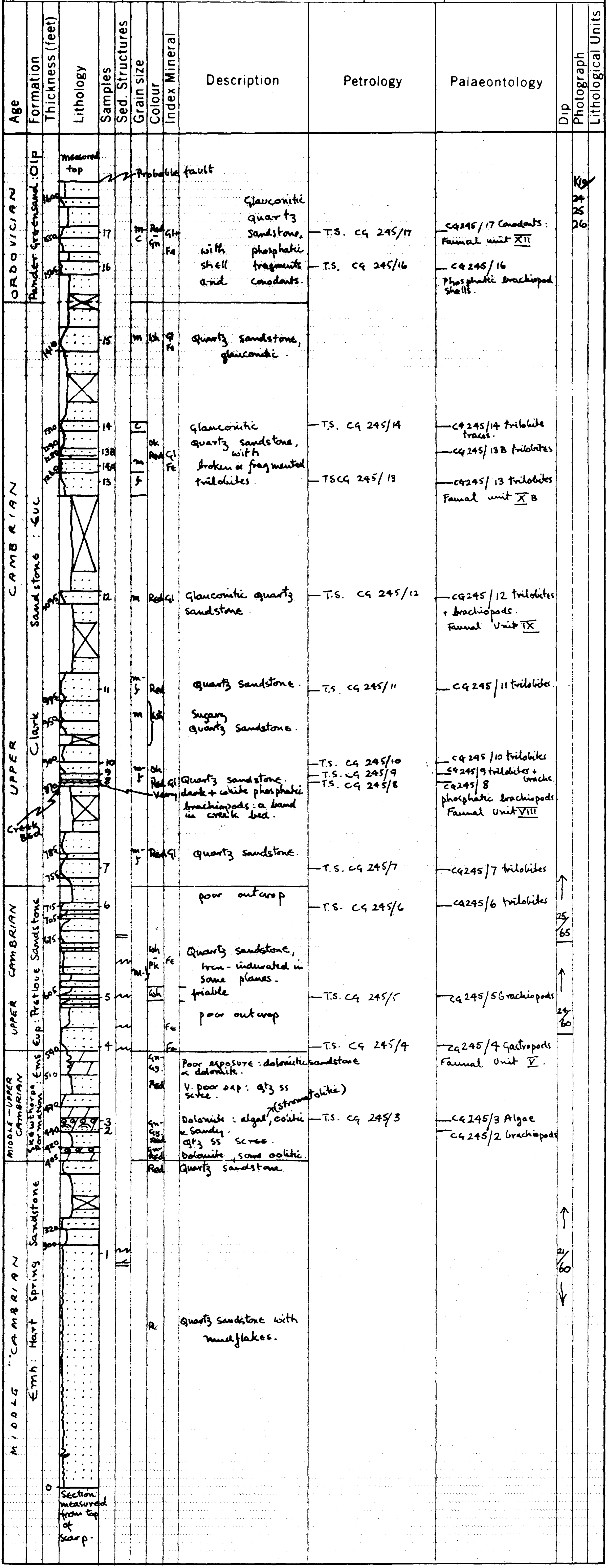
Section	C.G. 245	SECTION	245
Locality	South-east Pretlove Hills	SCALE	1" : 100'
Air Photograph	C.G. 8/03	MAP	Fig. 3
Topography	High cliff scarp at base; rolling plain to N.	DATE	14 / 10 / 64
Outcrop	Cliff exposure at base, poorer to north.		
Notebook	BP 63 JAK 41 – 43		
Method	Abney traverse		



Samples	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology
				Probable fault		
17	m-c	Red-Gn	Gl+ Fe	Glauconitic quartz sandstone, with phosphatic shell fragments and conodants.	T.S. CG 245/17	CG245/17 Conodants: Faunal unit XII
16					T.S. CG 245/16	CG 245/16 Phosphatic brachiopod shells.
15	m	Wh	Gl Fe	Quartz sandstone, glauconitic.		
14	c			Glauconitic quartz sandstone, with broken or fragmented trilobites.	T.S. CG 245/14	CG245/14 trilobite traces.
13B		Dk Red	Gl Fe			CG245/13B trilobites
14A	m					
13	f				TSCG 245/13	CG245/13 trilobites Faunal unit X B
12	m	Red	Gl	Glauconitic quartz sandstone.	T.S. CG 245/12	CG245/12 trilobites + brachiopods. Faunal Unit IX
11	m-f	Red		quartz sandstone.	T.S. CG 245/11	CG 245/11 trilobites.
	m	Wh		Sugary quartz sandstone.		
10	m-f	Dk			T.S. CG 245/10	CG 245/10 trilobites
9		Red	Gl	Quartz sandstone.	T.S. CG 245/9	CG245/9 trilobites + brachs.
8		Very		dark + white phosphatic brachiopods: a band in creek bed.	T.S. CG 245/8	CG245/8 phosphatic brachiopods. Faunal Unit VIII
	m-f	Red	Gl	quartz sandstone.		
7					T.S. CG 245/7	CG245/7 trilobites
6				poor outcrop	T.S. CG 245/6	CG245/6 trilobites
	m-f	Wh-Pk	Fe	Quartz sandstone, iron-indurated in some planes.		
5		Wh		friable	T.S. CG 245/5	CG 245/5 Brachiopods
			Fe	poor outcrop		
4			Fe		T.S. CG 245/4	CG 245/4 Gastropods Faunal Unit V.
		Gn-Gy.		Poor exposure: dolomitic sandstone & dolomite.		
		Red		V. poor exp: qtz ss scree.		
3		Gn-Gy.		Dolomite: algal (stromatolitic), oolitic & sandy.	T.S. CG 245/3	CG 245/3 Algae
2						CG 245/2 Brachiopods
		Red		qtz ss scree.		
		Gn-Red		Dolomite, some oolitic.		
		Red		Quartz sandstone		
1						
		R		Quartz sandstone with mudflakes.		

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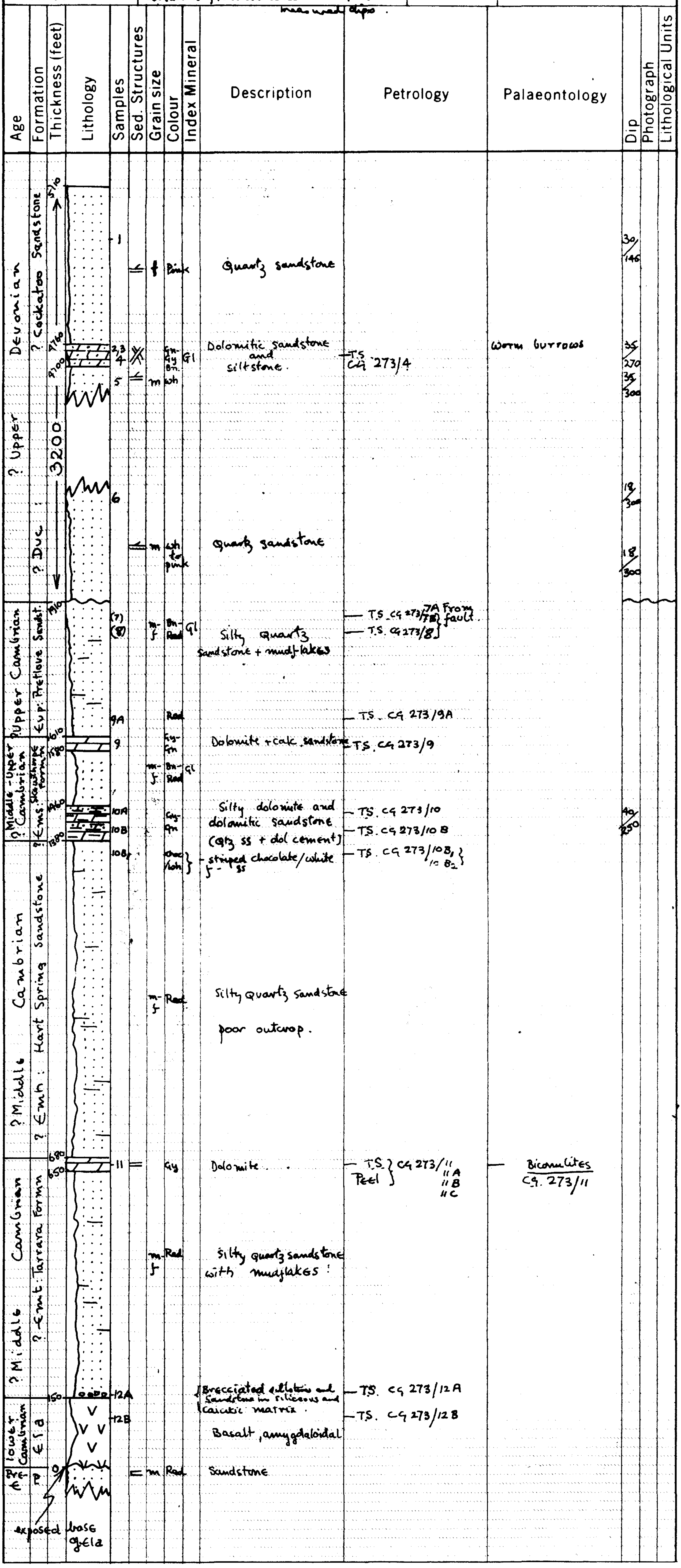
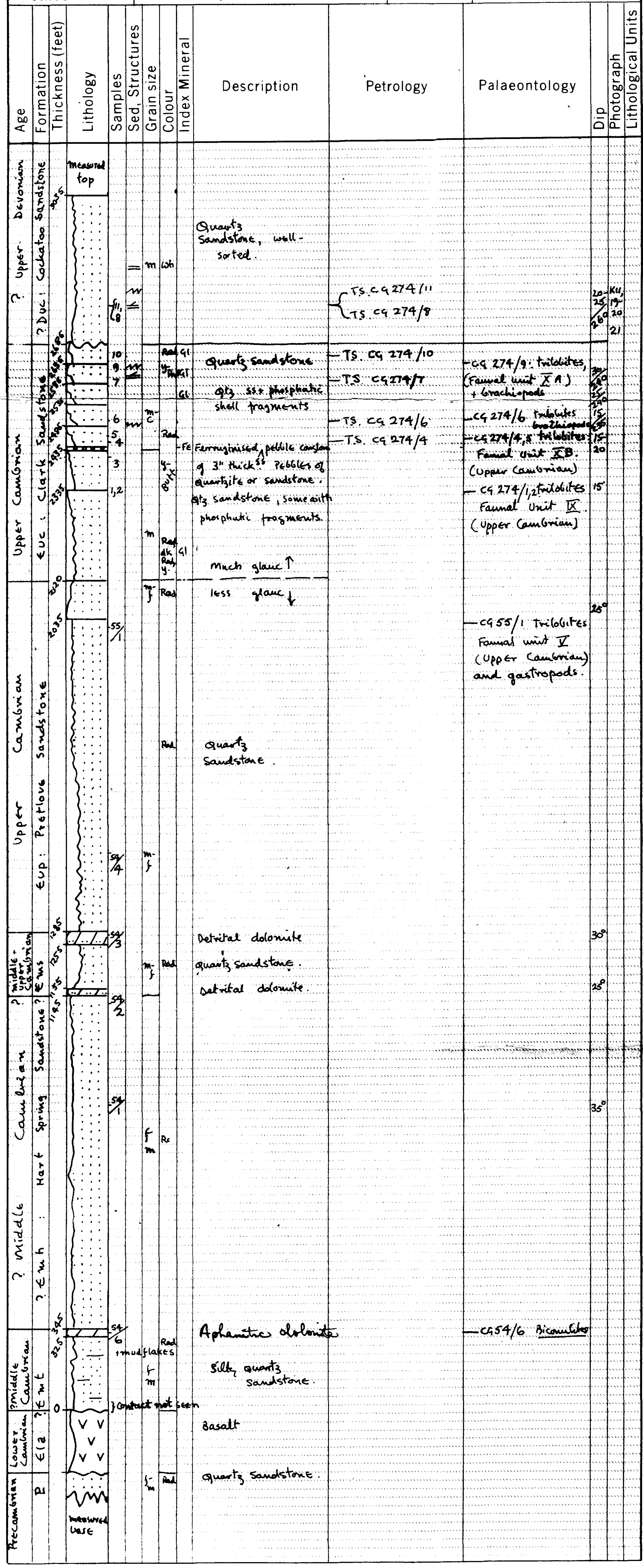
Section	CG 273
Locality	Mount Rob, South.
Air Photograph	C.G 14/23
Topography	Sandy Plain with Strike-ridges.
Outcrop	Ribbed strike ridges. Fair outcrop
Notebook	BP 63 JAK p 59-60
Method	Estimated from distance on air-photo and measured dips.

SECTION	273
SCALE	1" : 200'
MAP	Fig. 12
DATE	14 / 10 / 64



Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/78

Section	CG 274, CG 54, CG 55.	SECTION	274, 54, 55
Locality	South of Mount Rob	SCALE	1" : 200'
Air Photograph	CG. 13/73	MAP	Fig. 12
Topography	Sand-covered plain	DATE	14 / 10 / 64
Outcrop	Ribbed strike-ridges.		
Notebook	BP. 63. JAK. 60-62/JVV 41,42		
Method	Measured by distance and dip.		



Quartz sandstone, well-sorted.

Quartz sandstone

Qtz ss + phosphatic shell fragments

Ferruginised pebble conglom. ss of 3" thick. Pebbles of quartzite or sandstone.

Qtz sandstone, some with phosphatic fragments.

Much glauc ↑

less glauc ↓

Quartz sandstone.

Detrital dolomite

quartz sandstone.

Detrital dolomite.

Aphanitic dolomite

+ mudflakes

Silty quartz sandstone.

} Contact not seen

Basalt

quartz sandstone.

TS. CG 274/11

TS. CG 274/8

TS. CG 274/10

TS. CG 274/7

TS. CG 274/6

TS. CG 274/4

CG 274/9: trilobites, (Faunal unit X A) + brachiopods

CG 274/6 trilobites brachiopods

CG 274/4,5 trilobites Faunal Unit X B. (Upper Cambrian)

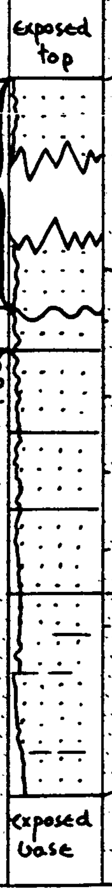
CG 274/1,2 trilobites Faunal Unit IX. (Upper Cambrian)

CG 55/1 Trilobites Faunal unit V (Upper Cambrian) and gastropods.

CG 54/6 Biconulites

Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/79

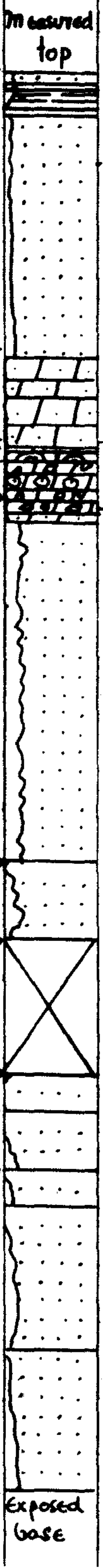
Section	CG. 275	SECTION	275
Locality	GAP POINT		
Air Photograph	C.G. 12/35	SCALE	1" : 200'
Topography	Low, gently sloping towards creek in north		
Outcrop	Low ribbed strike-ridges in plain.	MAP	Fig. 12
Notebook	BP. 63. JAK. 1, p 62.		
Method	Estimated by distance & dip.	DATE	14/10/64



Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
		3450	exposed top						probably faulted against P: dip is reversed towards upper part of section			Dip towards north		
Upper Devonian	Duc	2950				m	wh		quartz sandstone					
				6		m	wh	Gl		T.S. CG 275/6		15/130		
? ORDOVICIAN	Olp	500		5		m-c	y, wh gn	Gl+	Glauconitic qtz ss + phosphatic brach. fragmts	T.S. CG 275/5				
Upper Cambrian	Єuc	460		4		m-c	y	Gl		T.S. CG 275/4	trilobites: Faunal Unit XI (Trempealeau)	25/140		
				3		m-c	rd-y	Gl	quartz sandstone with mudflakes.	T.S. CG 275/3	trilobites + brachiopods poor preservation.			
				2		m-c	y	Gl		T.S. CG 275/2	trilobites & brachiopods			
	Єuc ?			1		m-f	Rd	(Gl)	Silty quartz sandstone with mudflakes.	T.S. CG 275/1				
		0	exposed base						probable fault					

Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/80

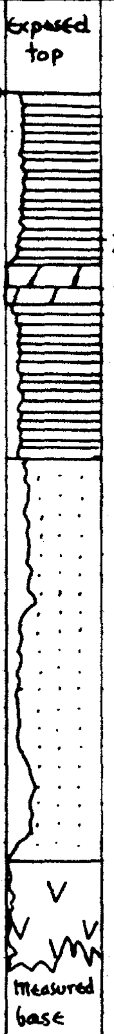
Section	CG 277	SECTION	277
Locality	LITTLE TARRARA BAR		
Air Photograph	KRS 15/09	SCALE	1" : 100'
Topography	Rocky Bar across Ord River.		
Outcrop	Poor in lower sandstones. Good above.	MAP	Fig. 10
Notebook	BP 63 JAK pp 64-66, 69.		
Method	Abney traverse	DATE	16 . 10 . 64



Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
UPPER CAMBRIAN	? €up		Measured top											
		745					Red		Silty shale					
				10							cq 277/10 Gastropods + Brachiopods in quartz sandstone			
					=	m-f	Pk-Bn		quartz sandstone					
? M-U CAMBRIAN	€ms	595					Red Gy	Gl	Sandy dolomite interbedded with pink siliceous quartz sandstone.					
		575												
		545		9							cq 277/9 Brachiopods in glauc dol.			
		540							Algal dolomite; dolomite; oolitic dolomite, with		Algae, stromatolitic			
		520					Red Gy		Dolomitic breccia, interbedded with quartz sandstone.	cq 277/11 Peel: Shows soln of ferroan-dol in oolites to be cause of collapse of beds of less soluble dol.				
		510		11										
MIDDLE CAMBRIAN	€mh: Hart Spring Sandstone.					f	Dk Red		Silty micaceous quartz sandstone.					
		330										45/100		
		290												
		220			〰							40/65		
		200										35/120		
		170										29/115		
		150				f	Dk Red		Silty micaceous quartz sandstone.			30/150		
		75										30/150		
												45/150		
		0	Exposed base											

Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/74

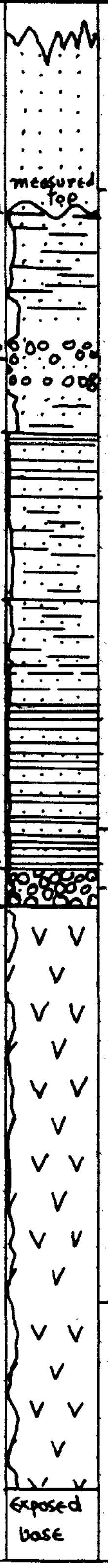
Section	C.G. 278	SECTION	278
Locality	TARRARA BAR		
Air Photograph	KRS 14/01	SCALE	1" : 50'
Topography	Bank of Ord River.		
Outcrop	Poor in sediments: Good in basalt.	MAP	Fig. 10
Notebook	BP 63 JAK pp 67, 70		
Method	Abney traverse.	DATE	16.10.64



Age	Formation	Thickness (feet)	Lithology	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
Lower Middle Cambrian	Emt: Tarrara Formation	200		2		f	Gn, Choc & Rd		Shale		C.G. 278/2 m shls. Biconulites			
				1			Gy		Dolomite, xlline. Some silicified.		C.G. 278/1 Biconulites * Redlichia fragmts	30/55		
		145				f	Gn, Choc & Rd		Shale and mudstone.		Faunal Unit II			
		105				f-m	Rd		Micaceous silty Qtz sandstone: poor exposure					
Lower Cambrian	Ela Antrim Plateau Volcanics	0							Volcanics, amygdaloidal.			30/70		

Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/75

Section	CG 283	SECTION	283
Locality	Martin's Bluff	SCALE	1" : 50'
Air Photograph	CG 10/01	MAP	Fig. 1
Topography	Steep cuesta scarp	DATE	14/10/64
Outcrop	Fair but often scree-covered.		
Notebook	BP 63 JAK p 70,71,73		
Method	Abney & staff traverse.		

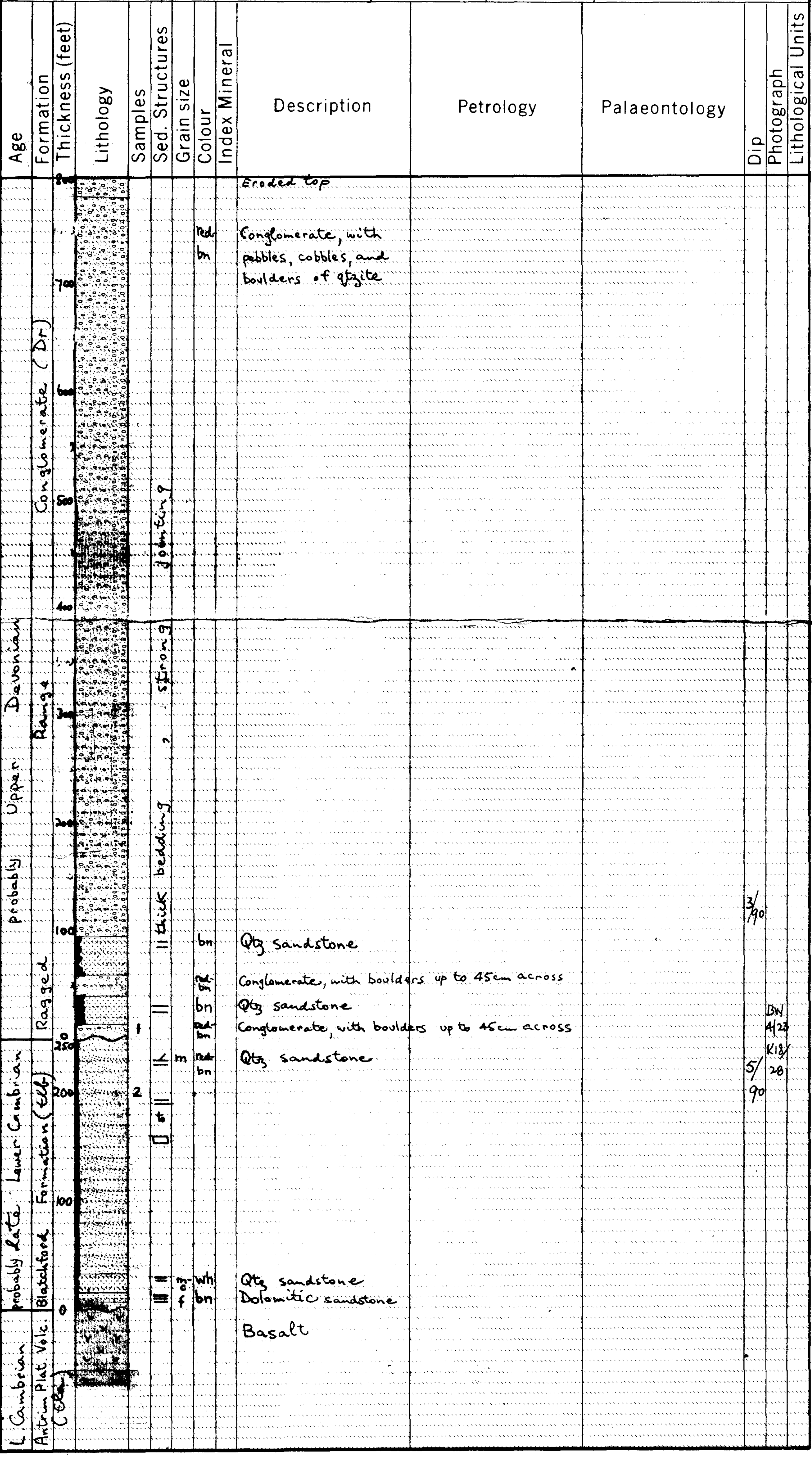


Age	Formation	Thickness (feet)	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph	Lithological Units
Upper Devonian	Cockatoo Sandstone				m	Wh		Quartz sandstone continues ↑					
? MIDDLE CAMBRIAN	Probably Ɛmt: Tarrara Formation	340	4		f - m	choc - Rd		v. poor exposure: flaggy silty ss + shale.					
		300						Volcanic pebble bands.					
					f - m	choc - Rd		Flaggy siltstone, and shale.					
		235		═	f - m	Choc - Pple - Gn - Rd		Banded chocolate-green-purple mudstone + shale + siltstone.			12/165		
			3						TS. CG 283/3				
		164	2					conglomerate of basalt pebbles, in sandy limestone matrix	TS 86/1A,M				
LOWER CAMBRIAN	Ɛla	154				Dk Rd + Pple		Basalt: amygdaloidal.	T.S. Mg 1,2				
			1						T.S. CG 283/1				
		0						Poor exp. at base.					

Bureau of Mineral Resources, Geology and Geophysics. March 1965 To accompany Record 1965/49 AUS/1/66

Section	L 12
Locality	Ragged Range
Air Photograph	Lissadell 6/76
Topography	escarpment
Outcrop	100 %
Notebook	BP 63 JJV 61
Method	Abney section (0 - 300); rest estimated by Abney & A.P.

SECTION	L 12
SCALE	1" : 100'
MAP	Fig. 15
DATE	14.V.64 6.10.64 21.V.64



Eroded top

Conglomerate, with pebbles, cobbles, and boulders of qtzite

Qtz sandstone

Conglomerate, with boulders up to 45cm across

Qtz sandstone

Conglomerate, with boulders up to 45cm across

Qtz sandstone

Qtz sandstone

Dolomitic sandstone

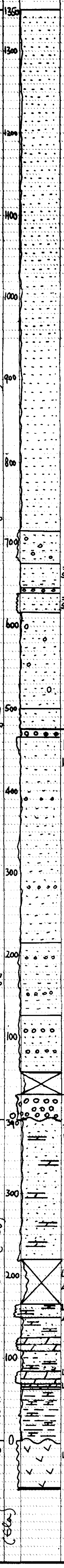
Basalt

Bureau of Mineral Resources, Geology and Geophysics. March 1965 To accompany Record 1965/49 AUS/1/81

Section	L 13, 14, 15 (composite)	SECTION	L 13, 14, 15
Locality	Ragged Range		
Air Photograph	Lissadell 4/88	SCALE	1" : 100'
Topography	Cambrian in an escarpment, Devonian in dissected range		
Outcrop	almost 100%.	MAP	Fig. 16
Notebook	BP 63 JJV 62-64		
Method	Abney traverse	DATE	14. V. 64 19. V. 64 21. V. 64 6. X. 64

Age: probably Upper Devonian; probably late Lower Cambrian; L. Cambrian

Formation: Ragged Range Conglomerate (Dr); Blatchford Formation (Єlb); Antrim Plat. Volcanics (Єla)



Thickness (feet)	Samples	Sed. Structures	Grain size	Colour	Index Mineral	Description	Petrology	Palaeontology	Dip	Photograph
						Eroded top				
1350	L 15	⊏	m-c			Qtz. fels. sandstone friable				
700			m-c	red		Pebbly qtz sandstone	52/2 T.S.: qtz grains angular tightly packed but not visibly enlarged. Matrix of redbrown ?clay			
	= 52/2	⊏	f	gy, red		Qtz sandstone				
						conglomerate, qtzite boulders up to 50cm across in gy qtz sandstone				
	= 52/1		f-m	red		Qtz sandstone		= 52/1 pelecypods		
600		⊏		pink wh		Friable qtz sandstone with pebbles, cobbles, and boulders of qtzite			Sub-horizontal	
500	L 15	⊏	m-c	pink wh		Friable qtz sandstone				
						Conglomerate, cobbles of qtzite				
	L 14/2	☐	m	pink		Qtz sandstone with rare pebble bands	TS: pressure solution fabric of qtz grains, no cement, film of limonite clay.			
400										
300										
200		☐	m	pink		Qtz sandstone c̄ pebble bands			2/130	
100		⊏ ≤	f-m	pink		Sugary qtz sandstone, thin beds of qtzite conglomerate				
	L 14					Scree of qtzite boulders				
0	L 13					Silicified wedge conglomerate, qtzite cobbles. Faulted		= 53/2 pelecypods gastropods	5-20/120	
390	= L 14/1	≡ ≤	f	bn		Dolomitic qtz sandstone	L14/1 T.S.: angular qtz grains (< 80u), dolomite mosaic	⫽	25/130	GW 11/25-29
300										
200	L13/4B					Floaters of dolomitic sandstone and dolomite	T.S.: angular qtz grains (~ 250u), dolomite mosaic			
	L13/4A	≡	vf	bn		Dolomitic qtz sandstone	TS: similar to B, but finer-grained	= 51/1 trilobites		
		≤	f	gy		Dolomitic qtz sandstone				
					Gl	Glauconitic dolomite		Biconulites		
100		≡	f	gy		Dolomitic qtz sandstone	TS: glauc. grains < 3mm, some ?replacing fossil.	Biconulites		
	L13/3	=		gy+red	Gl	Glauconitic dolomite				
	L13/2			gy-gn	Gl	Silty glauconitic dolomite				
		≡		bn		Dolomitic siltstone, weathered	TS: qtz 25%, rare biotite, muscovite, glauconite		15/150	K18/31-35
0	L13/1					Amygdaloidal basalt.	TS: amygdales of qtz and calcite and veins in felt of feldspar laths in a groundmass stained red by iron oxides		25/150	

Bureau of Mineral Resources, Geology and Geophysics March 1965 To accompany Record 1965/49 AUS/1/82