COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF NATIONAL DEVELOPMENT.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS.

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THE CAMBRIAN GEOLOGY OF AUSTRALIA

BY

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CAMBRIAN GEOLOGY OF QUEENSLAND

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ABSTRACT

The Cambrian deposits of Queensland are described and the history of exploration is discussed. The current stratigraphical nomenclature is regarded as obsolete, or only of historical interest. The main subdivision of the Cambrian in the current nomenclature, the "Georgina Limestones," includes an apparently Precambrian dolomite—the Camooweal Dolomite. The Cambrian sequence comprises Middle and Upper Cambrian, with some Tremadocian on top. Most of the Cambrian rocks form blankets, except in the Undilla Basin, where the sequence is thicker. The fauna is essentially Acado-Baltic, and most of the Scandinavian agnostid zones are represented by the nominate zone species, starting with *Ptychagnostus gibbus* and ending with *Leiopyge laevigata* in the Middle Cambrian.

The Upper Cambrian follows, beginning with a *Cedaria*-fauna, followed by *Olenus* and *Glyptagnostus*.

Erosional residuals of "Subcambrian" sequences occur below the base of the Cambrian.

INTRODUCTION

HISTORY OF EXPLORATION

The early history of exploration of the Cambrian region of northwestern Queensland has been presented in detail by Whitehouse (1936).

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In this history the year 1924 is significant: Saint-Smith (1924) gave evidence for the Cambrian age of sediments previously believed to be Devonian to Tertiary. Whitehouse (1927) first identified the fossils collected as Middle Cambrian in age, and Chapman (1929) described some of them as Middle and Upper Cambrian. Whitehouse later (1939-1949) added several more localities, described the fossils, and demonstrated the wide regional distribution of Cambrian rocks and faunas in Queensland. He also demonstrated the absence of metamorphism and igneous rocks in the Cambrian sequence and the presence of the great unconformity against the Precambrian basement. A stratigraphy based on the sequence of rock-units was at that time beyond the reach of a single explorer, and Whitehouse therefore constructed a scale of regional stages based on the occurrence of trilobite genera and correctly placed them in the Middle and Upper Series of the Cambrian System.

In 1947-48 the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) surveyed the Barkly region, the eastern part of which covers the Cambrian areas of northwestern Queensland. Geologists of the Commonwealth Bureau of Mineral Resources, Geology and Geophysics, L. C. Noakes and D. M. Traves, studied the geological problems of the survey (see C.S.I.R.O., 1952) and collected more information and fossils. As a first geological result of this survey the Urandangi 4-mile Geological Sheet (1951) may be mentioned. Since 1950, field parties of the Bureau of Mineral Resources have mapped the Precambrian rocks of the region, and consequently the study of the sedimentary cover, consisting mainly of Cambrian deposits, became necessary. The present writer has been engaged in this work continuously from 1948.

CURRENT STRATIGRAPHICAL NOMENCLATURE

The geology of the Cambrian deposits as presented in this article differs considerably from the current concept based on Whitehouse's research. Not all the discrepancies can be discussed in the present short paper, but some comments are called for on the accepted usage of stratigraphical nomenclature, and on the current concepts of structure and geographical distribution of the Cambrian of Queensland. The latest modifications of this usage are given in David and Browne (1950, vol.

1, pp. 115-118) and are followed in the Geological Map of Queensland (1953) and the Geological Map of Australia and New Guinea (1953).

The general terms in current use are "Barkly Group," "Templeton Series" and "Georgina Limestone" or "Series," and twelve fossil stages.

BARKLY GROUP

On the maps, the Cambrian sequence of northwestern Queensland and adjoining parts of the Northern Territory is referred to as a whole as the "Barkly Group." The major part of this Group, however, is the Camooweal Dolomite of the present paper (figs. 1 and 2), a unit older than the known fossiliferous Cambrian. The Cambrian deposits of Queensland and the Northern Territory are nowhere continuous and form two separate provinces, as is explained in the article "Cambrian palaeogeography of Australia" (this Symposium), and thus the unity of the Barkly Group is illusory. It is an historical term, difficult to assign to a concrete rock sequence and impossible to tie up with any type locality except the Barkly Tableland in general. The term is therefore not used by the present author.

TEMPLETON SERIES AND GEORGINA LIMESTONE

The Barkly Group is not recognized in David and Browne (1950), where Whitehouse's two subdivisions, Templeton Series and Georgina Series, are adopted. The Templeton Series can be easily identified: it covers the ranges of the trilobites *Redlichia idonea, Xystridura, Dinesus, Ptychagnostus gibbus,* and *Pt. atavus,* and can be either used as a stage reference for the lower half of the Middle Cambrian (if necessary), or restricted to the *Redlichia-Xystridura* fauna, for which it was originally intended. Above the Templeton Series follows the Georgina Series (or Georgina Limestones), which covers the rest of the Middle Cambrian and part of the Upper Cambrian of the region. In this form the term is of little use. The name was originally proposed by Ogilvie *(vide* Whitehouse, 1931) and may have referred to some Upper Cambrian limestones on Glenormiston Station. However, the Camooweal Dolomite was also included in the Georgina Series, as well as the rocks of the Undilla Basin, which do not belong to the Georgina Basin at all. The locality of the Georgina Series is described as being "in and around the basin of the Georgina River."

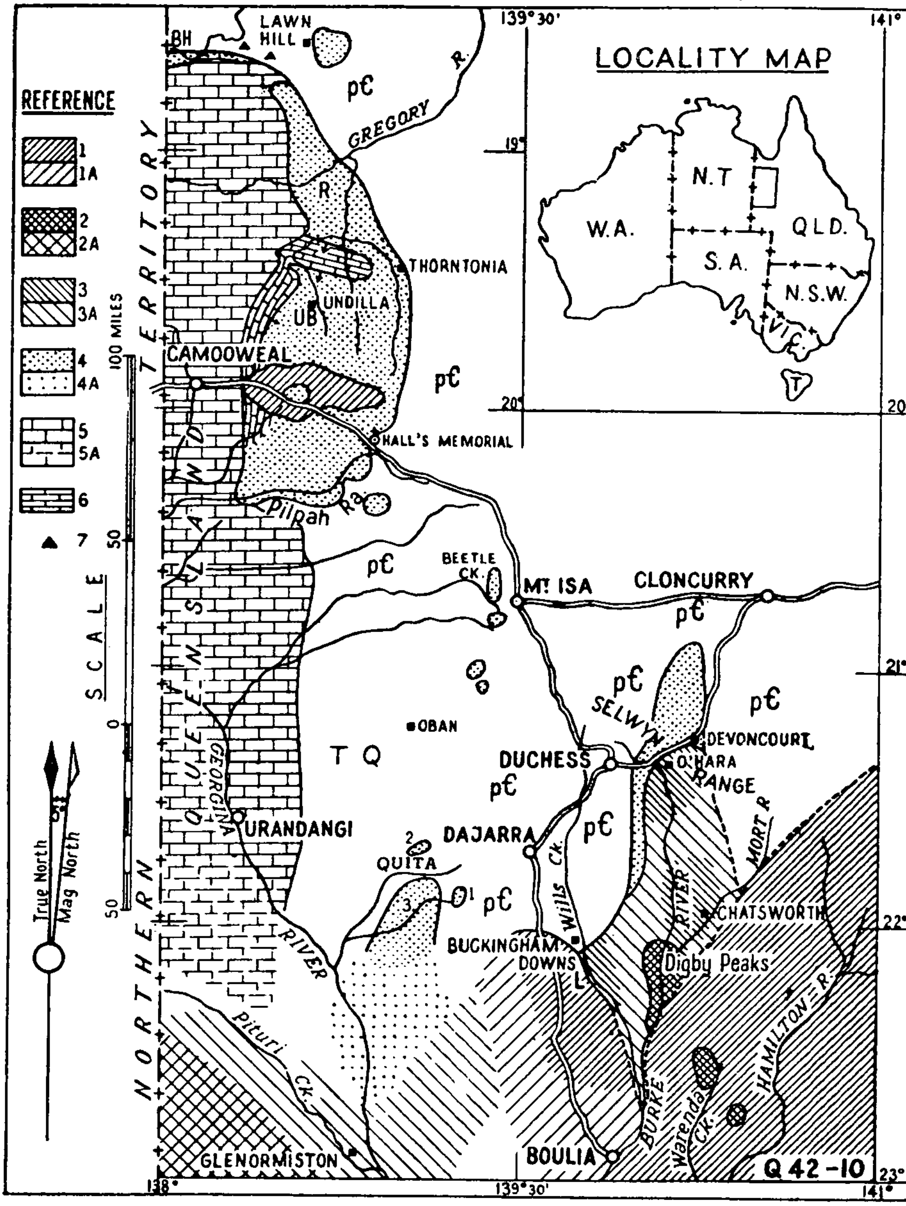

Fig. 1. Map of northwestern Queensland. 1. Mesozoic sediments, mapped. 1A. Mesozoic sediments, evident. 2. Ordovician limestone and dolomite, mapped. At Warenda Creek it is the Ninmaroo Series (or limestones) of Whitehouse (1936). At Digby Peaks no fossils have been found, but north of it, at Chatsworth, and strati-

Originally it was believed that the Georgina Series consisted predominantly of limestone and the Templeton Series of shale and chert, and that the Georgina Limestones were consistently later than the Templeton Series (or *Dinesus*-beds). In David and Browne *(loc. cit.*, p. 116), the Templeton Series is, however, regarded as a "stratigraphical equivalent of the lower part of the Georgina Limestones." But the illustrating section *(ibid.*, p. 116, fig. 40) follows the older concept unchanged, and the two subdivisions are shown in strict superposition. However, the rock that is interpreted as the "Georgina Limestones" in the above-mentioned section is in reality older than the "Templeton Series," and is the Camooweal Dolomite in our section (fig. 2). The bed of the Georgina River is in the dolomite, and, except for the occurrence at Glenormiston, no Cambrian rocks occur along the Georgina.

The lithological distinction—Georgina Series predominantly calcareous and Templeton Series developed as shale and chert—is, in a regional sense, non-existent as is seen from the chart (fig. 3); consequently the concept of the Georgina Series is rather indistinct and broad and cannot be used in the present paper. In the meaning of a stage it has no limits, because even rocks believed to be Upper Cambrian have been included in the sequence (Whitehouse, 1940, p. 44). If viewed typologically, the name "Georgina" in a lithological sense can be applied

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graphically below the Digby Peaks beds, a fauna with *Geragnostus* and *Bellefontia* occurs. 2A. Ordovician on Pituri Creek (Toko Range), evident. 3. Upper Cambrian O'Hara Shale in the Selwyn Range, and north of Chatsworth (Pomegranate and limestone with *Olenus* and *Gliptagnostus),* mapped. L marks the D Little Range on the Wills Creek, with Upper Cambrian limestone *(Glyptagnostus)*. 3A. Upper Cambrian limestone and sandstone in the Glenormiston area (Pituri Series and Georgina Series proper). 4-4A and 6. Middle Cambrian. 4A indicates the areas which are not yet mapped in detail. BH = Border Waterhole area. R (between Lawn Hill and Thorntonia) contains only the Thorntonia Limestone and the "*Girvanella* puddings." UB = Undilla Basin, with the Middle Cambrian sequence complete. At Hall's Memorial is the occurrence of the Yelvertoft bed with *Redlichia idonea* and *chinensis*. In the Quita area, Outlier No. 1 (Ardmore), Thorntonia Limestone and Beetle Creek Formation overlie "subcambrian" redbeds. The Outlier No. 2 contains some Camooweal Dolomite with sandstone interbeds, overlain by Middle Cambrian shale. No. 3 is the Quita area proper. 5-5A. Camooweal Dolomite, mapped and (A) evident. 6 = Age Creek Formation (Middle Cambrian), the slope deposit of the Undilla basin. 7. Volcanic rocks of probable Lower Cambrian age in the Border Waterhole area.

only to the Camooweal Dolomite or the Upper Cambrian limestones of the Glenormiston area. The name must be reserved for the latter, because the original intention of Ogilvie and Whitehouse was to name fossiliferous Cambrian limestones of the Georgina River and not unfossiliferous dolomite.

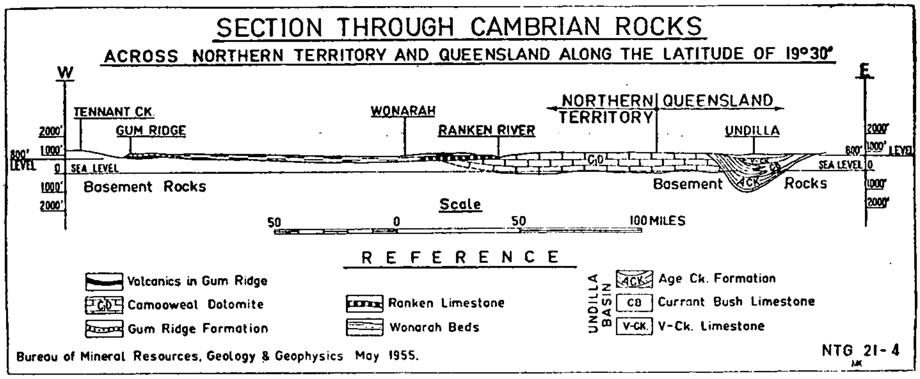

Fig. 2. In this section the thickness of the Gum Ridge Formation and the Ranken limestone are exaggerated. The thickness of the Undilla Basin is reduced; the inferred thickness is about 4000 feet.

STRUCTURAL INTERPRETATIONS

Two major differences in structural interpretation may be mentioned: (1) all the maps published to date show a continuous blanket of Cambrian deposits, whereas the accompanying map (fig. 1) demonstrates that the Cambrian occurs as disconnected areas; (2) it was believed (David and Browne, 1950, vol. I, fig. 40) that the Cambrian deposits of Queensland and the Northern Territory formed a continuous basin, whereas our section (fig. 2) contradicts this.

FOSSIL STAGES

The Cambrian sequence of northwestern Queensland was originally divided by Whitehouse (1936; 1939) into twelve stages of regional significance. This subdivision is not applied in the present paper for various reasons: some of the stages cannot be identified with certainty; the position of others in the sequence is not clear; and the real sequence of the stages is different from the original arrangement. This is evidently in accordance with Whitehouse's own attitude, as reflected in his later papers.

The *Amphoton*-Stage and the corresponding Split Rock Sandstone, originally believed to be just above the *Redlichia*-Stage, belong in reality to the uppermost Middle Cambrian. The *Phoidagnostus*-Stage, correlated with the *Paradoxides davidis* Zone, and established for the Devoncourt area, corresponds to the uppermost Middle Cambrian Zone with *Leiopyge laevigata*. However, the subdivision by ranges of trilobite genera, as shown by Whitehouse (1940, p. 45, fig. 12), in the surface section from Thorntonia to Bull Creek, is acceptable: the range of *Amphoton* in this section covers the upper half of the Middle Cambrian, by which the "*Amphoton*-Stage" in the sense used in 1939 is practically deleted by the author himself. A subsequent contribution (Whitehouse, 1945) simplifies the subdivision still further; the *Amphoton*-Stage remains deleted and other stages of the Middle Cambrian are not mentioned at all.

In David and Browne (1950, vol. I, pp. 115-118), the stages are not mentioned in the text, but an abbreviated list of stages is given in Table V, "Tentative correlation of the Cambrian rocks of the Commonwealth" *(ibid.*, p. 140). Here the "Georgina Limestone Series" is shown to cover the uppermost Lower Cambrian, the whole of the Middle Cambrian, and limestones of the lower Upper Cambrian. The "Templeton Facies" (previously "Templeton Series") is only a local variation of the lower part of the "Georgina Limestone Series."

The following Middle Cambrian stages are shown in the abovementioned Table V (ascending order): (1) *Redlichia*, (2) *Xystridura*, (3) *Agnostus seminula*, (4) *Phoidagnostus*, (5) *Papyriaspis*, and (6) *Anomocare*. The first three are in the correct order, although the existence of an *Agnostus seminula* Stage is in doubt. The "*Phoidagnostus*-Stage" (4) is the top of Middle Cambrian, and the position of the *Papyriaspis*-Stage (5) (if restricted to the species *P. lanceola* Whitehouse) is more-or-less correct. The real position of the "*Anomocare*-Stage" (6) in the sequence is not yet identifiable: in the type locality of the nominate species of this stage *(Anomocare confertum* Whitehouse) rocks of the Currant Bush Limestone and V-Creek Limestone occur (see fig. 3); both contain *Anomocare*-like trilobites, and *Anomo-*

care confertum is not identifiable with certainty from the existing description and illustrations. In any case, the "*Anomocare*-Stage" is not the topmost division of the Middle Cambrian in Queensland. The four stages of the Upper Cambrian as shown in the same table (*Eugonocare, Glyptagnostus, Rhodonaspis,* and *Elrathiella,* in ascending order) are discussed below.

The foregoing remarks are meant for the attention of palaeontologists and stratigraphers endeavouring to correlate intercontinental occurrences or interpret phylogenetic trends of trilobites. The trilobites described by Whitehouse are referred to the stages and his sequence of stages cannot be used for correlation. The reference to localities, however, is correct, but contains little information on the real stratigraphical position of the fossils.

STRATIGRAPHICAL RANGE OF CAMBRIAN ROCKS OF NORTHWESTERN QUEENSLAND

The presence of Middle and Upper Cambrian rocks in Queensland has been established by Whitehouse (1927-1939). The limits of the Upper Cambrian are discussed below, and the possibility of a gradation into Lower Ordovician (Tremadocian) is indicated. The lower limit of the Middle Cambrian in the region, and the question of the actual presence of fossiliferous Lower Cambrian deposits, must be discussed.

The lowermost fossiliferous beds contain *Redlichia* and are known as the "Yelvertoft Bed" (David, 1932). The chart (fig. 3), shows the Yelvertoft Bed as contemporaneous with the lower part of the Thorntonia Limestone, the two forming the base of the fossiliferous Cambrian sequence of the region. According to Whitehouse (1936-1939) and David and Browne (1950), the *Redlichia*-fauna of Queensland belongs to the uppermost Lower Cambrian, whereas in the present paper it is placed in the lower Middle Cambrian, near, but not quite at, the base of the Series. A comparable occurrence of *Redlichia* in the Northern Territory (Öpik, 1954b) is associated with *Peronopsis* cf. *elkedraensis* (Etheridge) and *Pagetia* cf. *significans* (Eth.), which are regarded as Middle Cambrian in age. The *Redlichia*-fauna of the Wirrealpa Limestone (South Australia) is of a similar age.

Pagetia and *Redlichia* are also associated in Queensland at a locality near Lawn Hill. The *Redlichia*-fauna in Queensland merges without breaks into the succeeding *Xystridura-Dinesus* fauna, and the two faunas occur in one and the same formation. It has been found that the *Xystridura-Dinesus* fauna corresponds to the lower part of the European Zone with *Ptychagnostus gibbus* and the upper part of the *Oelandicus*-Stage. Consequently, the *Redlichia*-fauna of Queensland belongs to the middle levels of the *Oelandicus*-Stage and therefore remains above the lower limit of the Middle Cambrian.

The Queensland species, *Redlichia idonea* Whitehouse, is associated with *R. chinensis* Walcott, which may indicate a Middle Cambrian age for corresponding faunas in eastern Asia. This is supported by the occurrence in Korea of *Oryctocephalus* and *Pagetia* immediately above the beds with *R. chinensis* (Saito, 1934). The Korean "*Ptychoparia*"-beds with *Oryctocephalus*, *Pagetia*, and *Peronopsis*, are regarded by the present writer as contemporaneous with the *Xystridura-Dinesus* fauna of Queensland.

To conclude, fossiliferous Cambrian in Queensland begins with the Middle Cambrian, and evidence for the presence of Lower Cambrian is missing.

GEOGRAPHICAL AND STRUCTURAL SUBDIVISIONS OF THE CAMBRIAN OF QUEENSLAND

The geographical and structural subdivisions of the Cambrian deposits of Queensland are shown on the map (fig. 1). The Cambrian rocks occur in a number of isolated areas—either as erosional residuals or grabens, or both. A former continuous blanket of Cambrian rocks over the whole of the region may be postulated. The time of faulting and erosion is post-Ordovician. A considerable part of the Cambrian rocks was already eroded away before the marine Mesozoic inundation.

The main area of the Cambrian is the Undilla Basin, bounded by the Pilpah Range in the south, the O'Shannassey River in the north, and the Camooweal Dolomite in the west. The section (fig. 2) illustrates the structure. The complete Middle Cambrian sequence is preserved in the Undilla Basin; Upper Cambrian is missing. Part of the basin is concealed by a thin blanket of Mesozoic radiolarian shale.

North of the Undilla Basin (at letter "R" on the map), a veneer of Thorntonia Limestone is present, which along its southern edge dips south into the Undilla Basin. The rocks are limestone and dolomite with *Redlichia* and "*Girvanella* puddings"; similar rocks occur at Lawn Hill, where, however, *Xystridura*-bearing rocks are also preserved. The writer believes that the western limit of the "*Girvanella* puddings" corresponds to the shoreline of the Thorntonia Limestone: the "puddings" are current bedded, and the *Redlichia*- and *Girvanella*-bearing beds of the Thorntonia Limestone are absent farther north (at Border Waterhole).

The Border Waterhole area is a narrow latitudinal fault-zone, over 30 miles long, with Cambrian rocks preserved in the graben. The sequence begins with a *Xystridura*-bearing formation above which follows the Currant Bush Limestone. The latter, of *Ptychagnostus gibbus*/*Pt. atavus* age, contains a prolific fauna not yet studied in detail but including two species of *Fuchouia* and *Paterina* cf. *superba* Walcott. The highest beds of the sequence consist of an unfossiliferous current-bedded dolarenite, gritty with chert fragments. The material seems to have been derived from the Camooweal Dolomite. Two small occurrences of volcanics are indicated at the eastern end of the Border Waterhole area. They are below the Cambrian sediments and are tentatively assigned to the Lower Cambrian by the present author as well as the discoverer, K. A. Townley (verbal communication).

At the Border Waterhole the Camooweal Dolomite and the Cambrian rocks are down-faulted against Precambrian rocks in the north. The Dolomite is horizontal and younger than the folded but unmetamorphosed late Precambrian Constance beds north of the fault, and is from a diastrophistic point of view closer to the Cambrian than the Precambrian. The same applies to the volcanics, whose relationship with the Camooweal Dolomite is not, however, evident.

In the Pilpah Range (the southern limit of the Undilla Basin), only residuals of the Yelvertoft Bed and Beetle Creek chert occur, followed above by erosional residuals of Split Rock Sandstone. Consequently, a sedimentational break during the middle Middle Cambrian is here apparent, indicating that the Range itself was only temporarily submerged during the continuous sedimentation in the Undilla Basin to the north.

Between the Pilpah Range, Mt. Isa, and Quita Creek, only scattered erosional residuals of Cambrian rocks occur. They all consist of

Yelvertoft Bed (with *Redlichia*) followed above by Beetle Creek chert and shale (with *Xystridura, Dinesus, Kootenia,* and *Peronopsis),* which pass into the siliceous shale of the Inca Formation (with *Ptychagnostus gibbus* and *Pt. atavus*). At Oban, the existence of Cambrian deposits under a late Tertiary and Quaternary cover is proved by bore-logs. The age of the Cambrian is unknown. The best known locality of the residuals, and indeed of Cambrian in Queensland, is at Beetle Creek, which yielded the first Cambrian fossils found in Queensland. The fauna has been described by Chapman (1929) and Whitehouse (1936; 1939).

In the Quita Creek area three separate areas of Cambrian rocks occur; in part they are comparable with the deposits of the Undilla Basin, and in part display a different lithology. A depositional and erosional break of *Ptychagnostus gibbus/Pt. atavus* time is present here.

South of the 22nd parallel, along the Georgina River (Glenormiston or Pituri area), no additional information is available, except for the material published by Whitehouse. Middle Cambrian is present south of Quita Creek; around Glenormiston on the Pituri River, Upper Cambrian is present ("Georgina Limestones" in its original meaning), which is discussed below. Ordovician rocks occur in the southwest.

East of Duchess, in the area between the Selwyn Range and Chatsworth, Middle Cambrian, Upper Cambrian, and, probably, lowermost Ordovician are represented. The tongue-shaped area is a graben bounded by post-Cambrian faults, which explains the preservation of the lower Palaeozoic sediments. The rocks are slightly folded and a thrusting from the east is apparent.

South of Buckingham Downs on Wills Creek at the foot of the De Little Range, which consists of Mesozoic shale, a small stretch of Upper Cambrian limestone with *Glyptagnostus, Clavagnostus,* and *Eugonocare* is present.

The rocks of Digby Peaks (sandy limestone and dolomite with chert) and the inliers at Warenda (described by Whitehouse) are most probably Ordovician in age.

The sequences of the Undilla Basin, the Quita Creek area, and the Selwyn Range are shown in figure 3 and are discussed in more detail below.

BASE OF CAMBRIAN IN QUEENSLAND

The Cambrian in Queensland rests on four different kinds of older rocks:

1) Between the Border Waterhole and Lawn Hill some volcanic rocks occur which are assumed to be Lower Cambrian in age, and are not discussed further;
2) The Precambrian rocks proper, consisting of sediments, igneous rocks, and metamorphics, and folded in various degrees, represent the old basement of the region; the topography of this basement has affected the distribution of the Cambrian sediments (see, for example, the description of the Pilpah Range);
3) The Camooweal Dolomite is the substratum of the Cambrian in the west;
4) Some clastic sediments, termed "subcambrian" in the stratigraphic chart (fig. 3), occur in the Selwyn Range and Quita areas.

Some further discussion of (3) and (4) is given below.

The Camooweal Dolomite is a bedded dolarenite with nodules, stringers, and small lenticles of chert; some admixed fine quartz sand and interbeds of quartz sandstone occur at its base and locally thin beds of limestone and dolomitic limestone occur at various horizons. It is 800-1000 feet thick, with its base just below sea-level, and appears to be a uniform blanket extending into the Northern Territory (see section, fig. 2). Within the large area occupied by the Dolomite, pockets of Middle Cambrian rocks may still be present unnoticed under the soil cover, as suggested in the article "Cambrian Palaeogeography of Australia" (Öpik, this Symposium, map 6). The Age Creek Formation along its western edge overlaps the Camooweal Dolomite, and so do the "*Girvanella* puddings" north of the Undilla Basin. The "*Girvanella* puddings" form the base of the fossiliferous Middle Cambrian of the region, and the Camooweal Dolomite is therefore older than Middle Cambrian.

The Cambrian rocks of the Undilla Basin rest along their eastern edge on the Precambrian basement; at the Border Waterhole the Cambrian sediments rest partly on the basement and partly on the Camooweal Dolomite; the Cambrian dolarenites and calcarenites of the Border

Waterhole area and the Age Creek Formation are evidently derived from the Camooweal Dolomite or similar rocks. All this may indicate an erosional break between the Camooweal Dolomite and the overlying Cambrian rocks.

The eastern boundary of the Camooweal Dolomite in the Undilla Basin is in reality an erosional slope or cliff covered by the Age Creek sediments; a similar cliff is present at the Border Waterhole, trending latitudinally. The attitude of the Camooweal Dolomite is horizontal, and its relationship with the basement is similar to that of the Cambrian rocks in the east. The Camooweal Dolomite is unfossiliferous except for rare calcareous algae (stromatolitic and columnar types). The age of the Camooweal Dolomite could be Lower Cambrian, or late Precambrian, but cannot be decided on the available evidence.

A complete section of the Camooweal dolomite has not yet been seen, and all available information refers to numerous shallow outcrops in creeks, representing the upper levels of the formation. The basal part (with sandstone interbeds) and its contact with the basement is seen in the Nº 2 outlier at Quita Creek (fig. 1) and in several places south of the Pilpah Range. The thickness of the Dolomite as given above is estimated from water bores. The Middle Cambrian and Upper Cambrian sequence of the region is so well known that it is obviously impossible to fit the Dolomite into that sequence. The possibility that the Dolomite is of post-Cambrian age is discussed in the paper "Cambrian geology of Northern Territory" (Öpik, this Symposium).

The name Camooweal Dolomite has been proposed by the present writer in previous, unpublished reports.

Arenitic "subcambrian" rocks are found in the Quita area and along the western limit of the Selwyn Range area. In the Quita area they are present only in the Ardmore outlier (No. 1 on the map, fig. 1), where conglomerate, red sandstone, and a sandy red dolomite, altogether 150 feet thick, are seen below the *Redlichia*-bearing Thorntonia Limestone. These "subcambrian" redbeds occur as a pre-*Redlichia* erosional residual. The structural position of the redbeds on the basement is similar to the position of the Camooweal Dolomite elsewhere. It may be assumed that the redbeds are contemporaneous with the Camooweal Dolomite, or the lower, sandy, part of it, and were deposited outside the big pool in which the dolomite was precipitated.

The "subcambrian" rocks along the western limit of the Selwyn Range area consist of micaceous arkose (at Mt. Birnie south of Duchess), or impure sandstone; northeast of Duchess the "subcambrian" is a purple clay with sand, grading into the decomposed regolith of the basement below. The age of these rocks in the Selwyn Range is uncertain, because they are overlain by marine uppermost Middle Cambrian rocks with *Leiopyge laevigata*, and could as easily be terrestrial, or non-marine aquatic, deposits of Middle Cambrian age, as residuals of an older sequence similar to that observed in the outlier at Ardmore.

At Beetle Creek, at the base of the Cambrian sequence, silicified *Collenia-* and *Cryptozoon*-like bodies occur, probably attached to the basement. They may belong to the Middle Cambrian *Redlichia*-time, or may represent the last residuals of an otherwise completely eroded "subcambrian" sequence, corresponding to the base of the Camooweal Dolomite.

To conclude, in northwestern Queensland, at the base of the fossiliferous marine Middle Cambrian, and separated from the latter by an erosional break, residuals of possibly Lower Cambrian or Late Precambrian are preserved. The largest of the residuals is the Camooweal Dolomite, a rock body of regional significance.

MIDDLE CAMBRIAN SEQUENCE

The stratigraphy of the Middle Cambrian sequence of Queensland is based in its lower portion on the occurrence of the *Redlichia* and *Xystridura* faunas. Above it, the orientation in time is provided for by the superposition of agnostid species as shown in the chart (fig. 3). They are the Swedish agnostid zones (Westergaard, 1948), and the species named actually occur abundantly in Queensland in the given order. *Hypagnostus parvifrons* is the only zone-agnostid not yet found, but the gap in the chart between the ranges of *Ptychagnostus atavus* and *Pt. punctuosus* represents the range of the zone. Some of the agnostids *(Pt. gibbus, Pt. atavus,* and *Goniagnostus nathorsti)* were identified by Whitehouse (1936; 1939) and are referred to by Westergaard (1948). Subsequently Dr. Westergaard examined actual material from Queensland, and confirmed the presence of *Ptychagnostus gibbus* and the identity of *Ceratagnostus magister* Whitehouse with *Doryagnostus incertus* (Brögger), a species associated in Sweden with *Pt. punctuosus* and *G. nathorsti.*

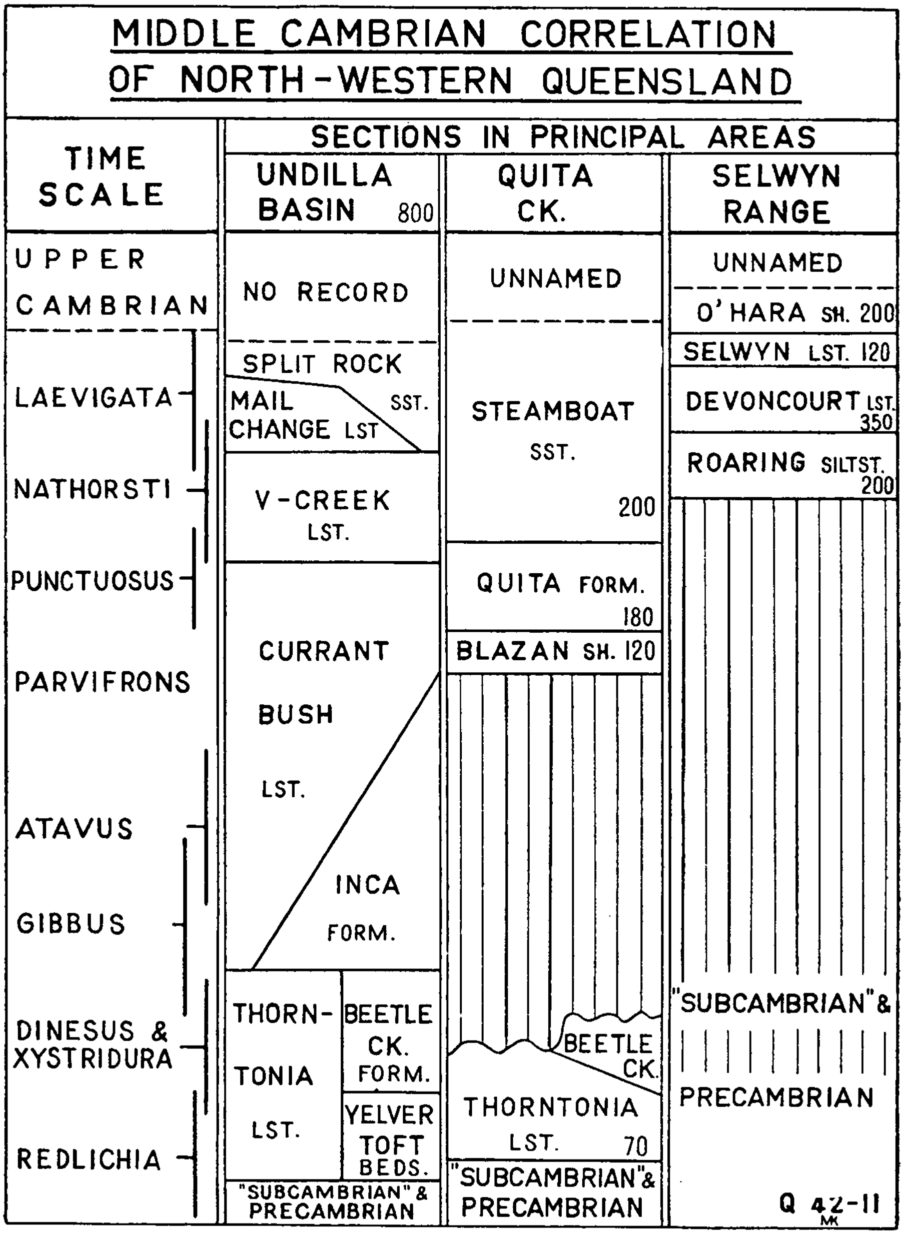

Fig. 3. Stratigraphic chart of the Cambrian sequence in Queensland. In the Selwyn Range column the unnamed rocks refer to sandstone above the O'Hara Shale. The relationship of this sandstone with the Pomegranate limestone (with *Glyptagnostus)* south of Selwyn Range is unknown. The Roaring Siltstone in the same

The Middle Cambrian agnostid fauna of Queensland contains a number of undescribed species, most of which can be accommodated in known genera. The index species of the chart (fig. 3) are groups of similar morphology and time range, and some of them may even be split into several species if necessity arises in future.

The Australian *Ptychagnostus gibbus* differs little from the Scandinavian form. In some specimens the genal spines and the spine on the second segment may be longer, and a form with pygidial spines has been separated by Whitehouse as *Goniagnostus purus*. The Scandinavian and the Australian *Ptychagnostus atavus* are equally variable, but the varieties match in both. The Australian *Ptychagnostus punctuosus* may be intermediate between the Scandinavian subspecies *Pt. punctuosus affinis* (Brögger) and the main form.

Goniagnostus nathorsti (Brögger) is not very common in Australia and some specimens have a slightly wider pygidial axis than the Scandinavian form. Associated with it is *Goniagnostus scarabaeus* Whitehouse, and another, undescribed, form with a swollen axis and a spine on the second segment.

Leiopyge laevigata (Dalman) occurs in Australia as three varieties, comprising *rugifera* Westergaard and cf. *armata* (Linnarsson), as well as the type variety already described from Scandinavia.

Ptychagnostus aculeatus (Angelin), mentioned below in the description of the Selwyn Range, is identical with the Scandinavian form.

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column contains fossils of the Swedish *Solenopleura brachymetopa* Zone and is shown as older than the *Laevigata* Zone, although, as in Sweden, *Leiopyge laevigata* is actually present. In the Quita Creek column the unnamed rocks are completely unexplored, but their age could be Upper Cambrian, including upper levels of the *Laevigata* Zone. In the Undilla Basin, "no record" refers to the actual absence of Upper Cambrian rocks. If they were present, they have been eroded away before the Mesozoic time. The time scale, based on the Acado-Baltic agnostids, reflects the sequence of the species as constructed from observations of about 300 field stations in the Undilla Basin and Quita Creek area. The figures refer to thicknesses in feet. For the Undilla Basin the total thickness of 800 feet refers to the eastern edge of the basin; the structure of the basin and the Middle Cambrian Age Creek Formation are shown in the section, fig. 2. Thicknesses of individual formations of the Undilla Basin are not shown because of their variability, but they can be estimated, because they are shown approximately to scale, the column taken as = 800 feet.

The abundance of agnostids begins everywhere about the time of *Ptychagnostus gibbus;* in Sweden it starts just before, in the upper part of the Stage with *Paradoxides oelandicus.* A similar picture is present in the Beetle Creek Formation and in the upper part of the Thorntonia Limestone of Queensland, where agnostids representing the upper *Oelandicus*-Stage to lower *Gibbus*-Zone occur.

The names of formations in the chart (fig. 3) have been previously suggested by the present writer in unpublished reports and were confirmed as formal by the Stratigraphic Nomenclature Committee of Queensland in June, 1955.

The Middle Cambrian sequence in Queensland is complete only in the Undilla Basin, with breaks in other areas, as seen in the chart (fig. 3); the Undilla Basin will therefore be considered first.

Two contemporaneous formations, replacing each other in space, form the base of the Cambrian sequence of the Undilla Basin: (1) The Thorntonia Limestone in the north, which consists of thick-bedded limestone and dolomitic limestone with chert nodules; and (2) the Beetle Creek Formation in the south, consisting of a basal conglomerate, chert, siliceous shale, and lenses of silicified limestone. In the Beetle Creek area, in depressions of the subsurface of the Cambrian, the basal conglomerate grades into an arkosic sandstone with *Scolithus*-like pipes. The Beetle Creek Formation appears in the southern part of the Undilla Basin and continues in the Mt. Isa area. The lower part of the formation is known as the Yelvertoft Bed (David, 1932), with the type locality at Hall's Memorial.

The lower parts of the Thorntonia and Beetle Creek Formations contain *Redlichia idonea* Whitehouse, which is associated at Hall's Memorial with *R. chinensis* Walcott. In the upper half, several species of *Xystridura* and *Lyriaspis*, *Pagetia* cf. *significans* (Etheridge), and *Peronopsis normata* Whitehouse are common. *Kootenia modica* (Whitehouse) and *Dinesus ida* Etheridge are rare. *Paradoxides peregrinus* Whitehouse and *Oryctocephalus discus* Whitehouse may represent together the tail and the head of a *Lancastria* Kobayashi. *Lancastria*, according to Resser and Howell (1938) is a rare Lower Cambrian Appalachian trilobite, which seems to pass into the Middle Cambrian in Australia. Undescribed are a genuine *Oryctocephalus*, two bathyuriscids *(Fuchouia)*, an *Eodiscus?*, *Elrathina*, and some ptychoparids.

As already observed by Whitehouse (1940; 1941), the ranges of *Xystridura* and *Redlichia* overlap; *Redlichia* and *Pagetia* also overlap, and the continuity of sedimentation thus seems to be proved.

Aspects of the correlation of the *Redlichia* and *Xystridura* faunas of Queensland have already been discussed above. The aspects of the correlation of the *Xystridura*-fauna (and the upper portions of the Thorntonia Limestone and Beetle Creek Formation) may be amplified. The *Xystridura*-fauna contains *Dinesus ida* Etheridge, whereby the *Dinesus*-beds of Victoria can be correlated with the *Xystridura*-fauna of northern Australia. In the Northern Territory, the Sandover beds have the same age and can be correlated with the Spence shale fauna of Utah, U.S.A. The result is a correlation of the upper *Oelandicus*-Stage and the lower part of the *Gibbus*-zone of Sweden, the Spence shale fauna of the United States, and the *Xystridura-Dinesus* fauna of Australia.

In the Undilla Basin, above the Thorntonia and Beetle Creek Formations, two more formations follow: (1) The Currant Bush Limestone in the north, and (2) the Inca Creek Formation in the south. The Currant Bush Limestone consists of thin-bedded limestone with interbedded thin shaly bands; the Inca Formation of siliceous shale and chert beds with extended limestone lenses (members). The two formations are contemporaneous, and the "rising" contact between them "dips" north. The fauna of the Inca Formation consists predominantly of agnostids, which are abundant, whereas the Currant Bush Limestone, which has the same agnostids, also contains numerous polymerid trilobites. The sequence of agnostids is the same in both formations (fig. 3).

The overlap of the ranges of *Ptychagnostus gibbus* and *Pt. atavus* as shown in the chart is also the position of *Agnostus seminula* Whitehouse (and the corresponding Stage) and is observed in the Inca Formation and in the Currant Bush Limestone. The fauna and lithology of the Currant Bush Limestone have never been described; but some of the agnostids of the Inca Formation have been described by Whitehouse (*Agnostus seminula, Goniagnostus purus, Hypagnostus vortex, Ptychagnostus gibbus, Pt. atavus*). For correlation some fossils of the Currant Bush Limestone may be mentioned: *Paterina* cf. *superba* (near the base); *Koptura; Anomocare* cf. *confertum* Whitehouse and *Mapania* (in the upper half); and *Doryagnostus incertus* and *Ptychagnostus punctuosus* (near the top).

The V-Creek Limestone (above the Currant Bush Limestone) is a sequence of laminated impure limestone with calcilutitic interbeds. The fauna is described by Whitehouse as the "*Papyriaspis* Stage." The agnostids are Acado-Baltic. The occurrence of *Koptura* cf. *lisani* (Walcott) and *Leiopyge laevigata rugifera* Westergaard in the upper levels of this formation is important.

Common fossils are *Solenopleura (Asthenopsis) levior, Mapania angusta* (Whitehouse), *Amphoton serotinum, Papyriaspis lanceola, Goniagnostus scarabaeus,* all described by Whitehouse, *G. nathorsti, Ptychagnostus punctuosus* (in lower beds), *Phalacroma,* and many other, undescribed, agnostids.

The Mail Change Limestone (a two-colour calcilutite above the V-Creek Limestone) contains a similar fauna. Baltic agnostids persist and *Crepicephalina* makes its first appearance.

The highest unit of the Undilla Basin is the Split Rock Sandstone (the obsolete *Amphoton* Stage). It has a rising contact against the Mail Change Limestone and the V-Creek Limestone below it, which explains its wide stratigraphical range: *Goniagnostus nathorsti* at the base, and agnostids of the *Leiopyge laevigata* assemblage in higher levels. Other fossils are *Nepea narinosa* Whitehouse, *Crepicephalina, Aojia,* and *Lisania,* all of which range through the sandstone. It seems that the Split Rock Sandstone belongs to the *Leiopyge laevigata* Zone and represents the top of the Middle Cambrian Series.

The total number of fossil species collected in the rocks of the Undilla Basin is estimated to be near 150.

In the Quita area the Middle Cambrian differs in its development from the continuous sequence of the Undilla Basin: the times of *Ptychagnostus gibbus* (upper part) and *Pt. atavus* are represented by a non-depositional and erosional break. The lower units, the Thorntonia Limestone and the Beetle Creek chert and shale, are preserved as erosional residuals only. The Blazan Shale rests partly on the Precambrian basement, and partly on the Thorntonia Limestone where it fills gullies and canyons. The Blazan Shale (siliceous shale with chert, and a conglomerate at its base) contains agnostids only *(Diplagnostus* and "smooth" undescribed agnostids which cannot be identified). Above it follows the Quita Formation, consisting of hard siliceous shale and laminated limestone, and containing *Ptychagnostus punctuosus* over its full range. Above follows the Steamboat Sandstone (calcareous) with *Goniagnostus nathorsti* at its base and *Leiopyge* above; *Dorypyge, Mapania,* and *Nepea* aff. *narinosa,* are abundant and are associated with undescribed trilobites. Upper parts of the Steamboat Sandstone probably grade into the base of the Upper Cambrian, which occurs in the south near Glenormiston.

The sequence in the Selwyn Range area has been referred to by Whitehouse (1936; 1939) as the "*Phoidagnostus* Stage east of Duchess." Rocks of the uppermost Middle Cambrian only are present. The lowermost unit here is the Roaring Bore Siltstone (with siliceous shale and sandstone interbeds), containing, among other fossils, a new species of *Centropleura, Leiopyge laevigata, Ptychagnostus aculeatus* Westergaard, and *Acontheus* cf. *acutangulus* Angelin. According to Westergaard (1946; 1950), such an association is known only in the zone with *Solenopleura brachymetopa* of the Swedish Middle Cambrian, where the ranges of *Goniagnostus nathorsti* and *Leiopyge laevigata* meet or overlap (see chart, fig. 3). Above the Roaring Siltstone follows the Devoncourt Limestone, laminated and slightly bituminous. Some agnostids *(Diplagnostus humilis* (Whitehouse), *Leiopyge exilis* Whitehouse, *Phoidagnostus limbatus* Whitehouse, and *Phalacroma? dubium* Whitehouse) have been described. Originally Whitehouse (1936, p. 75, footnote) interpreted the age correctly as the "*Leiagnostus* Stage," but he later renamed it and placed it lower in the sequence as the "*Phoidagnostus* Stage." The presence of *Lisania* was also mentioned. The new record contains *Centropleura* aff. *loveni* Angelin, *Leiopyge laevigata laevigata, L. laevigata* cf. *armata, Mapania, Amphoton, Agraulos* cf. *difformis* Angelin, *Papyriaspis* aff. *lanceola* Whitehouse, and *Holteria* Walcott; other, undescribed, agnostids are present. *Holteria* is known only from the Secret Canyon shale of the Eureka District, Nevada, U.S.A., which is placed by Howell and others (1944) in the *Deissella/Centropleura vermontensis* Zone at the top of the Middle Cambrian and correlated accurately with the *Leiopyge laevigata* Zone of Sweden.

Above the Devoncourt Limestone rests the calcilutitic Selwyn Range Limestone. It is unfossiliferous and on lithological grounds is considered part of the Middle Cambrian. It is overlain by a shale formation (O'Hara) with an Upper Cambrian fauna.

UPPER CAMBRIAN SEQUENCE

Upper Cambrian rocks occur in three areas in northwestern Queensland: the Glenormiston and Pituri area south of the 22nd parallel; the Selwyn Range area between O'Hara and Chatsworth; and on Wills Creek south of Buckingham Downs.

The sequence in the Glenormiston and Pituri area has been discussed, and some of the fossils described, by Whitehouse (1936; 1939), who records limestone in the lower part of the sequence and sandstone and shale in the upper part. Whitehouse interprets the limestone as the upper part of the "Georgina Limestone Series," and names the sandstone and shale "Pituri Series" (="Pituri Sandstones," David and Browne, 1950).

According to Whitehouse, the limestone consists of three stages (in ascending order): (1) *Eugonocare,* (2) *Glyptagnostus,* and (3) *Rhodonaspis.* It may be understood that the intervening *Glyptagnostus* Zone necessitates the recognition of a zone below and a zone above it. The lower, *Eugonocare,* Stage is correlated by Whitehouse with the *Agnostus pisiformis* Zone of Scandinavia and placed at the base of the Upper Cambrian. It will be shown, however, that the *Eugonocare*-fauna is slightly younger.

The Pituri Sandstones contain only one stage—the *Elrathiella* Stage. The fauna consists of *Elrathiella plebeia, Pseudagnostus nuperus,* "*Aspidagnostus*" *parmatus, Idamea superstes, Protemnites elegans* (all described by Whitehouse, 1936; 1939) and *Olenus* sp. Whitehouse tentatively correlates this fauna with the Scandinavian *Orusia*-Zone. *Idamea* is a genus related to the Middle Cambrian genera *Lisania* and *Aojia;* the cephalon of "*Aspidagnostus*" is a *Clavagnostus* Howell, a genus of the upper Middle Cambrian and lowermost Upper Cambrian, and its pygidium belongs to a species of *Pseudagnostus.* As the structure of the Glenormiston area is unknown, additional evidence is necessary for placing the *Elrathiella* Stage above, and not below, the *Glyptagnostus* limestones.

However, it is Upper Cambrian, and the fauna of all three stages is so similar that it is a minor problem if viewed regionally.

It may be concluded that at Glenormiston at least two Upper Cambrian formations are present: the Pituri sandstone and shale, and a limestone, possibly the "Georgina Limestone" proper. Nothing is known about the rocks below the Upper Cambrian at Glenormiston. According to Whitehouse (1936, p. 66), Tyson's Bore on Glenormiston penetrated 1810 feet of limestone. This thickness may include Middle Cambrian sediments and the Camooweal Dolomite.

The new record of Upper Cambrian rocks from the Selwyn Range and Chatsworth area is contained in the O'Hara Shale. It consists of shale with interbeds of chert and sandstone and is lithologically similar to the Pituri sandstone and shale of the Glenormiston area. The O'Hara Shale rests on the Selwyn Range Limestone, which is believed to be Middle Cambrian, and the formations are separated by a diastem. About ten feet above the base of the shale, a chert layer contains an undescribed fauna which is essentially Upper Cambrian with some upper Middle Cambrian forms. The Middle Cambrian forms are *Blackwelderia?*, *Nepea* (or a subgenus), *Clavagnostus*, and *Holteria?*; the Upper Cambrian aspect rests on the presence of Norwoodiidae (*Holcacephalus?* and another genus), Cedariidae, Dikelocephalidae (probably a *Prosaukia*), *Coosia*, *Coosella*, *Deckera?*, *Pseudagnostus*, *Litagnostus*, and several other forms that are either new or not yet identified. It is a *Cedaria*-fauna resting on the rocks of the *Leiopyge laevigata* Zone. Therefore, the much-disputed question of the boundary of the Middle Cambrian and the Upper Cambrian is settled: the Middle Cambrian *Laevigata*-Zone is followed immediately by the basal *Cedaria*-Zone of the Upper Cambrian, which, in turn, corresponds to the Zone with *Agnostus pisiformis*.

About 60 feet above the *Cedaria*-fauna a thin sandstone bed of the O'Hara sequence contains *Eugonocare*, *Proceratopyge*, *Olenus*, *Pseudagnostus*, *Litagnostus*, *Clavagnostus*, and, a little higher, *Idamea* associated with some unidentified, or new, forms. This fauna may correspond to any of the stages of the Glenormiston area, but a correlation with a particular "stage" is doubtful.

The sequence south of O'Hara is not known except for a red sandstone with *Eugonocare*, *Proceratopyge*, and *Pseudagnostus*, which may, or may not, rest on the O'Hara Shale. The beds seem to have a southerly dip.

More Upper Cambrian rocks occur at Chatsworth and, in view of the general attitude mentioned above, are believed to lie above the O'Hara Shale, but the country between O'Hara and the boundary of

Chatsworth Station is unexplored and the contacts are not yet observed. Two localities on Chatsworth are fossiliferous: (1) heads of Pomegranate Creek north of the homestead, and (2) an unnamed outcrop 3 miles north of the homestead.

At Pomegranate Creek low outcrops of an ellipsoidal grey limestone contain abundant *Glyptagnostus reticulatus* (Angelin), complete specimens of *Olenus* aff. *transversus* Linnarsson, and *Homagnostus*. This fauna corresponds to the *Glyptagnostus*-Stage at Glenormiston, or to the *Olenus truncatus* and *O. gibbosus* Zones of Sweden *(vide* Westergaard, 1947), and is lower Upper Cambrian. The Pomegranate limestone contains a sandy, bituminous, slumped limestone band, from which *Glyptagnostus* is missing, but which contains *Eugonocare, Proceratopyge, Pseudagnostus, Litagnostus,* and fragments of *Olenus* in great numbers.

The southern outcrop of Chatsworth (the unnamed limestone) contains *Agnostus (Geragnostus)* and, probably, *Bellefontia* and is therefore of uppermost Upper Cambrian, or even Tremadocian, age.

The erosional inlier of Upper Cambrian on Wills Creek south of Buckingham Downs can be interpreted lithologically as the Pomegranate limestone; *Glyptagnostus reticulatus, Clavagnostus, Homagnostus, Eugonocare,* and an *Elvinia*?-like trilobite are present.

The upper limit of the Cambrian sequence in Queensland is not yet clear. The appearance of Lower Ordovician is already indicated at Chatsworth, and Whitehouse reports a Lower Ordovician nautiloid fauna from the Warenda area in the south. At the Pituri River, the Toko Range is Ordovician, but its contact against the Cambrian is a fault.

To conclude, in northwestern Queensland the lower half of the Upper Cambrian is represented, the top of the Series seems to be present also, and some rocks of the Chatsworth area may represent the rest of the Upper Cambrian sequence to be explored in the future.

PALAEOGEOGRAPHY

The palaeogeography of the Cambrian time in Queensland is discussed in the article on "Cambrian Palaeogeography of Australia" (Öpik, this Symposium), where the evidence presented here is exploited. The provincial relationship of the Queensland Cambrian deserves some comment.

The lower horizons *(Redlichia-Xystridura)* contain an Oriental-Pacific and an endemic fauna, where *Redlichia* is the "Oriental" and *Xystridura* the endemic representative. Together with *Xystridura*, however, American Pacific forms are intermingled *(Oryctocephalus; Lyriaspis = Clappaspis* Deiss), as well as some Acado-Baltic (Atlantic) elements *(Peronopsis* followed by the Baltic agnostids). Similar faunas are present in the Northern Territory, but the specific composition of these is completely different, and Pacific American forms are very prominent. This necessitates the assumption that the Cambrian seas of northwestern Queensland and the Northern Territory were not in direct communication.

The later faunas of the Queensland Cambrian contain representatives of all the above-mentioned provinces with the Atlantic province dominant. Almost purely Atlantic is the Middle Cambrian in the Selwyn Range with its *Centropleura* and agnostids, followed by the emphatically Appalachian *Cedaria*-fauna above it.

It now seems that, contrary to accepted opinion, the boundaries between the provinces were not completely closed in Cambrian time. In the Northern Hemisphere the provinces were separated, but to the south they were open for communication; this explains the intermingling and alternation of provincial faunas in one and the same section in Queensland. The zone-making blind agnostids are practically universal.

REFERENCES

(See the article "Cambrian palaeogeography of Australia," by A. A. Öpik, this Symposium).

CAMBRIAN GEOLOGY OF THE NORTHERN TERRITORY

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ABSTRACT

The exploration history, the regional and stratigraphic subdivision, correlation, and palaeogeographical aspects of the Cambrian deposits of Northern Territory, with some notes on the Cambrian of Western Australia, are presented. The Upper part of the fossiliferous Precambrian Victoria River Group may be "Eocambrian" in age. Conventional Lower Cambrian fossils are known only in the MacDonnell Ranges. This Lower Cambrian is separated by a break from the following lower Middle Cambrian with *Redlichia*. Above the *Redlichia*-faunas follow beds which are correlated by fossils with the American Spence shale and *Ptarmigania* faunas, and the upper *Oelandicus* stage and a lower part of the *Ptychagnostus gibbus* Zone of Scandinavia. Higher levels of the Middle Cambrian are represented only incompletely owing to regression. The Upper Cambrian (in central Australia) is represented by sandstones with abundant dikelocephalids similar to the Upper Cambrian of the Cambridge Gulf area of Western Australia. A connexion between the Northern Territory and northwestern Queensland is not evident in the Lower, and early Middle Cambrian, but is accepted for late Middle Cambrian and Upper Cambrian. Structurally, an epicontinental region (in the north) is separated by a Cambrian shelf belt from the basins of the MacDonnell Ranges in the south. The MacDonnell Ranges have the Cambrian sequence nearly complete, if compared with the shelf, where considerable breaks are present, and with the epicontinental region, where the sedimentation ended early (time of *Ptychagnostus gibbus*). The Cambridge Gulf sequence in Western Australia is complete. No igneous activity is observed after the Lower Cambrian, which is documented by basalts in the north. Orogenies are absent.

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HISTORY OF EXPLORATION

The existing record of Cambrian fossils and proven Cambrian rocks from the Northern Territory is very small and in no proportion to the size of the region and the variety of sediments that have been assigned by extrapolation to the Cambrian System. The first record of Cambrian fossils was made by Foord in 1890, when *Redlichia forresti* (Eth.) and *Biconulites hardmani* (Eth.) were described. *Girvanella* was added later by Etheridge (1917). The fossils were found not in the Northern Territory but in the Ord River area of Western Australia, but the rocks extend into the Northern Territory at Mt. Panton. The Mt. Panton area is discussed by D. M. Traves ("Upper Proterozoic and Cambrian geology in northwestern Australia," this Symposium), and will not be treated in the present paper.

The next record of Cambrian fossils was made by Brown (1895), and described by Etheridge (1897). This is the occurrence, in the old well at Alexandria, of *Xystridura browni* (Eth.), originally believed to be an *Olenellus*. The occurrence is referred to below as the "Alexandria beds," under the heading "Barkly Tableland." Additions to this fauna were subsequently published by Etheridge (1919) and Whitehouse (1939) and comprise *Lyriaspis alroyensis* (Eth.) *Eurostina trigona* Whitehouse, *Kootenia?*, and *Anomocarella?*.

In 1898, the explorer Davidson collected from southeast of Elkedra Station two specimens of a siliceous siltstone, from which Etheridge (1902) described *Pagetia significans* (Eth.) and *Peronopsis elkedraensis* (Eth.); these were redescribed by Whitehouse (1936). This locality is on the northern edge of the area of occurrence of the "Sandover beds" of this paper.

Finally, Etheridge (1905) described an occurrence of *Biconulites hardmani* from the area of the Daly River. All the above-mentioned localities are hundreds of miles apart and the fossils named cover only a fraction of the faunas. The localities belong to the Epicontinental region of the Cambrian deposits of the Northern Territory.

In the region of the MacDonnell Ranges the published record of Cambrian fossils is even smaller. The presence of Cambrian deposits was at first inferred for sediments below the fossiliferous Ordovician (Larapintine), and later demonstrated by Madigan (1932b), who discovered archaeocyathids east of Alice Springs at Love's Creek, interpreted as Lower Cambrian. In the Eastern MacDonnell Ranges he discovered a limestone with trilobite fragments and, perhaps, *Biconulites*, evidently of Middle Cambrian age.

New observations have become available since 1948. A number of new localities of fossiliferous Cambrian rocks of the Barkly Tableland were discovered by L. C. Noakes and D. M. Traves, geologists of the Bureau of Mineral Resources, during a regional survey arranged by C.S.I.R.O.; the geological results are not yet published, but the maps (C.S.I.R.O., 1952) already contain data on morphology from which the Cambrian areas and the covering rocks can be deduced. A. D. M. Bell and later N. O. Jones and D. E. Catley, Resident Geologists of the same Bureau in Alice Springs, have collected valuable information in Cambrian deposits of the region of MacDonnell Ranges. J. N. Casey (Bureau of Mineral Resources) with a survey party of C.S.I.R.O. recently investigated the Palaeozoic geology, including Cambrian, east of the MacDonnell Ranges ("Cambrian geology of the Huckitta-Marqua area, N.T.," this Symposium). The present writer has seen most of the occurrences in the field and all the fossils collected. Thus, this summary is based essentially on unpublished material, and some of its conclusions and interpretations may have to be modified after the detailed reports appear in print.

Three different maps of the Northern Territory are in current use: (1) the map by David (1931), (2) the Geological Map of Australia and New Guinea, (1953), and (3) the map by Hossfeld (1954).

The first map represents the state of knowledge before 1948, and some older rocks are included in the Cambrian. The second map incorporates a great deal of new information concerning the distribution of Cambrian deposits in the Northern Territory, and the Cambrian in this map is almost completely restricted to the accepted concept of the System. In Hossfeld's map the Cambrian is enlarged on account of rocks which may include Cambrian, but which may be regarded as mostly late Proterozoic in age.

The map in this paper (fig. 2) is a modification of the map of 1953; it shows the location of most recent discoveries and, separated from the Cambrian sequence, the Camooweal Dolomite (Öpik, "Cambrian geology of Queensland," this Symposium).

A. A. ÖPIK

STRATIGRAPHICAL RANGE OF CAMBRIAN ROCKS AND BASE OF CAMBRIAN IN NORTHERN TERRITORY

According to David and Browne (1950) and, for example, Browne (1953), an Upper Cambrian (Tyennan) orogeny is postulated for central Australia, "accompanied... by injection of granitic magma." Geologists recently engaged in the study of Northern Territory, including the present writer, affirm the contrary: no Cambrian orogeny is evident, and granitic activity ended before Cambrian time. Hossfeld (1954) also demonstrates the absence of intrusions in the Upper Proterozoic rocks of the Territory. Epeirogenetic movements, however, were widespread and common, and it is possible that between the MacDonnell Ranges and the Queensland border some faulting may have occurred after the Middle Cambrian *Atavus*-time and before the Upper Cambrian ingression. All the observed structures affecting Cambrian rocks in central Australia can be explained by a diastrophism after the Middle Ordovician, with plication, faulting, and thrusting, all of which occurred without igneous activity. Breaks within the Cambro-Ordovician sequence are, of course, present; even unconformities may be present, but the movements must have been of lesser magnitude than the post-Ordovician ones.

Lower, Middle, and Upper Cambrian rocks are present in the Northern Territory. A complete Cambrian sequence in any one section has not yet been seen, but it is possibly present in the MacDonnell Ranges, east of Alice Springs, at the heads of the Hale and Ross Rivers. Upper Cambrian is widespread in central Australia but is not yet known completely.

In the past, all Palaeozoic rocks of the Northern Territory above the Precambrian basement were regarded as "Cambrian" or "Lower Cambrian" in age, and distinguished by the absence of metamorphism and intrusions. Obviously, such a wide interpretation is not in conformity with the current concept of the Cambrian System. This wider concept of "Cambrian" implies a division of a diastrophistic time-scale, in which, seemingly by a tacit agreement among geologists, all unaltered sediments above the Precambrian basement were regarded as Palaeozoic and, therefore, Cambrian; and when the Middle Cambrian became apparent in the Territory, "Lower Cambrian" was introduced. In northwestern Queensland, however, where the basement was believed to be of "Silurian" age, the unaltered sediments were tentatively regarded as "Devonian" or younger.

A greater part of these "Lower Cambrian" sediments of the Northern Territory and Western Australia was subsequently recognized as Late Precambrian (Nullagine, "Pertatataka," Victoria River Group), but without a clearly defined boundary against the Cambrian. The *Redlichia*-bearing sequence was regarded as being upper Lower Cambrian in age, and was accepted as the beginning of the fossil record in northern Australia. According to the present author the *Redlichia* faunas of northern Australia are of lower Middle Cambrian age. A hiatus at the base of the *Redlichia* beds is obvious. Therefore "Upper Precambrian" as used for northern Australia means in effect "older than Middle Cambrian, and probably older than Cambrian."

The range of the hiatus is unknown. If it represents only a fraction of the conventional Lower Cambrian time, a part of the Nullagine and of the Victoria River sequence may be regarded as an undefined portion of the Lower Cambrian Series. Some of those doubtfully "Lower Cambrian" deposits are fossiliferous: Sprigg (1949) has described a jellyfish, *Protoniobia wadea*, from Mt. John in the Osmond Range, and the present writer and D. M. Traves have observed in the lower reaches of the Ord River in a shale of the Mt. House Beds forms similar to the South Australian *Pseudorhizostomites* Sprigg, associated with small stromatolites. The South Australian "jellyfishes" of the Pound Sandstone are regarded by Sprigg as early Cambrian, and a correlation with the occurrences on the other edge of the continent is tempting. The correct age, however, seems to be "Eocambrian."

Another fossil (fig. 1) was found by D. M. Traves in the rocks of the Victoria River Group, in the Willeroo area in the northwestern part of the Northern Territory. The rock is sandstone. The fossil is a lenticular object, 1½ inch across and ¾ of an inch thick. It can be described as two whorls locked together by the button-like apices, and with spiral channels on the surface and a spiral arrangement of the sandgrains. The opposite side of the fossil is not well preserved, but a similar spiral arrangement and even an elevated "button" are present. An interpretation of the fossil must be reserved. It has, however, some stratigraphical significance. Similar "double spirals" frequently occur in the Lower Cambrian rocks of Estonia associated with *Volborthella tenuis*, *Mickwitzia*, and the trilobite *Holmia*.

The occurrence of this fossil in Australia in rocks believed to be late Precambrian may be interpreted variously. It may indicate that in the late Precambrian and in the Lower Cambrian common organisms existed. On the other hand it may indicate that the Lower Cambrian *Olenellus* fauna had not reached northern Australia, except for the "double spiral" fossil, which may suggest a possible Lower Cambrian (Olenellan) age for the "Precambrian" Victoria River Group and its correlates like the Mt. House beds. All are younger than the late Precambrian tillites, and are, therefore, stratigraphically very near the Lower Cambrian as documented by conventional fossils.

However, the real range of the problematical "double spiral" fossils is unknown: they may have occurred in the Late Precambrian and in the Lower Cambrian as well, and a definite correlation would be premature. Therefore, for the present purpose, the term "Lower Cambrian" is applied only to rocks and fossils which satisfy the conventional, current, concept of the Lower Cambrian Series.

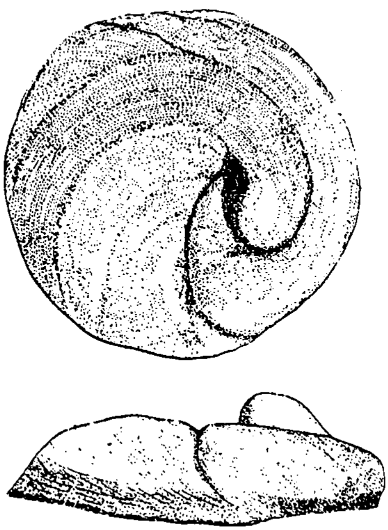

Fig. 1. A problematical fossil from the late Precambrian Victoria River Group, found at Willeroo, in northwestern Northern Territory. Natural size. No. R6054 (Bureau of Mineral Resources, Canberra). It is compared with similar fossils, which occur in the Lükati beds of the Lower Cambrian sequence of Estonia. A similar fossil is illustrated by Fenton and Fenton (1937, p. 1951, Fig. 20A) from the Beltian Sheppard formation of Montana. It coincides with the reverse side of the Australian specimen.

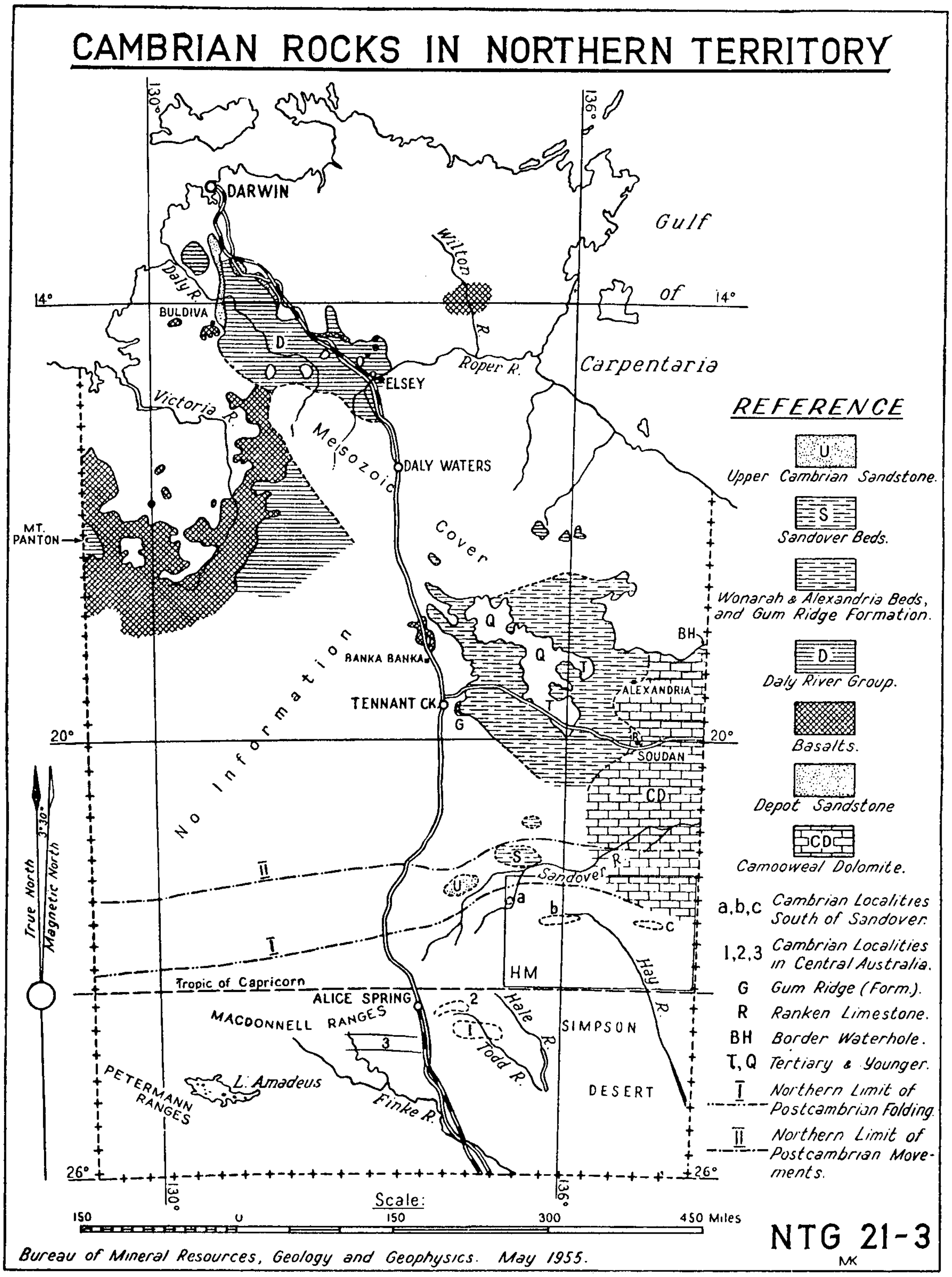

Fig. 2. Distribution of Cambrian rocks in Northern Territory, modified from the Geological map of Australia and New Guinea (1953). At Mt. Panton (north-western boundary) rocks of the Negri Group, with *Redlichia* and *Xystridura*, are present. The basalt (sills) on the Wilton River is marked diagrammatically. The Barkly Tableland is not marked; it extends from Tennant Creek and Banka Banka to the eastern border of the Territory; Soudan and Ranken limestone (R) at Soudan are near the centre of the Barkly Tableland. North of the line II extends the Epicontinental region of the Cambrian rocks of the Northern Territory; between the lines I and II is the Shelf region. South of the line I lies the region of the intracontinental basins folded after the Ordovician. The occurrences a, b, c, south of the Sandover in the HM rectangle north of the Simpson Desert are described in the article on the Cambrian rocks of the Huckitta-Marqua area (this Symposium). A section across the Barkly Tableland is given in figure 2, "Cambrian Geology of Queensland." The distribution of the basalts as shown on this map is diagrammatic; accurate is the map of D.M. Traves (Upper Proterozoic and Cambrian Geology in North-Western Australia, this Symposium).

There is no p.32

The Camooweal Dolomite is shown on the map (fig. 2) and in the section (fig. 2 in "Cambrian Geology of Queensland," this symposium) as a formation older than the Cambrian rocks of the region. This position of the Camooweal Dolomite is best understood in the Ranken River area, where bores record 750 feet of dolomite. On top of it rests a lower Middle Cambrian formation (the Ranken River limestone), indicating that the dolomite is older than the Cambrian of the region. Similar evidence for the age of the dolomite is given in the article, "Cambrian Geology of Queensland" (this Symposium).

The southwestern boundary of the Camooweal Dolomite (map, fig. 2) is not yet evident. The western limit of the Dolomite shown on the map as crossing the Sandover River, refers to the area of Landerra Landerra Waterhole, where erosional residuals of an Ordovician sandstone with rare pelecypods rest on dolomite and dolomitic limestone which may or may not be the Camooweal Dolomite. A confusion with a dolomitic formation of another age is possible, because, for example, Ordovician dolomites are known to occur in the region. In Queensland an Ordovician dolomite with chert occurs at Digby Peaks and field observations indicate Ordovician dolomite south and southwest of the Sandover River. Of course, lithological similarity alone is no evidence that the Camooweal Dolomite itself is of Ordovician age unless the Ranken limestone, seen as a veneer on the Dolomite, is interpreted as an erosional residual protruding through the surface of the Dolomite, and unless the contacts of the Cambrian and the Camooweal Dolomite in Queensland are interpreted in reverse. Such interpretations, though not altogether illogical, are not supported by the present field evidence. Similarly, the Camooweal Dolomite cannot be interpreted as a Middle Cambrian formation of a geographically stationary "dolomite environment" which excluded normal marine deposition.

GEOGRAPHICAL AND STRUCTURAL SUBDIVISIONS OF CAMBRIAN OF NORTHERN TERRITORY

The land boundaries of the Northern Territory are rectangular; it is not a natural geological unit, and some of the Cambrian deposits of the Territory are, therefore, discussed in "Cambrian geology of Queensland" (this Symposium), and in the paper of D. M. Traves (Western Australia, Kimberleys). Moreover, the nomenclature of the Cambrian stratigraphical divisions is the same as that applied in "Cambrian Geology of Queensland." On the other hand, the Upper Cambrian of the Northern Territory must be compared with the development at the Cambridge Gulf, in Western Australia, and for this reason some notes on the latter are included in the present paper.

Three regions of Cambrian development are seen in the Territory. The first is the Epicontinental northern region, comprising the Daly River area and the Barkly Tableland, the southern limit of which is line "II" on the map (fig. 2). The Cambrian here is nearly horizontal and tectonically little disturbed; and the known thicknesses are of the order of 500 feet. The Cambrian deposits of this region are *extensive:* a large volume of sediment was deposited as a thin blanket over a wide area. The marine history ended, as far as is known, before the Ordovician, and mostly before the end of the Middle Cambrian. A large part of this region is marked on the map by "no information." It is desert and semidesert, the rocks are concealed under sand, and the sediments are unexplored. Hossfeld (1954) calls it the "Wiso Tableland," or "Wiso Basin," or "Wiso Area," and believes that Cambrian sediments are present at shallow depths. The Precambrian rocks in the northeast (region of Arnhem Land and the Gulf of Carpentaria) and the northwest are the other limits of the epicontinental Cambrian. The northeastern limit may correspond to the shoreline of the Cambrian. In the northwest, however, the Cambrian deposits extend into Western Australia (Ord River and Cambridge Gulf region). Volcanic activity of an early Cambrian age was intense in the northern part of the region.

The second region is south of the line "I" on the map. It is often referred to as the MacDonnell Ranges (in a broad sense). Sedimentation was here *intensive:* a large volume of sediment was deposited as a thick pile within the restricted area of a trough or in an intracontinental string of basins sometimes called the "Amadeus geosyncline." Thicknesses of formations are measured here in thousands of feet; all three Series of the Cambrian are represented, followed by the Ordovician, and the current belief is that sedimentation of Late Precambrian and Cambrian was continuous. The region was folded and strongly faulted after the Middle Ordovician, but it is barren of any Palaeozoic or younger igneous rocks. The regional trend is latitudinal. The youngest igneous rocks are represented by insignificant dolerite dykes in the Precambrian basement (as, for example, at Undoolya, east of Alice Springs); but these dykes are cut off by the overlying unaltered Late Proterozoic rocks.

The main regions mentioned above are not in immediate contact; between them extends the third region as a transitional belt (between lines "I" and "II" on the map). The rocks here are not horizontal; the attitude is shallow, the trends are variable, and a south-southeasterly direction seems to prevail. Faulting is present but is not strong. Middle and Upper Cambrian are both present, but the thicknesses are small compared with those of the MacDonnell Ranges. Ordovician, mostly as sandstone, occurs as erosional residuals in the east (on the Sandover River). The Cambrian sequence in this region is interrupted by breaks that are also present in the eastern extension of the MacDonnell Ranges.

This intermediate belt represents the "shelf" in relation to the basin in the south and was the foreland limiting the post-Ordovician folding and thrusting. The main thrusting and folding, however, abut on the southern edge of the Arunta Block on the latitude of Alice Springs. No thinning of Cambrian and Ordovician sediments has been recorded along the present border of the Arunta Block, and no rudites which may indicate a shoreline have been observed. However, an Ordovician or Silurian uplift of the Block is evident from the "Pertnjara" Conglomerate (Madigan, 1932a). Consequently, the Arunta Block was submerged during the Proterozoic and Cambro-Ordovician sedimentation and did not form a barrier or island in the marine palaeogeography of the region.

"Shelf," of course, is used here in a structural, tectonic sense, and not to indicate depth of water. "Dep"-water conditions are recognised nowhere in the Cambrian deposits of the Northern Territory, even in the intracontinental basins, where intensive sedimentation countered the subsidence. The present writer assumes that in the MacDonnell Ranges Cambrian deposition was going on in lower middle Cambrian time, when the Sandover beds were deposited in the shelf. The evidence, however, is geological only, because corresponding fossils are as yet unknown in Western MacDonnell Ranges. Thus the term "shelf," as applied here, is correct for the Upper Cambrian but is conjectural for Lower Middle Cambrian time.

Line "II" (northern limit of the lower Palaeozoic shelf) is approximately the northern boundary of central Australia in a geological sense.

The post-Cambrian history of the lower Palaeozoic rocks of central Australia has, naturally, no bearing on the Cambrian history, but is essential in understanding of Cambrian palaeogeography. It is traditional to connect the trends of the MacDonnell Ranges with the trends of the South Australian ranges by means of a postulated bend between them, concealed under Mesozoic sediments and desert sands, and to regard both structures as being two segments of a single arc (orogen) and a single geosyncline, which also implies a single orogenic event. However, tectonic trends, postulated or otherwise, are no evidence of marine palaeogeography. Thus, a marine connexion between central Australia and the Adelaidean geosyncline evidently existed in late Proterozoic, Lower Cambrian, and early in Middle Cambrian time but it is not evidence supporting the postulated continuity of the trends of a post-Cambrian age.

After the early Middle Cambrian no marine connexion between South Australia and central Australia was present; the central Australian intracontinental sea extended longitudinally to the east, and the Ordovician trends of the MacDonnell Ranges can be traced in the same direction towards the Queensland border. It seems that central Australia and the South Australian region had different histories from early Middle Cambrian time onward and may have been folded at different times, one after another. It seems that the Adelaidean chains were folded and consolidated first. This is in accordance with Browne (1950), who dates the folding in South Australia as Tyennan (Middle/Upper Cambrian) and in the MacDonnell Ranges as Bowningian (Upper Silurian). In the article "Cambrian Palaeogeography of Australia," the beginning of the South Australian orogeny is dated as of the age of the Zone with *Ptychagnostus gibbus*, which is much older than the "Tyennan" event.

THE EPICONTINENTAL REGION

GENERAL SUBDIVISIONS

In the Cambrian Epicontinental region the following areas are known: (1) the "Border Waterhole" in the northeast, (2) the Daly River/Mt. Panton/Victoria River area in the northwest, and (3) the Barkly Tableland in the east.

The Border Waterhole area and its extension in the Northern Territory are discussed in the paper "Cambrian Geology of Queensland" (this Symposium). In the Northern Territory, west-northwest from the Border Waterhole extends the Oggajumna Range which is discussed by Whitehouse (1936, pp. 63, 65). He considers that the transgressive "Georgina Limestones" rest here upon the Precambrian complex, and the Templeton series (*Redlichia* and *Dinesus-Xystridura* beds), believed to be below the "Georgina Limestones," is missing at the Oggajumna Range. In reality, the Camooweal Dolomite abuts here against the elevated ridges of its basement, and the Cambrian above the Dolomite is absent, perhaps by non-deposition. The basement consists here of an arenitic sequence (Constance beds) of late Proterozoic age. It is moderately folded and un-metamorphosed.

DALY RIVER AREA

Cambrian sediments and volcanic rocks have been mapped in the Daly River Area (proper) by Noakes (1949), who refers the Cambrian deposits to the Daly River Group, which is a substitute for "Daly River Limestones" (Voisey, 1939a). The rocks of the group are sandstone, limestone, and shale. The basal bed is a *Girvanella* limestone. It seems that on the Daly River itself and to the west, *Girvanella*, which is low in the Middle Cambrian sequence, is the only fossil. Along the northeastern limit of the Daly River Group several fossil localities are known; Etheridge (1905) mentions *Biconulites hardmani* and fragments of *Redlichia*. Other fossils from the Daly River sequence are: *Lingulella (Westonia)*, *Obolus*, *Paterina*, *Acrotreta*, *Chancelloria*, *Helcionella*, and *Hyolithes*.

In the southeastern corner of the area, A. D. M. Bell (unpublished) collected at Elsey Station on the Roper River small ptychoparids which may indicate rocks younger than the *Redlichia*-fauna, and similar rocks have been collected by J. H. Rattigan (unpublished). North of Elsey, and of the Roper River, at Beswick Station (not shown on the map), coarse conglomerate, sandstone, volcanics, and glauconitic limestone have been observed by B. P. Walpole (unpublished); the present writer has seen them and believes them to be near the base of the Cambrian sequence. Halite pseudomorphs have been observed in dolomite (interbedded with shale) 5 miles west of Katherine. The lower unit of the Daly River Group is a marine fossiliferous limestone. Conformably above it rests a formation of varicoloured siltstone, sandstone, marl, and dolomite with salt pseudomorphs, as seen in the northern portion of the area.

The thickness of the rocks of the Daly River Group is generally small (some hundreds of feet), but in the southeast it is considerably greater, and a basin may exist under the Mesozoic cover. It is also probable that within the area shown on the map as Daly River Group unaltered rocks older than Cambrian are included.

In the same area, Noakes (1949) described another unit, the Elliott Creek Formation, from near the mouth of the Daly River. It is shown as an isolated occurrence, but not otherwise marked, on the map (fig. 2). According to Noakes, it is unfossiliferous, resembles both Permian and Cambrian rocks of the area, and is considered to be Palaeozoic. Here it is included in the Daly River Group, as an erosional residual of the latter, following a recent map by B. P. Walpole (unpublished).

In 1955 M. A. Randal (unpublished) discovered phtychoparid trilobites and *Paterina*-like brachiopods in the Elliott Creek formation. Below and conformable with the phtychoparid horizon, *Redlichia* occurs in limestone interbeds. The upper beds of the Elliott Creek formation are saline, rich in halite pseudomorphs.

Along the northern end of the area of the Daly River Group an arenitic formation which underlies the Cambrian sequence crops out. This is the "Buldiva Quartzite" (Noakes, 1949) and is, according to him, late Precambrian in age. The Daly River Cambrian rocks overlap the "Buldiva" formation, indicating the presence of a non-conformity or a mild unconformity. According to Hossfeld (1954), the name "Buldiva" Series designates originally a time-rock unit (Buldivan) consisting at the type locality of the "Buldiva" sandstone (below) and the Daly River Group (Upper Buldivan) above. The series, according to Hossfeld, covers late (latest) Precambrian and lowermost Cambrian rocks of the whole of the epicontinental region of the Northern Territory; it is not assigned to a particular system, and seems to be a unit of a diastrophistic geological scale. Subsequently, "Buldiva" being preoccupied as described above, the name "Depot Sandstone" was introduced for it by B. P. Walpole (unpublished) as an informal name. The Depot

Sandstone is dominantly arenitic, but contains some shale and conglomerate also. The now formal usage is given under Tolmer Group, by L. C. Noakes, this Symposium.

The upper portion of the Depot Sandstone has been recently recognized to represent a formation on its own consisting of micaceous fissile sandstone and shaly and silty material. In its upper levels jellyfish (cf. *Beltanella* Sprigg) occur. Above it follow erosional residuals of a flaggy red dolomite with large algal reefs. The Daly River limestone above it is lower Middle Cambrian in age and the break in between represents the conventional Lower Cambrian (Georgian). The present writer assumes that erosional residuals of Georgian deposits may be also present.

It seems that some of the volcanic rocks of the area are younger than the late Proterozoic, as for example the Collia Series of Hossfeld (Collia Volcanics of Noakes), or even younger than the Cambrian Daly River sequence.

On the Wilton River, outside the known Cambrian areas, several diabase sills are intruded into a sequence of sandstone, silicified oolitic limestone, dolomite, and flaggy shale. In the dolomite, *Collenia* occurs abundantly. The present writer has examined the occurrence together with B. P. Walpole, and considers that the sediments represent two sequences separated by a mild unconformity; the upper sequence contains *Collenia* pebbles at its base, derived from the lower sequence. Therefore the lower sequence is regarded as late Proterozoic, whereas for the upper sequence the possibility of a Lower Cambrian age may be considered. The diabase is younger than either sequence, and the present writer correlates the time of intrusion of the basic sills of the Wilton River with the Antrim volcanic activity (plateau basalts) of the Kimberleys, of Lower Cambrian age. This basalt is younger than the upper Victoria River Group (with *Protoniobia* and the "double spiral" problematicum) and could therefore be within the range of the Olenellan Lower Cambrian.

THE BARKLY TABLELAND

The Cambrian rocks of the Barkly Tableland are to a great extent concealed beneath soil and Quaternary and Tertiary deposits. Known or examined localities are few and are separated by great distances. The

Cambrian rocks are siliceous shale, siltstone, fine-grained sandstone, chert, and limestone. In the east the Cambrian rocks overlap the Camooweal Dolomite, and in the northeast and west they rest on the Precambrian basement; the base is not seen in the north. A connexion with the Daly River Group is possible under the cover of Mesozoic rocks. The extent of the Cambrian deposits of the Barkly Tableland to the south has not been studied, but the assumption of a former connection with the occurrence on the Sandover River seems reasonable.

The northern outcrops of Cambrian rocks on the Barkly Tableland, at Alexandria and to the west at Alroy Downs, are referred to in this paper as "Alexandria beds," and may constitute a separate formation; the occurrences along the Barkly Highway are designated here tentatively as "Wonarah beds," which may, or may not, be a synonym of "Alexandria beds." The most westerly occurrence, at Tennant Creek, is described by Öpik *(vide* Ivanac, 1954) as the "Gum Ridge Formation"; the eastern occurrence is tentatively named "Ranken River limestone."

The main outcrop of the Alexandria beds is the old well on Alexandria Station 7 miles N.W. of the Homestead, with a section of 120 feet of Cambrian sediments resting on a late Precambrian sandstone. In this section no calcareous rocks are present. The rocks are soft friable mudstone and slightly bituminous hard siliceous shale. The only fossil described from here is *Xystridura browni* (Etheridge). This trilobite was originally described as an *Olenellus* because of the absence of cephalic sutures. For this and other reasons the writer considers it not congeneric with *Xystridura* Whitehouse, which has the sutures developed. *Xystridura templetonensis* (Chapman) is the type, with the synonym *saint-smithi* (Chapman). The fauna is rich: besides "*Xystridura*" *browni*, two other species of *Xystridura* are present, as well as *Lyriaspis alroyensis* (Eth.), *Eurostina trigona* Whitehouse, *Pagetia significans* (Eth.), *Pagetia* aff. *significans*, *Oryctocephalus*, *Peronopsis elkedraensis* (Eth.), *Peronopsis* sp., *Beyrichona*, *Stenotheca*, *Obolus*, *Acrotreta*, *Lingulella*, *Acrothele*, and *Biconulites*, to name only the forms so far identified.

At Alexandria Homestead (at the Playford River), a limestone is interbedded, and contains *Hyolithes* and *Eurostina*. East of Alexandria, a silicified shoreline coquina consisting of trilobite fragments with cystid oscicles and oolites rests on the slope of a low rise of Precambrian sandstone. *Xystridura* (undescribed), *Pagetia*, *Kootenia*, *Lyriaspis*, a bathyuriscid *(Fuchouia?)*, and *Peronopsis* are present. North-northeast of Alexandria, near the edge of the Precambrian, a chert with *Xystridura, Oryctocephalus, Peronopsis*, and *Archaeocyathus*, is underlain by beds with *Redlichia, Pagetia, Peronopsis*, and *Biconulites*.

The Alexandria beds contain no species in common with the *Xystridura-Dinesus* fauna of Queensland.

The Wonarah beds, along the Barkly Highway between Tennant Creek and the Ranken River areas, differ from the Alexandria sequence in containing frequent interbeds of silicified oolitic limestone in fissile siliceous shale. The fauna contains "*Xystridura*" *browni*, *X.* aff. *browni*, *Xystridura, Pagetia significans, Oryctocephalus*, several species of *Peronopsis*, three genera of ptychoparids, brachiopods, and *Helcionella*. No Queensland species occur, but the Alexandria fauna is well represented.

The Ranken limestone rests on the Camooweal Dolomite. The limestone consists of oolitic and crystalline fragmented beds, with limestone pebbles of similar appearance. Shell-in-shell structure is prevalent in accumulations of brachiopods and *Biconulites*, and ripple marks are present. The limestone is interpreted, therefore, as a shoreline deposit of the Cambrian sea of the Barkly Tableland. The fauna contains *Kootenia, Asaphiscus, Peronopsis, Archaeocyathus, Biconulites, Hyolithes*, several forms of *Helcionella*, the cystids *Cymbionites, Peridionites*, and *Eocystis*, and the brachiopods *Acrothele, Lingulella, Bohemiella? Nisuia?*, a new orthoid, and a syntrophioid genus. The limestone seems to intertongue in the west with the Wonarah beds, as suggested in the section (fig. 2 in the paper "Cambrian Geology of Queensland").

The upper part of the Ranken limestone was re-worked in upper Middle Cambrian time by a short-lived ingression from the east (Undilla Basin). At one locality in the fragmented and re-cemented top of the Ranken limestone, *Asthenopsis* and *Papyriaspis* were found, corresponding to the *Nathorsti* Zone, or the lower *Laevigata* Zone. This is supported by the occurrence on the surface of the Camooweal Dolomite east of the Ranken River of rare limestone and chert boulders with a fauna of similar age; a similar boulder with *Amphoton* was found downstream on the Ranken River south of the Barkly Highway. The residuals described above are the only upper Middle Cambrian occurrences of the Barkly Tableland.

The Gum Ridge formation (Öpik, in Ivanac, 1954) rests partly on the Precambrian basement and partly on volcanics, which are evidently Lower Cambrian. The formation is transgressive, and parts of it may be interpreted as shoreline deposits of an island in the Tennant Creek area. The rocks are shale, fine-grained sandstone, and silicified limestone. The fauna contains *Xystridura* aff. *browni* (at base), *Peronopsis* cf. *elkedraensis*, *Pagetia* cf. *significans*, *Chancelloria*, *Eiffelia*, *Biconulites*, and *Billingsella* cf. *humboldti* Walcott. *Redlichia* is here associated with Middle Cambrian fossils, and is regarded as of the same age. The fauna is not related to the Yelvertoft bed of Queensland, but corresponds to the upper part of the Cambrian sequence at the Negri River at Mt. Panton in the northwest. At Banka Banka, north of Gum Ridge on the Stuart Highway, a new species of *Xystridura* is associated with *Biconulites* and brachiopods of Gum Ridge and Mt. Panton aspect.

Structurally, the Cambrian of the Barkly Tableland is a thin horizontal blanket, and only in the northwest may a shallow basin exist. Stratigraphically it belongs to the lower Middle Cambrian, and is to be correlated with the Yelvertoft bed, the Thorntonia Limestone, and the Beetle Creek Formation, of Queensland. Palaeontologically interesting is the abundant occurrence of *Archaeocyathus* (cf. *atlanticus)*, which is therefore not strictly a Lower Cambrian index fossil. The palaeogeographical significance of the fauna is discussed below (Sandover beds).

SHELF REGION

SANDOVER BEDS (MIDDLE CAMBRIAN)

Little is known of the deposits of the Cambrian Shelf Belt in Central Australia. Lower Middle Cambrian occurs north of the Sandover River (Sandover beds), and to the south-southwest Upper Cambrian sandstone has recently been discovered.

The first information on the Sandover beds was collected in 1898 by Davidson, and the fossils were later described by Etheridge (1902). It is known as the occurrence 45 miles southeast of Elkedra Station. In 1947-48, D.M. Traves (unpublished) collected fossiliferous pebbles in the flood plain of the Sandover in the Argadargada area. The occurrence is in the area of the Camooweal Dolomite and was re-examined by Traves and the writer in 1952. The fauna of the pebbles is very abundant and well preserved; its full description, prepared by the present writer, was subsequently destroyed, together with the fossils, in a fire. In 1953 the Sandover area was examined by A. A. Öpik and J. N. Casey, and was recognized as being the bedrock area of the Argadargada pebble fauna and also as the beds "forty-five miles south-east from Elkedra," with *Pagetia significans* and *Peronopsis elkedraensis*, described by Etheridge (1902).

The Sandover beds consist of friable mudstone, laminated fine-grained sandstone, shale, and chert. They are slightly and broadly folded with a west-northwesterly trend. The fauna is well preserved, and contains "*Xystridura*" *browni*, *Xystridura* aff. *browni*, two species of *Xystridura* (sensu stricto), *Lyriaspis*, *Elrathina*, *Oryctocephalus* (cf. *reynoldsi* among other species), *Oryctocara* aff. *geikiei* (Walcott), *Oryctocephalites* cf. *typicalis* Resser, a new genus of oryctocephalids, several species of *Ptychagnostus (Triplagnostus)*, *Ptychagnostus (Tr.)* cf. *gibbus*, *Peronopsis elkedraensis* (Eth.), *Peronopsis scutalis*, (Salter) and *Pagetia significans* (Eth.). The similarity of this fauna to the Spence Shale and the *Ptarmigania* faunas of the Rocky Mountains of North America is apparent, particularly as the genus *Lyriaspis* Whitehouse is considered to be the earlier, and valid, synonym of *Clappaspis*.

Within the Barkly Tableland the Sandover beds and their fauna are a correlate, if not simply an extension in space, of the Alexandria and Wonarah beds. No species common with Queensland are present, except for *Peronopsis scutalis*, which is associated with *Ptychagnostus (Tr.) gibbus* in the Inca Formation. However, the genera of the Sandover beds and the Inca Formation are the same, and in both regions they follow immediately after *Redlichia:* the contemporaneity of the Beetle Creek fauna of Queensland and the Sandover beds can be safely assumed. The presence of *Peronopsis scutalis* and the abundance of species of *Ptychagnostus* correlates all the occurrences with part of the Zone with *Ptychagnostus gibbus*, and the correlation is fully supported by the presence of the *Gibbus* fauna above the Beetle Creek sequence in Queensland. In Queensland, above Pt. *gibbus*, and overlapping its range, *Ptychagnostus atavus* appears.

At the northern limit of the Sandover area Resident Geologist D. E. Catley collected several specimens of *Bathynotus* cf. *holopyga* (Hall). No other fossils are associated with this trilobite. The rock is a siliceous shale the relationship of which to the Sandover beds is unknown. This *Bathynotus* is a new species which differs from *holopyga* by its slightly simpler pygidium and, perhaps, ornament. *Bathynotus holopyga* itself is a constituent of the *Olenellus* fauna of western Vermont, U.S.A. It is, however, hazardous to assign a Lower Cambrian age to the Australian occurrence at the present state of knowledge. The occurrence of an Appalachian Lower Cambrian genus, *Lancastria,* in the Middle Cambrian of Queensland is already discussed in the paper "Cambrian geology of Queensland" (this Symposium). The distribution of *Bathynotus holopyga* and *Lancastria* in the Appalachian Province is given by Resser and Howell (1938).

CORRELATION OF THE SANDOVER FAUNA AND THE AMERICAN SPENCE-*PTARMIGANIA* FAUNAS

As stated above, the Sandover fauna, by virtue of the oryctocephalids, but also by the presence of *Elrathina* and *Lyriaspis (=Clappaspis),* is a correlate of the Spence and/or *Ptarmigania* faunas of Utah (see Howell and others, 1944). Consequently, both the American faunas should be correlated with the lower part of the *Ptychagnostus gibbus* Zone and the upper part of the *Paradoxides pinus* Zone (below *Pt. gibbus)* of Westergaard (1946). In terms of Chart Nº 1 (Howell and others, 1944), the stratigraphical position is intermediate between the Zones of *Paradoxides hicksi* and *P. oelandicus.* This correlation seems to be supported by *Triplagnostus burgessensis* Rasetti associated with the Spence fauna. *Triplagnostus burgessensis* and *Tr. praecurrens* (Westergaard) differ from *Tr. gibbus* in the same manner, and the synonymy of *burgessensis* Rasetti and *praecurrens* Westergaard is suggested. *Triplagnostus praecurrens* (see Westergaard, 1946, p. 100) is a species of the upper *Oelandicus* Stage and of the *Ptychagnostus gibbus* Zone above it.

The occurrence of *Ptychoparia anderseni* Henningsmoen (1952) in the upper zone of the *Oelandicus* Stage of Norway is also significant. According to Henningsmoen, "it reminds one of North American genera like *Clappaspis* and *Elrathia.*" It seems to be a *Lyriaspis,* related to *L. alroyensis* (Eth.) from the Northern Territory. Other correlates of the Sandover beds are the Himalayan, Siberian, and Korean sequences with oryctocephalids.

UPPER CAMBRIAN (UNNAMED)

The Upper Cambrian sandstone of the Shelf Belt on the Sandover River has not yet been studied. It is marked "U" on the map (fig. 2), where "U" stands for Utopia, the nearest station; the formation is not yet named. The fossils, recently collected by N. O. Jones, contain dikelocephalids *(Prosaukia?)*, *Pseudagnostus,* and ribeirioids, and may correspond to a horizon of the Ross River section described below. The thickness is considerable (several hundreds of feet); the sandstone is broadly and slightly folded. In the west it may rest on the Precambrian basement; in the east it probably overlaps the Sandover beds. The contacts are obscured by desert sands.

The Cambrian sequence of the Shelf Belt is more complete than that of the Epicontinental region, but a break in the Middle Cambrian is obvious. This break extends to the east into Queensland, where it is seen in the Quita area and the Selwyn Range. The range of the break is variable, but it marks events of regional significance.

MACDONNELL RANGES

DISCOVERY AND DIVISION

The Cambrian deposits of the region of the MacDonnell Ranges are very little known. Information has been published by Mawson and Madigan (1930), Madigan (1932a; 1932b), and Voisey (1939b), and a bibliography is given in Hossfeld (1954). The first actual proof of fossiliferous Cambrian rocks in the region was given by Madigan (1932b), who discovered archaeocyathids at Love's Creek (Ross River, "2" on map, fig. 2) and Middle Cambrian fossils in the Oorabra area ("a" on the map, fig. 2).

The region is divided here into two regions: the MacDonnell Ranges (proper), where the lower Palaeozoic sequence preserves its continuity, and the "eastern" or "northeastern" MacDonnell Ranges (HM on map, fig. 2), where the Cambrian is preserved in outliers, and which is discussed in the article "Cambrian deposits of the Huckitta-Marqua region" (this Symposium). The Cambrian occurrences in the MacDonnell Ranges are entered on the map schematically (by the numbers "1", "2", and "3"). Hossfeld (1954) shows the trends and structures more realistically, but without discrimination of Cambrian and Ordovician rocks.

ROSS RIVER SECTION

In the MacDonnell Ranges (proper), the Cambrian sequence is best known in the Ross River section ("2" on map, fig. 2). The Cambrian rests here on late Precambrian sediments with *Collenia.* The Cambrian itself is several thousands of feet thick and consists of a repetition of limestone, oolitic limestone, sandstone, and shale. It is not possible to assign the rocks satisfactorily to the Series divisions of the Cambrian, because the recorded fossil horizons are far apart and interpretation of the age of the rocks between the fossiliferous horizons is inconclusive. Near the base of the Cambrian sequence of the Ross River, archaeocyathids of a South Australian aspect have been recorded by Madigan and dated as Lower Cambrian. Subsequently G. F. Joklik and S. A. Tomich collected more fossils from the same section, which are interpreted below by the present writer.

In the Ross River area, above the archaeocyathid horizon of Madigan and, seemingly, separated by an undefined thickness of sediments, a hand specimen of slightly bituminous limestone was collected. It contains fragments of cystids and trilobites (two forms) and *Hyolithes.* Middle Cambrian is suggested, but the precise age is unknown. Above it follows a great thickness of rocks (mostly oolitic limestone) from which no fossils have been recorded. On top of this rests a sandstone with Upper Cambrian fossils. The section of the Ross River has been measured and structurally and lithologically explained by Madigan (1932b, p. 72), who noted the presence of fossils and who interpreted the sandstone (by its lithology, postulated continuity of trends, and apparent similarity of the section below the sandstone) as the Larapintine (Ordovician) "No. 4 Quartzite,'" which occurs south and west of Alice Springs. On the Ross River it is, however, not Ordovician, but Upper Cambrian.

It is a quartzose sandstone with worm tracks, and some beds are so full of fossils that the term "coquinoid sandstone" seems appropriate.

Two fossil horizons are present, without a single species in common. The horizons are, however, separated by a fault and the superposition is not evident. Therefore the interpretation of the relative age, as given below, is tentative and could be reversed.

The sandstone on the west bank of the Ross River contains *Calvinella*, a number of other unidentified trilobite genera, and *Billingsella*. The age seems to be upper Upper Cambrian (Trempealeauian). The sandstone on the east bank of the Ross River is older and perhaps of upper Franconian age. It contains *Prosaukia*, *Dikelocephalus*, a *Burnetia*-like trilobite, several other trilobite genera, a cyrtolitid gastropod (cf. *Strepsodiscus* Knight, according to Miss. J. G. Tomlinson, personal communication), two genera of ribeirioids, and *Diplocraterion*.

Fossils of higher horizons (the Larapintine Ordovician) have not yet been recorded on the Ross River.

OTHER OCCURRENCES

South of the Ross River area ("1" on the map, fig. 2), A. D. M. Bell has collected archaeocyathids in a pink limestone, and, possibly in the same limestone, N. O. Jones found brachiopods which, according to the present writer, are a new species of a brachiopod related to *Kutorgina*. As *Kutorgina* has been found only as yet in the Lower Cambrian, the presence of Lower Cambrian in Central Australia, as already inferred by Madigan from the archaeocyathids, seems to be confirmed.

In the western MacDonnell Ranges no obvious Cambrian fossils have been found, but the thick sequence known to exist below the proven Ordovician rocks certainly represents Cambrian of various ages. The oldest dated horizon of the Ordovician of the MacDonnell ranges contains *Didymograptus nitidus* (unpublished) and is therefore Lower Ordovician. Below it, in the Alice Springs area, in the sandstone of the "No. 4 Quartzite" a fauna was collected by A. D. M. Bell and the present writer. It contains ellesmeroceroid nautiloids, *Technophorus*?, and abundant trilobite fragments of an undescribed genus, suggesting an asaphid or even a *Kingstonia*. It is possibly Tremadocian or upper Upper Cambrian. It is a glauconitic sandstone with numerous problematical burrows and tracks, resembling the Upper Cambrian sandstone of the Ross River and the Sandover area.

To conclude, the upper limit of Cambrian deposits in the MacDonnell Ranges remains a matter for further study and discussion.

A. A. Öpik

CAMBRIAN SEQUENCE OF NORTHERN TERRITORY

The sequence of the Cambrian within the regions and areas of the Northern Territory has been discussed above; a general retrospect, historically arranged, is a necessary preliminary to the palaeogeographical outline presented in the article "Cambrian palaeogeography of Australia" (this Symposium).

LOWER CAMBRIAN

It is customary in Australia (and for the most part elsewhere) to regard the *Redlichia*-bearing rocks as upper Lower Cambrian. The reason for such dating is the "ancient" organization of the trilobite *Redlichia* and the absence of other, stratigraphically diagnostic, fossils in its association whereby the postulated Lower Cambrian age may be proved or disproved. However, in northern Australia, Middle Cambrian fossils are associated with *Redlichia,* and the *Redlichia*-bearing beds are followed conformably by faunas which must be correlated with the lower part of the Middle Cambrian *Ptychagnostus gibbus* Zone, which is well above the base of the Middle Cambrian. If the *Redlichia* faunas of northern Australia are regarded as Lower Cambrian, *eo ipso* a considerable break is postulated above the last *Redlichia* in the sequence, whereas no such a break exists. Moreover, if the *Redlichia* faunas are left in the Lower Cambrian, the boundary between Lower and Middle Cambrian must be shifted to a level above the *Paradoxides oelandicus* Stage, and the Middle Cambrian commenced with the Zone of *Ptychagnostus gibbus.*

In placing the *Redlichia* faunas of northern Australia in the Middle Cambrian the author makes no attempt to claim that all faunas with *Redlichia,* or with redlichioid trilobites, are of the same age. For this reason he evades the term "*Redlichia* stage," which, in the universal application, covers parts of two Series (Lower Cambrian and Middle Cambrian) and confuses the understanding of the age of the *Redlichia* faunas of northern Australia.

In South Australia *Redlichia* occurs in two horizons. The fauna of the upper horizon (Wirrealpa limestone) is comparable with the *Redlichia* faunas of northern Australia and can be therefore regarded as lower Middle Cambrian. The fauna of the lower horizon, known from

Kangaroo Island (see Daily, Cambrian Geology of South Australia), has a *Redlichia* different from the forms of the Wirrealpa limestone; it is associated with *Isoxys* and protolenids indicating a Lower Cambrian age of the deposits.

It is generally believed that Lower Cambrian is equivalent to "Olenellan" and Middle Cambrian to "Paradoxidian" or "Paradoxididian" and that these divisions settle the matter of boundaries between the Series. However, palaeontological concepts are in fluctuation: *Redlichia* may be regarded as an olenelloid, and *Paradoxides* as a redlichioid trilobite and no stability is reached. Whatever the palaeontological criteria may be, the Gum Ridge fauna of Northern Territory is Middle Cambrian: at the base of the sequence the paradoxidid *Xystridura* appears and is followed by two successive species of *Redlichia.*

The only evidence for Lower Cambrian in northern Australia are the archaeocyathids and the brachiopod cf. *Kutorgina* found in the MacDonnell Ranges. The archaeocyathids occur also in Middle Cambrian (Ranken limestone, Barkly Tableland) and are not necessarily indicative of Lower Cambrian; *Kutorgina* is a requisite of the *Olenellus* fauna and is widespread throughout the world. The occurrence of a marine Lower Cambrian fauna in the middle of a continent must be palaeogeographically explained. A connexion with South Australia, where a *Kutorgina* also is present, seems evident. A connexion with the Daly River area can be postulated only. If all the deposits considered to be late Precambrian (Camooweal Dolomite, Victoria River Group, Mt. House beds) are in reality Lower Cambrian, a total submergence of the Northern Territory at that time results, as already assumed by Hossfeld (1954). The present writer, however, has tried to interpret the sequence and palaeogeography on the background of a restricted "Olenellan" and shows in his conjecture the minimal extent of this, restricted, Lower Cambrian (See: Cambrian Palaeogeography of Australia). The author also considers it more probable, that in the Northern Territory between the Lower and the Middle Cambrian a general erosional break occurs, so that the Lower Cambrian is restricted to residuals; it is less probable that the Lower Cambrian sea extended from South Australia only as far as the MacDonnell Ranges.

MIDDLE CAMBRIAN

The earliest Middle Cambrian faunas with *Redlichia* occur in the Daly River area and on the western and northern fringe of the Barkly Tableland and mark the ingressive marine phase of the incipient subsidence. A connexion with the Negri and Ord River area of Western Australia is obvious. No evidence for the presence of *Redlichia* in the MacDonnell Ranges is available. However, Madigan (1932a) reports *Girvanella* limestones from the Western MacDonnell Ranges, which may serve as circumstantial evidence: *Girvanella* is a rock-forming alga in the *Redlichia* sequence of Western Australia, the Northern Territory, and Queensland. Communication with South Australia, already evident in Lower Cambrian time, was maintained, and is supported by the presence of *Biconulites, Redlichia, Chancelloria,* and *Girvanella*, in the south. The geological and palaeontological evidence gives no support to a direct connexion between the Northern Territory and Queensland in the *Redlichia* time...

In the succeeding *Xystridura-Dinesus*, or lower *Gibbus*, time, the Middle Cambrian transgression spread to the southeast over the Sandover River, but no evidence for such a transgression or of younger Middle Cambrian faunas exists in the Western MacDonnell Ranges, except for the continuity of deposition as seen from sections published by Madigan (1932a). The palaeontological evidence is against a direct connexion with Queensland: shore-line deposits of this time are seen to rest on the Camooweal Dolomite at the Ranken River and on the Precambrian basement in the Alexandria area. No marine connexion to the south existed, because at that time regression prevailed in South Australia.

The *Xystridura-Dinesus* time ended the Middle Cambrian marine history of the Northern Territory, except for the following ingressions from Queensland: (1) in the *Atavus* time an inlet north of the Tropic of Capricorn reached into the Eastern MacDonnell Ranges, but did not survive the *Atavus* time; (2) at the end of the Middle Cambrian the sea from the Undilla Basin transgressed the barrier of the Camooweal Dolomite and reached the Ranken River, but receded soon after, and (3) about the same upper Middle Cambrian time (end of *Nathorsti* and

Laevigata Zones) another ingression followed the path of the *Atavus* inlet north of the Tropic of Capricorn, and persisted into Upper Cambrian and Ordovician time.

UPPER CAMBRIAN AND ITS RELATIONS WITH QUEENSLAND AND TASMANIA

The late Middle Cambrian ingression north of the Tropic of Capricorn was followed by an Upper Cambrian intracontinental sea which extended northwest into the Cambridge Gulf area. It marks a change in the prevalent trends of subsidence and marine ingressions: in the Lower Cambrian and lower Middle Cambrian a near-meridional trend is apparent, whereas in the Upper Cambrian and Ordovician the trend in the Northern Territory is near-latitudinal.

The discoveries of Upper Cambrian in central Australia, in the Cambridge Gulf area (see D. M. Traves, this Symposium), and in Tasmania (Elliston, 1954), are very recent and not generally known. To understand the occurrence of Upper Cambrian in the Northern Territory, in the middle of the continent, the other occurrences should be discussed. Previously Upper Cambrian sediments were known in Victoria and in northwestern Queensland. In Victoria the cherts on the Howqua River are not fossiliferous enough to be correlated with any particular horizon of the Upper Cambrian elsewhere. The Upper Cambrian rocks of north-Western Queensland have not been studied above the beds with *Glyptagnostus* and *Olenus*, where dikelocephalid faunas of the central Australian aspect are expected to be present. The *Glyptagnostus-Olenus* fauna, in turn, is not yet recorded in central Australia. The known part of the Upper Cambrian sequence of Queensland, however, can be tied up with the Upper Cambrian of Tasmania.

On the Ring River, Dundas, Tasmania, badly distorted fossils occur, among which could be identified *Pseudagnostus*, a dikelocephalid, and *Coosia*, with an undescribed nepeid genus which seems to occur also in the lower horizon of the O'Hara Shale in Queensland. The rocks which contain this Upper Cambrian fauna (at Bonnie Point and in the Fahl Syncline, northeastern part of Dundas Sheet) are, however, placed by Elliston (1954) on lithological grounds in the Middle Cambrian.

In Tasmania, in the Leven Gorge, the same *Pseudagnostus* and dikelocephalid are present, associated with trilobites of a lower Upper

Cambrian aspect; a different horizon in the Leven Gorge contains *Leiopyge laevigata* and must be regarded as the top of the Middle Cambrian. A correlation of these Tasmanian Upper Cambrian faunas with the lower Dresbachian *(Cedaria)* fauna of the Selwyn Range of Queensland seems therefore appropriate. Furthermore, *Glyptagnostus reticulatus* (Ang.), already known in northwestern Queensland, has been recognized in a black shale on the Huskisson River in northwestern Tasmania (discovered by J. Elliston). Thus, a communication between Tasmania and northwestern Queensland, in spite of the great distance, is apparent, but a communication between the Northern Territory and northwestern Queensland is not yet proven on available faunal evidence. The only indication of such a continuity is the presence of *Pseudagnostus* on the Sandover River ("U" on the map, fig. 2). Consequently, the probability exists that in Upper Cambrian time the central Australian dikelocephalid sea was temporarily separated from Queensland. A complete study of the Upper Cambrian sequence of the two regions may solve the riddle.

NOTES ON CAMBRIAN DEPOSITS OF WESTERN AUSTRALIA

THE ORD RIVER AREA

The Cambridge Gulf area is beyond the boundary of Northern Territory, but the Cambrian deposits of this area (and of the Ord River) are regionally related to the Cambrian of the Territory. The geology of the Cambrian deposits of the Cambridge Gulf area and of the Ord River basins is treated by Traves (this Symposium). Here the stratigraphy of these areas will be discussed in relation to the Cambrian deposits of Northern Territory.

The lower part of the Cambrian of the Ord River (Negri Group) belongs to lower Middle Cambrian, and its *Redlichia-Xystridura* fauna is closely related to the fauna of the Gum Ridge formation at Tennant Creek and Banka Banka. The Elder Sandstone of the Ord River is unfossiliferous, but by its position above the Negri Group it must represent an undefined part of the upper Middle Cambrian and, probably, Upper Cambrian. Lithologically the Elder Sandstone corresponds to the Cambrian sandstones of the Cambridge Gulf area and both may have been deposited in the one and the same inlet of the Cambrian sea.

THE CAMBRIDGE GULF SEQUENCE

In the Cambridge Gulf area the Cambrian sequence is continuous from the lower Middle Cambrian into the Lower Ordovician, as expressed by the term "Carlton Group" by Traves. However, not all parts of the sequence have produced fossils as yet and a detailed correlation must be reserved. The Middle Cambrian sequence starts with *Redlichia.* The next fossil horizon, well above the base, contains only brachiopods (a *Billingsella*-like form). The highest known Middle Cambrian fauna (Carlton Formation, Noakes, Öpik and Crespin, 1952, or Skewthorpe Formation, Traves, 1955, in press) contains *Solenoparia, Blackwelderia, Damesella,* and *Ptychagnostus?* and is therefore, upper Middle Cambrian (*Nathorsti* or *Laevigata* Zone). The age suggested by Teichert (1952), as the Zone with *Paradoxides hicksi,* is certainly too low.

Above this horizon the *Cedaria* fauna must be expected, but has not been seen as yet. But the middle Dresbachian is indicated by a sandstone with *Crepicephalus* and syntrophoid brachiopods, all in a single locality. Above it follows the Clark Sandstone of Traves. It is richly fossiliferous over the whole of its thickness of 600 feet. In its lower part *Maryvillia* (in great numbers), *Saukia?, Prosaukia, Ptychaspis?, Coosia,* and several not yet identified genera of small trilobites are present, and *Hypseloconus* (abundant), *Pelagiella,* and syntrophoids are seen in some of the localities. A not yet properly correlated locality contains *Idahoia?* associated with dikelocephalids and a probably olenid trilobite. The upper part of the formation contains micaceous shaly interbeds with dikelocephalids, which are not well enough preserved, but *Tellerina?* is suggested. Conformably above it follows the Lower Ordovician Pander Formation (a "greensand" with limestone and sandstone interbeds). In a sandstone interbed asaphid and pliomerid trilobites are present. The present author thinks that the fauna of the Upper Cambrian of the Cambridge Gulf area is closely related with the fauna of central Australia; the Lower Ordovician, in turn, with its pliomerids, can be compared in a provincial sense with the Price's Creek fauna of Western Australia (Guppy and Öpik, 1950), with the Larapintine of central Australia, with the fauna of Wilson's Promontory in Victoria (Lindner, 1953), and with lower horizons of the Tasmanian Ordovician. All these occurrences are thought of as being connected by a seaway passing through the southern parts of the Northern Territory, because otherwise the occurrence in the centre of the continent of Upper Cambrian faunas in a "Wisconsin" style, followed by Ordovician, cannot be understood satisfactorily.

REFERENCES

(See "Cambrian Palaeogeography of Australia," by A. A. Öpik, this Symposium.)

CAMBRIAN GEOLOGY OF THE HUCKITTA-MARQUA REGION, NORTHERN TERRITORY

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ABSTRACT

The lithology and fossil content of samples from nineteen localities in the Huckitta-Marqua region of the Northern Territory of Australia are briefly outlined. Middle and Upper Cambrian fossils are present, but neither Lower Cambrian nor lowermost Middle Cambrian (*Redlichia*-fauna) has been observed. In the Middle Cambrian, three horizons—referable to those of *Dinesus-Xystridura, Ptychagnostus atavus,* and, probably, *Leiopyge laevigata,* of the Queensland sequence—are present. In the Upper Cambrian, four faunas are present, representing the middle Upper Cambrian (Franconian) and, possibly, upper Upper Cambrian (Trempealeauian); the provincial relationship is Pacific, with a marked Oriental aspect.

The lower Middle Cambrian *Xystridura*-fauna consists of species characteristic of the Northern Territory and indicates that the area of deposition was separate from that of Queensland at that time; the younger Middle Cambrian faunas are comparable with those of Queensland, and lateral continuity of sedimentation is evident. The Upper Cambrian faunas show no close resemblance to any known Australian fauna outside central Australia, although a connexion with Queensland is probable.

No igneous activity is evident in rocks younger than Lower Proterozoic, and granitic intrusion preceded the deposition of Upper Proterozoic sediments. Tectonic movement took place at the end of the "Time of *Ptychagnostus gibbus*" and, prob-

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ably, immediately before the "Time of *L. laevigata*." The main orogeny is provisionally dated as Silurian.

Recent work shows that the greater part of the area previously mapped as Cambrian is *Collenia*-bearing dolomite, here assigned to the Eocambrian. The area mapped as Ordovician by earlier workers contains Upper Cambrian as well as Ordovician sediments.

INTRODUCTION

The presence of Cambrian sediments in the western part of the Huckitta-Marqua region of the Northern Territory of Australia was first suggested by Madigan (1932b, p. 96), who listed possible Cambrian fossils from a locality northwest of Oorobbra Rockholes in the West Jervois Range and at the same time published a sketch-map showing a large area of Cambrian sediments in the vicinity of the Dulcie Range.

Reconnaissance in 1954 and 1955 by geologists of the Commonwealth Bureau of Mineral Resources, Geology, and Geophysics, has confirmed the presence of Cambrian sediments in the region, although their areal distribution is somewhat different from that envisaged by Madigan and later authors.

Middle and Upper Cambrian fossils have been collected from nineteen widely separated localities in an area of 12,000 square miles; no Lower Cambrian fossils have been observed. Palaeontological studies show that the sequence, as at present known, is incomplete, and field observations indicate that post-Ordovician faulting has further obscured the depositional sequence. The Cambrian outcrops are mostly preserved as erosional residuals.

In the western part of the region (Huckitta and Lucy Creek), the broad outlines, though not the details, of Cambrian geology are discernable: in the eastern part (Marqua), the available data are insufficient for a satisfactory estimation of the geology. It is considered inadvisable to attempt a geological map at this stage, and no stratigraphical units have been named.

This paper presents the first results of recent surveys as they apply to the Cambrian; a detailed account of the general geology is in preparation by J. N. Casey. The present paper is based on field observations and collections by J. N. Casey and N. O. Jones and air-photo interpretation by J. N. Casey.

The first author (J. N. Casey) is responsible for the field data, and the map is an abridgement from his unpublished maps. The second author (J. Gilbert-Tomlinson) is responsible for the palaeontological determinations and for interpretation of the general sequence, correlation, palaeogeography, and tectonics. The text has been compiled by J. Gilbert-Tomlinson in close consultation with the first author and Dr. A. A. Öpik.

GEOGRAPHY

The Huckitta-Marqua region lies in the southeastern part of the Northern Territory, northwest of the intersection of the Tropic of Capricorn with the Northern Territory/Queensland border (Long. 138°E). It is bounded on the west by Longitude 135°30′E and on the north by the Sandover River and Pituri Creek. The region covers the greater part of the Huckitta and Tobermory (4-mile) Sheets of the Australian National Grid.

The northern part of the region is drained by tributaries of the Sandover River and Pituri Creek; the southern part by the Plenty, Marshall, and Field Rivers, and their tributaries, which flow southeast into the Simpson Desert.

In the west, north of the Marshall River, the East and West Jervois Ranges form an arc open to the north, and the Dulcie Range lies northwest of the West Jervois Range. The Tarlton Range forms a longitudinal elevation about the centre of the region, and the Toko Range crosses the Queensland border in the east.

The highest point is 1670 feet at Grant's Bluff in the West Jervois Range; the lowest is 650 feet at Manners Creek Homestead near the Queensland border.

The annual rainfall is between 10 and 15 inches, and the country is largely uninhabited. Mining and cattle-raising for beef production are the only industries of the region.

Cambrian fossils have been collected from three main areas in the region: Huckitta, in the west; Lucy Creek, a little to the west of centre; and Marqua, in the southeast. These localities are shown as "a," "b," and "c," on figure 2 in Öpik, "Cambrian geology of the Northern Territory" (this Symposium).

HISTORY OF INVESTIGATION

The explorers Winnecke, Lindsay, Davidson, and Barclay crossed the region in the late 19th century, and H. Y. L. Brown (1897) published the first account of the geology. Brown's observations were confined to the western part—the Dulcie and Jervois Ranges.

Results of later geological reconnaissance in the Huckitta area are published by Tindale (1931), Hodge-Smith (1932), and Madigan (1932b).

Madigan in 1935 crossed the region from Huckitta in the west to Tobermory in the northeast; in a brief summary (1937a) he presented the first account of the geology of the eastern part of the region. His route passed to the north of the Cambrian outcrops now known to occur in the Marqua area farther south, and Ordovician fossils only were observed. Madigan's intention of publishing a detailed account of this hitherto undescribed area was not realized, owing to his death in 1946.

General descriptions of the region, and of central Australia as a whole, are given by Madigan (1933; 1938) and Hossfeld (1954), and the greater part of the region is shown on a geological sketch-map by Whitehouse (1936, text-fig. 2, p. 63).

Since 1949 the region has been examined on five occasions by geologists of the Bureau of Mineral Resources: A. A. Öpik (1949) studied the Upper Proterozoic sequence of the East Jervois Range; G. F. Joklik (in press) in 1952 made observations in the Huckitta area; L. C. Noakes and J. N. Casey (unpublished) in 1953 crossed the region from west to east and collected Ordovician fossils in the Tarlton Range; J. N. Casey in 1954 accompanied a field-party of the Georgina Poison Survey of the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) and made the first collection of Cambrian fossils in the Marqua area and the first collection of Upper Cambrian fossils in the region; and N. O. Jones, Resident Geologist, Alice Springs, N. T., in 1955, in connexion with problems of water-supply, collected Cambrian fossils from hitherto unknown localities in the Lucy Creek area.

No detailed mapping of the region has yet been carried out, and no fossils have been described. The only record of Cambrian fossils from a specific locality is that mentioned by Madigan (see Introduction, above, and Palaeogeography, below).

Investigations by the C.S.I.R.O. and the Bureau of Mineral Resources are still in progress, and the Proterozoic, Cambrian, and Ordovician fossils are being studied by A. A. Öpik and J. Gilbert-Tomlinson.

GENERAL GEOLOGY

Precambrian rocks are exposed along the southern border of the Huckitta-Marqua region, where they form the northern edge of the Precambrian block of the Eastern MacDonnell and Harts Ranges. Archaeozoic and Lower Proterozoic metamorphics are recognized. Muscovite is mined in the Archaeozoic and copper and lead in the Lower Proterozoic.

Near the northern edge of the Precambrian, the East and West Jervois Ranges occur as fault blocks. They consist of Upper Proterozoic sediments with a *Collenia*-bearing dolomite near the base.

The northern part of the region is occupied by algal dolomite and dolomitic limestone, overlain by Cambrian and Ordovician sediments. The dolomite contains two species of *Collenia* and for it an Eocambrian age is postulated.

The youngest known Palaeozoic rocks are Ordovician, and no Mesozoic rocks are known; unfossiliferous freshwater limestone, probably of Tertiary age, occurs in small outcrops in the eastern part of the region.

EOCAMBRIAN

Algal dolomite and dolomitic limestone are widespread in the region. Two main areas are apparent: one in the east, the other in the west. It is possible that the two areas are continuous, but this cannot yet be proved, as the intervening country north of the Tarlton Range is largely covered by sand.

The "eastern dolomite" is exposed north of Southern Cross (Marqua) Bore and west of Manners Creek Homestead; it occupies the basins of Blackfellow and Manners Creeks. No data whereby its age may be estimated are available.

The "western dolomite" is exposed north and west of Lucy Creek Homestead in the basin of Lucy Creek and north of Arthur Creek. This outcrop of dolomite apparently coincides, in part at least, with "the vast extent of limestones north of the Dulcie Range and the Arthur River" containing "algal forms in profusion" observed by Madigan (1937a, p. 91).

To the southwest of the main outcrop, the "western dolomite" appears to continue west to form a narrow latitudinal strip south of the Dulcie Range. Here the dolomite is faulted on the south against Proterozoic granite and Upper Proterozoic sediments of the West Jervois and Mopunga Ranges. On the north it is overlain by Upper Cambrian sandstone.

The "western dolomite" has not been studied in detail, but the possibility of an Eocambrian age may be examined.

Madigan *(loc. cit.)* considers it to be Cambrian in age, but this interpretation is rejected because of the presence of *Collenia* and the absence of undoubted Cambrian fossils. One of the species of *Collenia* is similar to, and possibly identical with, *Cryptozoon* (=*Collenia*) *tesselatum* Howchin. *Collenia tesselata* is one of the commonest algae in central Australia; it occurs in association with other species of *Collenia* of late Proterozoic aspect, and is not known to occur with Cambrian fossils. A very similar form is found in the Flinders Ranges of South Australia, and Mawson and Madigan (1930, p. 416) consider this South Australian form "to be probably late pre-Cambrian or Lower Cambrian" in age.

The structural relationship of the "western dolomite" with the Upper Proterozoic sequence of the Jervois Ranges is obscured by faulting, and the contacts have not been studied in detail. The dolomite, however, does not appear to follow the strike of the folded and faulted beds of the Jervois Ranges, and seems to be unconformable. Moreover, it is lithologically quite dissimilar to any dolomite in the Jervois Ranges.

It has been observed that, in many parts of the Lucy Creek area, dolomite occupies a higher topographical position than the Upper Cambrian sandstone. A possible explanation is that a younger (Upper Cambrian or Lower Ordovician) dolomite is present in the area as well as the Eocambrian dolomite, but no palaeontological evidence for a younger dolomite is known. Most probably the Cambrian sediments were deposited on an uneven surface of the dolomite and are now preserved as erosional outliers. The topographical anomaly may have been accentuated by post-Ordovician faulting.

ORDOVICIAN

Ordovician sediments are preserved as erosional residuals in the Dulcie and Tarlton Ranges and in the Toko Range and environs.

In the Dulcie Range, in the Huckitta area, Ordovician sandstone is underlain by Lower Ordovician limestone, which, in turn, overlies a 1000-foot sequence containing middle Upper Cambrian fossils in its lower third. No collections have been made from the intervening part of the sequence, and the continuity of the faunal succession has yet to be established; the Cambrian and Ordovician sediments appear to be conformable.

The discovery of Upper Cambrian fossils in the lower topographical levels of the Dulcie Range necessitates a revision of the concept of the "Dulcie Series" of Hossfeld (1954, p. 143). Hossfeld, following earlier authors, considered the whole sequence to be Ordovician and proposed the name for the beds "at Mt. Ultim in the Dulcie Ranges." Mt. Ultim is about five miles beyond the western border of the region, and from here to Huckitta Homestead, about fifteen miles to the southeast, the Cambrian sediments can be traced without a break. The "Dulcie Series," therefore, covers two systems, and re-definition is necessary.

In the Tarlton Range, Lower? Ordovician sandstone is underlain by recrystallized limestone in which no diagnostic fossils have been found (*cf.* Madigan, 1937a, p. 92).

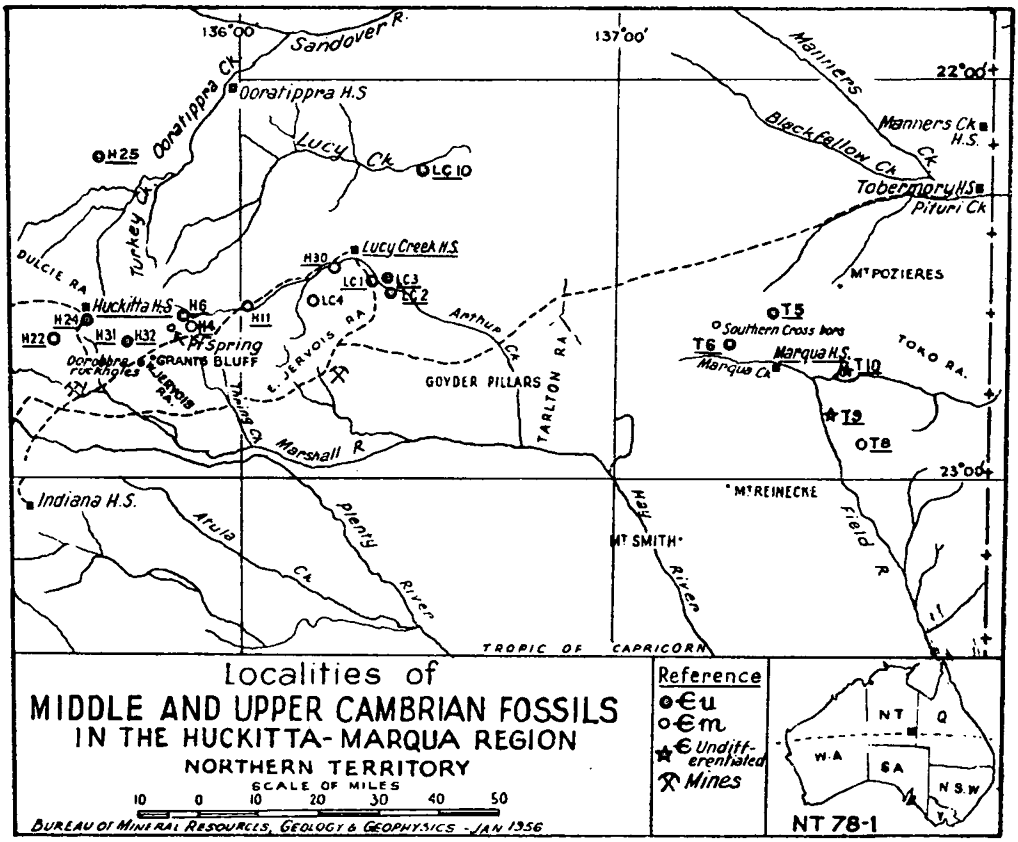
In the Toko Range and the surrounding area, Ordovician fossils have been collected in sandstone, limestone, and chert. Lower and Middle Ordovician fossils are present.

The fossiliferous sandstone east of Lucy Creek Homestead is not Ordovician but Cambrian. Cambrian fossils also occur in the sandstones north and south of Southern Cross Bore (Marqua). Large areas of sandstone are exposed along the northern border of the region, but no samples are available for study and their age is unknown.

IGNEOUS ACTIVITY

The Lower Proterozoic metamorphics contain basic igneous rocks which are probably interbedded; the same sequence is intruded by granite—the Jinka Granite (Joklik, in press)—which forms the plain-country north, south, and east of Oorobbra Rockholes in the West Jervois Range, and east of the East Jervois Range. The granite does not intrude the younger sediments but is itself cut by quartz shears—the "Oorobbra Reefs" (Brown, 1897). The reefs are over five miles long and less than 100 yards wide and do not intersect the Upper Proterozoic sequence of the Jervois Ranges.

As observed by Hossfeld (1954, p. 141), no igneous activity is evident in the Cambrian or Ordovician rocks.



Localities of
MIDDLE AND UPPER CAMBRIAN FOSSILS
IN THE HUCKITTA-MARQUA REGION
NORTHERN TERRITORY

CAMBRIAN GEOLOGY

DESCRIPTION OF CAMBRIAN FOSSILIFEROUS ROCKS

The Cambrian fossil localities in the Huckitta-Marqua region are grouped into three areas: A—Huckitta, in the west; B—Lucy Creek, between the Dulcie and Tarlton Ranges; and C—Marqua, in the south-east. The three areas are shown on figure 2 in Öpik, "Cambrian geology of the Northern Territory" (this Symposium), where, however, the Huckitta area is placed somewhat too far north. Positions of fossil localities are shown on the accompanying map.

All three areas have yielded Middle and Upper Cambrian fossils, and no Lower Cambrian fossils have been observed.

A—Huckitta area

Middle Cambrian

H 4—2 miles east of Point Spring in the Huckitta area
H 22—10 miles southwest of Huckitta Homestead

Upper Cambrian

H 24—about 3 miles south of Huckitta Homestead
H 6—16 miles east of Huckitta Homestead
H 31—9 miles southeast of Huckitta Homestead
H 32—ditto., 300 feet above H 31
H 25—28 miles north of Huckitta Homestead on the Ooratippra road

Middle Cambrian—In the Huckitta area, the lowest known Cambrian horizon occurs in a fault block at H 4, where 50 to 100 feet of laminated black bituminous limestone (Cambrian) overlie yellow dolomite and dolomitic limestone (Eocambrian). Both Cambrian and Eocambrian are downfaulted on the south against Upper Proterozoic sandstone of the Jervois sequence. The upper contact is faulted.

The bituminous limestone is richly fossiliferous and contains the brachiopod *Lingulella* and the trilobites *Fouchouia* and an undescribed genus of Nepeidae Whitehouse. Near the top of the sequence, the zone-agnostid *Ptychagnostus atavus* is associated with *Peronopsis* spp. and establishes the age as middle Middle Cambrian ("Time of *Pt. atavus*").

South of the Dulcie Range, at H 22, a fossiliferous white calcareous sandstone, 10 feet thick, overlies 30 feet of fragmental limestone with indeterminable fossils. The limestone rests directly on *Collenia*-bearing yellow dolomitic limestone of the Eocambrian sequence. Above the sandstone, a lack of exposure equivalent to 200 feet occurs, and the first recognizable unit above the break is 200 to 300 feet of two-colour grey limestone, apparently at the same attitude as the sandstone. Sandstone and limestone together form the southern limb of an east-west trending syncline.

The sandstone contains *Hyolithes* and undescribed billingselloid brachiopods, and its age cannot be determined from the contained fauna. It is provisionally correlated, on lithological grounds, with the upper level at H 11 in the Lucy Creek area *(q.v.)*, which is assigned to the upper Middle Cambrian ("Time of *Leiopyge laevigata*").

Upper Cambrian—The largest Cambrian outcrops in the Huckitta area are those on the flanks of the Dulcie Range, where Upper Cambrian sediments rest on Eocambrian dolomite and dolomitic limestone, and are overlain by Ordovician limestone and sandstone.

Samples have been collected from the southwestern flank of the Dulcie Range syncline (H 24, H 31, and H 32) and from the faulted southeastern nose of the syncline (H 6). H 25 occurs north of the Dulcie Range.

On the southwestern flank and the nose of the syncline, the Upper Cambrian sediments comprise flaggy calcareous sandstone (mostly leached), sandy limestone, and shale. The sandstone and shale are micaceous, and the sandstone and limestone are glauconitic. Surface silicification is evident at H 6.

Dips on the southwestern flank vary between 5 and 20 degrees; slumping gives erroneous high-dip readings in places. The sandstone shows current-bedding, ripple-marks, and ice-crystals. *Diplocraterion* occurs at H 6. Fossils are undistorted in the sandstone but distorted in the shale.

The maximum thickness of the Upper Cambrian sequence appears to be about 1000 feet—at H 24, where fossils have been collected in the lower third of the section. The Ordovician appears to be conformable with the Cambrian, and systematic collecting is needed to establish the continuity of the faunal succession and the position of the Cambrian-Ordovician boundary.

Fossils are abundant and well preserved. Samples H 6, H 24, and H 32 belong to the same horizon and contain the brachiopods *Eoorthis?*

and *Huenella?* and the trilobites *Litagnostus*, *Prosaukia* (2 spp.), *Sinosaukia*, *Saukia?*, *Pagodia* cf. *buda* Resser and Endo, "*Quadraticephalus*" aff. *teres* R. and E., and *Tsinania?*, as well as new genera of doubtful affinities. Two undescribed genera of ribeirioids (Gen. A and Gen. B) are common.

At H 31 and H 32, the Cambrian is thrown into shallow domes and basins; H 31 occurs about 300 feet below H 32 in the same section and contains the trilobites *Prosaukia* and *Kingstonia*.

At H 25, north of the Dulcie Range, at least 50 feet of sandstone occur. The beds are nearly horizontal, and the lower contact has not been seen. Ordovician? sandstone occurs about eight miles to the south. The sample is distinct both in lithology and fauna from any observed on the southern flank of the syncline: it is a white argillaceous sandstone, without mica or glauconite. The trilobites *Shirakiella?* and an indeterminable genus of Saukiinae are present, as well as a third new genus of ribeirioids (Gen. C).

The present collections of Upper Cambrian in the Huckitta area are correlated with the middle Upper Cambrian (Franconian) of the North American (Pacific) sequence, and the faunas show a strong resemblance to those of eastern Asia.

B—Lucy Creek area

Middle Cambrian

LC 1—5 miles south-southeast of Lucy Creek Homestead
H 30—2 miles southwest of Lucy Creek Homestead
LC 4—8 miles southwest of Lucy Creek Homestead
H 11—12 miles east-northeast of Point Spring

Upper Cambrian

LC 10—20 miles north-northeast of Lucy Creek Homestead
LC 2—8 miles southeast of Lucy Creek Homestead
LC 3—6 miles southeast of Lucy Creek Homestead

Middle Cambrian—Middle Cambrian sediments occur in two areas —distinguished as the "eastern outcrop" and the "western outcrop"—between Point Spring in the southwest and Lucy Creek Homestead in the northeast. Arthur Creek forms the northern boundary of the Middle Cambrian sediments, except in a small area west of Lucy Creek Homestead and beyond it Eocambrian dolomite is exposed; Upper Proterozoic sediments of the East Jervois Range are exposed on the southern boundary. The two outcrops of Middle Cambrian sediments are separated by a narrow longitudinal strip of dolomite.

The structure of the Middle Cambrian sediments is yet to be investigated, and it is not known whether the contacts with the older sediments are faulted or unconformable, though some faulting has occurred.

Altogether three horizons are represented: *Dinesus-Xystridura*, *Ptychagnostus atavus*, and *Leiopyge laevigata*. The faunal succession is discontinuous, but this is possibly accidental, and the missing horizons may be revealed by systematic collecting.

The "eastern outcrop" contains the oldest known fauna in the Huckitta-Marqua region. This is the lower Middle Cambrian *Xystridura*-fauna of the "Time of *Dinesus* and *Xystridura*," which occurs at two localities south of Lucy Creek Homestead (LC 1 and H 30).

At LC 1, a white siliceous shale contains the trilobites *Pagetia* cf. *significans* (Etheridge) and *Xystridura* aff. *browni* (Eth.), and the same trilobites are present at H 30, in a grey bituminous limestone with silica nodules and surface silicification. The limestone is part of a sequence about 200 feet thick; a higher horizon in the same sequence is represented at LC 4, 7 miles southwest of H 30, where a recrystallized limestone contains the trilobites *Fuchouia* and the same genus of nepeids as occurs in the lower level at H 4 in the Huckitta area (see above); this horizon is dated as middle Middle Cambrian ("Time of *Ptychagnostus atavus*").

The only available sample from the "western outcrop" (H 11) contains two horizons of Middle Cambrian fossils. The sequence is 100 to 200 feet thick and consists of dark grey bituminous limestone passing into calcareous sandstone at the top. The limestone contains the same genus of nepeid trilobites as occurs at H 4 and LC 4 and is dated as middle Middle Cambrian ("Time of *Ptychagnostus atavus*"). In the sandstone, the trilobites *Asthenopsis* and *Crepicephalina* establish the age as upper Middle Cambrian ("Time of *Leiopyge laevigata*"). The sandstone is lithologically similar to that at H 22 in the Huckitta area.

Upper Cambrian—Upper Cambrian sediments occupy a large area between Lucy Creek and Arthur Creek, east of Lucy Creek Homestead.

At LC 10, a horizontal sequence of interbedded leached and calcareous sandstone and siltstone rests on Eocambrian dolomite. The thickness is unknown. Fossils are abundant in a fine-grained white sandstone with black staining of iron or manganese. The trilobites are undescribed, but are referred to the genera *Pseudagnostus*, *Sinosaukia*, *Saukia?*, *Tsinania?*, and *Haniwa?*. Ribeirioid Gen. A is common. The age of the sandstone is middle Upper Cambrian (Franconian).

Two small samples—LC 2 and LC 3—are available from localities about 20 miles southwest of LC 10. The localities are about 2 miles apart, and no continuity between them can be observed. At LC 2 a whitish and red sandstone contains a trilobite resembling *Tellerina* and is provisionally dated as upper Upper Cambrian (Trempealeauian). LC 3 is a calcareous sandstone containing the brachiopod *Huenella?* and fragmentary trilobites, including large dikelocephalid cheeks and a pygidium resembling *Coosella*. Its position in the Upper Cambrian sequence is not evident.

C—Marqua area

Middle Cambrian
T 8—18 miles southeast of Marqua Homestead
Upper Cambrian
T 5—9 miles east-northeast of Southern Cross (Marqua) Bore
T 6—3 miles southeast of Southern Cross (Marqua) Bore
Cambrian, undifferentiated
T 10—10 miles east of Marqua Homestead
T 9—12 miles southeast of Marqua Homestead

Middle Cambrian—The only undoubted occurrence of Middle Cambrian fossils in the Marqua area is at T 8, where *Pagetia* cf. *significans* and *Xystridura* aff. *browni* have been collected in a white siliceous shale, apparently identical in lithology with that at LC 1. The shale is downfaulted against granite and dips steeply north. It is overlain, apparently conformably, by two-colour grey limestone in which no fossils have been found.

Upper Cambrian—At T 5, in a yellowish micaceous sandstone, *Kingstonia?* and other trilobites (unidentified) are associated with ribeirioid Gen. A. The sandstone is about 50 feet thick and overlies dolomite and dolomitic limestone. A red sandstone containing the brachiopod *Eoorthis?* occurs at T 6. The sandstone is sub-horizontal and about 20 feet thick; it overlies two-colour grey limestone containing cystids and brachiopods of unknown age.

T 5 is middle Upper Cambrian in age and may be correlated with sandstones in the Huckitta and Lucy Creek areas; T 6 is probably of the same age.

Cambrian undifferentiated—In the Marqua area, two samples of limestone have been collected whose contained fossils do not permit an estimation of their age. T 10 is a flaggy grey limestone with *Acrotreta* and other phosphatic brachiopods; it dips north and can be traced west along the strike to Marqua Homestead and beyond, where it may be overlain by Upper Cambrian sandstone and possibly by dolomitic limestone. T 9 is a brecciated grey limestone with unidentifiable trilobites.

CORRELATION

Middle Cambrian

The Middle Cambrian is correlated with the succession in Queensland (see Öpik, "Cambrian geology of Queensland," this Symposium), which is the best known in Australia. No stages are yet proposed for Queensland, and the seven horizons are temporarily referred to in terms of the time-range of selected index-fossils.

In the lower part of the Queensland sequence, the "Pacific" trilobite *Redlichia* is followed by the indigenous trilobites *Dinesus* and *Xystridura;* above them follow, in ascending order, the Swedish zone-agnostids *Ptychagnostus gibbus, Pt. atavus, Pt. punctuosus, Goniagnostus nathorsti,* and *Leiopyge laevigata.*

In the Huckitta-Marqua region, the *Redlichia*-fauna is missing, and the oldest known fauna is the *Xystridura*-fauna at LC 1, H 30, and T 8. T 8 is the southernmost occurrence of the fauna in the Northern Territory. The species are distinct from those of Queensland, but are comparable with those of the Northern Territory, particularly of the Sandover Beds of the Elkedra area, immediately north of the Huckitta-Marqua region (see Öpik, "Cambrian geology of the Northern Territory," this Symposium).

Pt. gibbus is missing, and a break above the *Xystridura*-fauna is evident, but the next younger zone-agnostid—*Pt. atavus*—occurs at H 4. The species is common in Queensland, but has not previously been recorded in the Northern Territory. Similarly, the trilobites *Fuchouia* and the undescribed nepeid recorded at H 4, LC 4, and H 11, are common and widespread in Queensland, but are not known elsewhere in the Northern Territory.

Above the horizon of *Pt. atavus* no higher zone-agnostids have been observed; in the sandstone at the top of the sequence at H 11, however, the trilobites *Asthenopsis* and *Crepicephalina* occur and indicate an upper Middle Cambrian horizon. In Queensland they are recorded in the Split Rock Sandstone, which is dated as uppermost Middle Cambrian ("Time of *Leiopyge laevigata*"). The apparent continuity between the lower and higher levels at H 11 suggests that at least a part of the sequence between *Pt. atavus* and *L. laevigata* may be discovered by systematic collecting.

The sandstone at H 22 appears to be lithologically identical with that at H 11, and is provisionally correlated with it.

Upper Cambrian

The Australian Upper Cambrian faunas are almost undescribed, and the succession is virtually unknown. The faunas in the Huckitta-Marqua region are "Pacific" in aspect, and for the present are correlated with the North American stages. Some of the trilobites can be referred to described genera; the ribeirioids (pelecypod-like Crustacea) appear to be of importance in local correlation, and for them an open nomenclature is used.

A close resemblance to one of the faunas of the Ross River is evident (see Öpik, "Cambrian geology of the Northern Territory," this Symposium), but the "Pacific" faunas of the Ord-Victoria region (see Traves, this Symposium) seem to be distinct. The upper part of the succession in Queensland is not well enough known to permit a correlation, but a connexion seems probable. Outside Australia, the faunas of northern China and southern Manchuria are closely allied to those of the Huckitta-Marqua region.

The lower Upper Cambrian (Dresbachian) is not represented in the collections; six samples are assigned to the middle Upper Cambrian

(Franconian), and one is assigned to the upper Upper Cambrian (Trempealeauian). Three of the samples cannot be dated on their fossil content, but appear to belong to the upper half of the series.

The oldest datable fauna occurs at H 31, where the presence of *Prosaukia* indicates the middle Upper Cambrian (Franconian) stage.

In the same section as H 31, and 300 feet higher, H 32 contains the most widespread of the Upper Cambrian faunas of central Australia. This is the fauna characterized by the undescribed ribeirioids Gen. A and Gen. B. Gen. A, a concentrically ribbed form, occurs at five localities in the Huckitta-Marqua region—H 24, H 6, H 32, LC 10, and T 5—and, in addition, at the Ross River, about 100 miles south of Huckitta; Gen. B, a smooth form, is present at H 24 and H 6 of the Huckitta area, at the Ross River, and possibly at Utopia, about 60 miles west of Huckitta (see Öpik, "Cambrian geology of the Northern Territory," this Symposium).

Ribeirioid Gen. A appears to be confined to central Australia. Its stratigraphical range is not known, and a somewhat different assemblage of trilobites is associated at each locality; but it does not range into the higher levels of the sequence at the Ross River, nor is it associated with *Tellerina?* at LC 2. The presence of *Prosaukia* at H 24 indicates a Franconian age, and in the same sample occur three species comparable with *Pagodia buda*, *"Quadraticephalus" teres*, and *Saukia(?) (=Sinosaukia) orientalis* described by Resser and Endo (Endo and Resser, 1937) from the Yenchou formation of southern Manchuria, which is correlated by Endo and Resser with the upper part of the Franconian.

Cranidia comparable with the upper Upper Cambrian (Trempealeauian) genus *Saukia* occur at H 6 and LC 10 and may indicate that the present age-determination is incorrect and that *Prosaukia*, like *Kingstonia*, ranges into higher levels of the Upper Cambrian. On the other hand, the genus, or a form with a similar cranidium, may appear earlier in Australia than in North America.

The occurrence of *Tellerina?* at LC 2 may indicate the upper Upper Cambrian; no ribeirioids are present at this locality.

It is possible that in the Dulcie Range the complete sequence from middle Upper Cambrian to Lower Ordovician will be revealed by systematic collecting. The youngest known fauna is that with ribeirioids Gen. A and Gen. B, and about 600 feet of sediments occur between this horizon and the Lower Ordovician. In the Ross River area, the same ribeirioid assemblage is overlain by two distinct Upper Cambrian faunas, the lower of which contains the trilobites *Calvinella* and *Loganellus* and is apparently younger than any seen in the Huckitta-Marqua region. Lower Ordovician occurs still higher in the sequence.

It is not yet clear whether the absence of lower Upper Cambrian fossils represents a break in the sequence or is merely an accident of collecting. Lower Upper Cambrian has not been recorded in the Ross River area, but in Queensland several lower Upper Cambrian faunas occur with an alternation of Acado-Baltic and Pacific species. In the Ord-Victoria region, a sandstone with *Crepicephalus* forms the lowest Upper Cambrian unit.

The discovery of the Oriental trilobite *Pagodia* in the Huckitta area is of interest in being the only known Australian occurrence outside Queensland. The genus was first recognized by Whitehouse (1931), who considered it characteristic of the upper part of the Upper Cambrian sequence of Queensland.

The stratigraphical range of the genus in Queensland has not been determined: its earliest occurrence may be that at Pomegranate north of Chatsworth. Here, Öpik (personal communication) reports a limestone sequence in which *Pagodia* immediately overlies a bed with *Glyptagnostus* and *Olenus*. Above the bed with *Pagodia*, the Cambrian faunas have not been studied; Ordovician occurs higher in the sequence. The species of *Pagodia* is distinct from that at Huckitta.

PALAEOGEOGRAPHY AND TECTONICS

Lithology and thickness

Except at the top of the sequence, the Middle Cambrian sediments consist of siliceous shale and limestone. The shale is confined to the oldest beds ("Time of *Dinesus* and *Xystridura*") and is apparently lithologically identical with that of the contemporaneous Sandover beds of the Elkedra area. The *Xystridura*-bearing limestone at H 30 is exceptional.

The bituminous limestone of the "Time of *Pt. atavus*" indicates a closed embayment in which free circulation was impeded.

At the top of the Middle Cambrian sequence, the calcareous sandstone at H 11 represents an abrupt change in lithology.

In the Upper Cambrian sequence, sandstone forms the most conspicuous rock-type, but it has been observed by N. O. Jones (personal communication) that the Upper Cambrian sediments at the foot of the Dulcie Range consist mainly of shale.

The Upper Cambrian sandstone shows current-bedding and ripple-marks, and shallow water is indicated. The prevalence of glauconite in samples from the southern flank of the Dulcie Range may indicate proximity to a shore-line. Ice-crystals occur in the same area.

The thicknesses have not been accurately measured but are everywhere small and indicate epicontinental, rather than geosynclinal, conditions. In the Middle Cambrian, no more than 500 feet is evident, and in the Upper Cambrian about 1000 feet seems to be present.

Faunas

No Lower Cambrian fossils have been seen by the present authors. However, Madigan (1932b, p. 96) records "obscure remains of Archaeocyathinae" in the Huckitta area, and until the locality is re-examined the possibility of Lower Cambrian cannot be entirely excluded. The nearest known locality for Lower Cambrian fossils is the Hale River area, about 100 miles to the south, where the brachiopod *Kutorgina* is recorded by Öpik (see "Cambrian geology of the Northern Territory," this Symposium).

The lowermost Middle Cambrian *Redlichia*-fauna is also missing, and it is probable that the region was dry land during early Cambrian time, the first transgression of the sea occurring during the "Time of *Dinesus* and *Xystridura*."

The lower Middle Cambrian faunas of Queensland—of the times of *Redlichia* and *Dinesus-Xystridura*—are distinct from those of the Northern Territory, and no common species are known. Öpik (see "Cambrian palaeogeography of Australia," this Symposium) has accordingly postulated a narrow longitudinal ridge—the "Meridional Divide"—separating the two faunas.

In the Huckitta-Marqua region, the species of *Pagetia* and *Xystridura* are comparable with those of the Northern Territory, and hence the Divide was functional at this southern end of the *Xystridura* sea. A similarity of the fauna to that of the Sandover beds is obvious.

The two younger Middle Cambrain faunas—the *Atavus*-fauna and the *Asthenopsis*-fauna—show no difference from those of Queensland, and free communication between the two areas is apparent.

The middle Upper Cambrian fauna indicates free communication in the central Australian sea, with the endemic ribeirioids common over a wide area. Communication with Queensland and eastern Asia is apparent.

Summary of tectonic events

1. During the Lower Cambrian and lowermost Middle Cambrian (*Redlichia*-time) land conditions prevailed, with the Eocambrian dolomite undergoing erosion.

2. At the close of *Redlichia*-time subsidence occurred, and a transgression from the north brought in the *Xystridura*-fauna, though the sea was separated from that of Queensland by a narrow divide.

3. At the end of the "Time of *Pt. gibbus*," further subsidence caused a breach in the divide, resulting in a narrow embayment accessible to faunas from Queensland, particularly the pelagic agnostids.

4. The history between the "Time of *Pt. atavus*" and the "Time of *Leiopyge laevigata*" is not yet known, but the abrupt change from limestone to sandstone suggests some tectonic movement before the "Time of *Leiopyge laevigata*."

5. The geological history during the lower Upper Cambrian is not known; sedimentation was probably continuous from the middle Upper Cambrian until the end of the Ordovician, and may have been continuous from the end of the Middle Cambrian. Some oscillation probably took place, but there is no evidence of orogeny.

6. Folding and faulting occurred after the Ordovician. Accurate estimation of their earliest possible date depends on the age of the youngest Ordovician faunas. The most recent systematic work on the Ordovician faunas is that of Teichert and Glenister (1952), who have

studied the nautiloids of the Toko Range but have reached no definite conclusions regarding their latest date.

Altogether, a Silurian age of the orogeny seems likely, and Browne (see David, 1950, vol. 1, p. 213) has suggested the late Silurian epoch (Browning Orogeny).

REFERENCES

FOR REFERENCES, see Öpik, "Cambrian palaeogeography of Australia," this Symposium.

UPPER PROTEROZOIC AND CAMBRIAN GEOLOGY IN NORTHWESTERN AUSTRALIA

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ABSTRACT

This paper describes the Upper Proterozoic or "Eo-Cambrian" units—some of which may extend into Lower Cambrian—and Lower, Middle and Upper Cambrian units that crop out in northwestern Australia. It includes the description of the fossiliferous Negri Group of eight Middle Cambrian formations and the richly fossiliferous Carlton Group, which contains two Middle Cambrian formations and two Upper Cambrian formations.

INTRODUCTION

Rocks of "Eo-Cambrian" and Cambrian age crop out over an area of approximately 120,000 square miles in the northwestern part of Australia, which includes the northern part of Western Australia, known as the Kimberleys, and the northwestern part of the Northern Territory. Most of these rocks have been mapped as Upper Proterozoic but they will be discussed in this paper, together with the Cambrian units.

INVESTIGATION

Probably the earliest geological work in the northwestern part of Australia was done in 1837-1843 when Commander Stokes examined rocks along the coast line and up the Victoria River. Hardman (1885) in 1883-1884 examined part of the East Kimberleys and was the first to examine the Cambrian rocks. He called them a Carboniferous age; later in England Cambrian forms were recognised by Foord (1890) from his fossil collections. H.Y.L. Brown from 1895-1909 traversed most of the northwestern part of the Northern Territory. Maitland (1903) in 1901 worked in the Kimberleys and assigned a Cambrian age to the unaltered, sub-horizontal, sediments of the Kimberley Block, now tentatively mapped as Upper Proterozoic. Woolnough (1912) and Jensen (1915) reconnoitred the western portion of the Northern Territory. Blatchford (1922-1928) and Mahoney (1922, in Hobson, 1936) worked in the East Kimberleys. In 1924 A. Wade examined the petroleum prospects of the Kimberleys and Northern Territory. In 1941 F.G. Forman (in Teichert, 1943) collected the first Devonian fossils from the Bonaparte Gulf Basin and this initiated the work in 1945 by Matheson and Teichert (1948), who mapped the Middle Cambrian basins and the southern part of the Bonaparte Gulf Basin. Reeves (1948) examined the petroleum prospects of Bonaparte Gulf Basin and was the first to record fossiliferous Cambrian sediments in that area. A Bureau of Mineral Resources field party, led by D. Guppy, has worked in the West Kimberleys from 1948 to 1953, and their observations concerning the Upper Proterozoic section are used in this paper. The writer has engaged in reconnaissance mapping of the East Kimberleys and northwestern portion of the Northern Territory since 1949 and results of the investigation are recorded (Traves, 1955). The writer was accompanied in two seasons by A.A. Öpik, who assisted in deciphering the Palaeozoic sequence.

STRATIGRAPHY

Before the stratigraphy of the "Eo-Cambrian" and Cambrian is discussed, mention of the tectonic units used throughout this paper is essential. These units are shown in figure 1. The Kimberley Block is separated from the Sturt Block (Noakes, 1951) by the tectonic zone called by Traves the Halls Creek Tectonic Belt. The discordant Palaeozoic Bonaparte Gulf Basin transgresses this zone in the north between the Ord and Victoria Rivers. Farther south along the Ord River are the Argyle, Rosewood, and Hardman Middle Cambrian Basins named by Matheson and Teichert (1948).

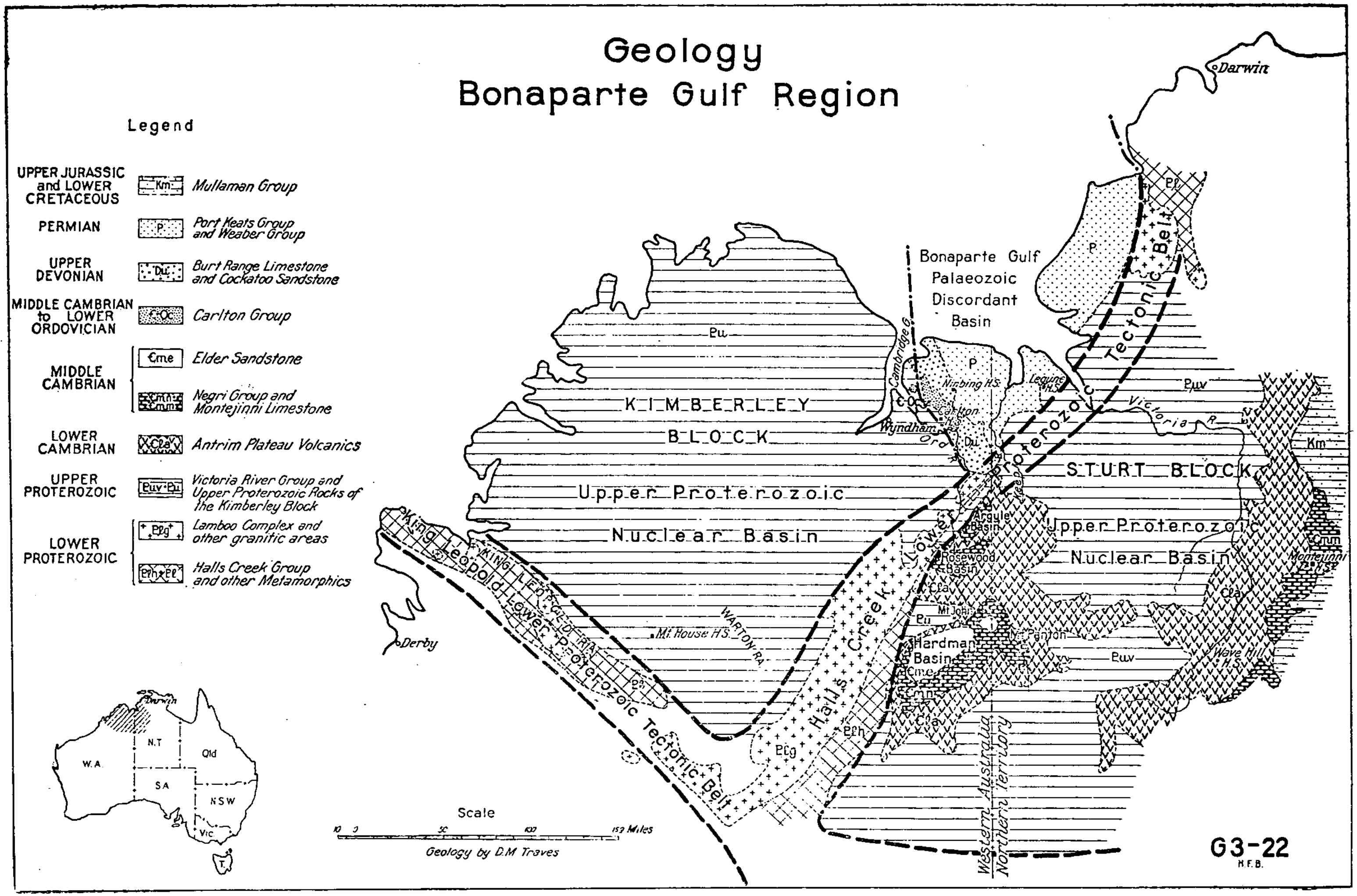

Fig. 1. Geological and tectonic map of northwestern Australia.

Stratigraphic units will be discussed under the headings of (1) Upper Proterozoic or "Eo-Cambrian," (2) Lower Cambrian, (3) Middle Cambrian, and (4) Middle and Upper Cambrian. These headings have been selected so that sections in the one area can be discussed under the one heading.

The Upper Proterozoic rocks crop out on the Kimberley Block, where they have been sub-divided into King Leopold Formation, Mornington Volcanics, Warton Beds, Walsh Tillite, and Mt. House Beds. Similar rocks which crop out on the Sturt Block have not been subdivided and have been named the Victoria River Group. The Lower Cambrian division contains the Antrim Plateau Volcanics, which crop out over a large area on the Sturt Block. Under the heading of Middle Cambrian have been included the Negri Group, which contains eight formations; the Elder Sandstone, which conformably overlies sediments of the Negri Group; the Ragged Range Conglomerate, which is thought to be a local marginal development of the Elder Sandstone; and the Montejinni Limestone, which has been equated to the basal formation of the Negri Group. The Middle and Upper Cambrian division contains the four Cambrian formations (Hart Spring Sandstone, Skewthorpe Formation, Pretlove Sandstone, and Clark Sandstone) of the Carlton Group.

UPPER PROTEROZOIC OR "EO-CAMBRIAN"

A large thickness of sediments and volcanics of Upper Proterozoic age is present in the Kimberley Block. Guppy, working in the Lennard River area, has divided them into the following units:

King Leopold Formation, Mornington Volcanics, Warton Beds, Walsh Tillite, and Mt. House Beds.

Work in the last two years has shown that these units can be extrapolated to cover most of the Kimberley Block, although in many places the Walsh Tillite is absent and on the eastern side of the plateau the Mornington Volcanics are absent.

King Leopold Formation (Guppy, 1953): Guppy (1953) stated: "The unit outcrops typically in the King Leopold and Precipice Ranges . . . although no detailed work has been attempted it is considered probable that the greater part of the section will be quartzite though the possibility exists that some shaly beds are interbedded. In places the basal beds are conglomeratic and contain well rounded cobbles and pebbles."

South of Mt. Cockburn on the eastern side of the Kimberley Plateau, approximately 1200 feet of coarse, poorly sorted, massive, strongly jointed sandstone and quartzitic sandstone of this unit are exposed. Southwest of Texas Station approximately 1800 feet of strongly jointed, coarse, poorly sorted sandstone crop out. The King Leopold Formation unconformably overlies Lower Proterozoic metamorphics and granites and is unconformably overlain in most places by the Mornington Volcanics and on the eastern edge of the Plateau by Warton Beds.

Mornington Volcanics (Guppy, 1953): The Mornington Volcanics have been named from Mornington Homestead. Guppy described the lithology as "grey-green, dense, fine-grained andesite, in places, amygdaloidal medium-grained dolerite. Indurated shale and quartzite occur interbedded in the sequence and intrusions of basalt and quartz in the form of dykes and veins were noted." Mornington Volcanics crop out between Precipice Range and Lady Forrest Range, and north of Mt. House, and in a long northerly trending belt in the Drysdale area. The Volcanics are absent on the eastern side of the Kimberley Plateau. The Mornington Volcanics unconformably overlie the King Leopold Formation and are conformably overlain by the Warton Beds.

Warton Beds (Guppy, 1953): This unit, named from the Warton Ranges, outcrops over a large area of the Kimberley Plateau. Guppy described the rocks as "well-bedded, medium-grained to fine conglomeratic, white to light brown quartzite, red micaceous sandstone and shale." South of Mt. Cockburn 4000 feet of sandstone, siltstone, and shale of this unit are exposed. A prominent shale member occurs about 1200 feet from the base, and seems to persist westward, forming a distinct marker in the Warton Sandstone in the Drysdale area. In the section southwest of Texas Station, the Warton Beds are represented by about 1200 feet of sandstone. Guppy (1953) wrote that "the unit is apparently conformable with the underlying Mornington Volcanics and is overlain unconformably both by Walsh Tillite and Mt. House Beds."

Walsh Tillite (Guppy, 1953): Guppy (1953) wrote the following: "the formation was originally examined and named in outcrop on the headwaters of Walsh Creek (Longitude 125°, 35′E., Latitude 17°, 12′S.). From a study of outcrop and aerial photographs further outcrops of the Tillite are presumed to occur near Glenroy Homestead and along the

Hann River... In the type area on Walsh Creek the formation consists of an extremely unsorted sediment ranging in size from silt to boulders (up to 7 ft. across) and in which bedding is absent or very crudely developed. The matrix consists of grey-green and red siltstone and unsorted sandstone. Erratics are predominantly quartzite of types occurring in the Warton Beds together with rare igneous rock types. Boulders are commonly faceted and show striations... the formation unconformably overlies the Warton Beds and is conformably overlain by the Mt. House Beds."

Mt. House Beds (Guppy, 1953): The Mt. House Beds is the name given by Guppy (1953) for the "interbedded siltstone, sandstone and quartzite with bands of limestone and dolomite" which crop out in the vicinity of Mt. House. The Mt. House Beds form the top unit of Upper Proterozoic rocks in the Kimberley plateau and have a wide distribution. The section at Mt. Cockburn contains 1000 ft. of medium-bedded sandstone overlain by 1000 ft. of shale and shaly thin-bedded dolomite. This in turn is overlain by approximately 800 ft. of well-bedded sandstone which forms the cap of Mt. Cockburn. On Texas Station the base of the unit is 1700 ft. of sandstone, overlain by 1000 ft. of shale with thin beds of dolomite and siltstone. This in turn is unconformably overlain by the Antrim Plateau Volcanics. The shale bed is also well exposed in the slopes of the Bastion at Wyndham and is capped by a few hundred feet of sandstone. A bore at Wyndham shows 156 ft. of shale underlain by 690 ft. of sandstone. Along the banks of the Ord River near Carlton Crossing stromatolitic structures and possible jellyfish marks were examined by Dr. Öpik and the writer. A number of undetermined fossils of a similar nature are illustrated in Wade's report (1924) as occurring at Mt. John, Osmond Range, W. A.

Victoria River Group (Brown, 1895; Traves, 1955): The Victoria River Group consists of sandstone, shale, dolomite, and siltstone, which outcrop in the middle and lower tracts of the Victoria River. The main area of outcrop extends from west of Port Keats and east of Willeroo in the north to Wave Hill Police Station and Limbunya in the south. The complete sequence of the Victoria River Group has not been worked out and in the large area of outcrop facies changes complicate the sequence. The following is a generalised sequence, excluding the large thickness of dolomite, which apparently underlies the other sediments in the Timber Creek/Jasper Gorge area:

Top:

80+′ white to grey sandstone and quartzite with mud pellets and ripple marks.
60+′ massive sandstone.
250-400+′ dolomite, shale, and thin beds of sandstone.
100-400+′ ripple-marked well-jointed sandstone with mud pellets.
60+′ quartizite or massive sandstone.
+′ dolomite.
140+′ shale with thin bands of dolomite and sandstone.

The thickness of the Victoria River Group is at least 2000 ft. and is probably far greater. Two inliers of silicified sediments of the Victoria River Group in the Antrim Plateau Volcanics contain abundant algae described (Traves, 1954) as closely resembling the form *Collenia frequens* Walcott (see Fenton and Fenton, 1931), from the Belt Series of North America.

LOWER CAMBRIAN

Antrim Plateau Volcanics (David, 1932): The Antrim Plateau Volcanics consist of basaltic flows with some agglomerate tuffs. Fine- to coarse-grained basalts form flows that are vesicular at the top. Edwards (in Edwards and Clarke, 1940) stated that the basalts "range from olivine basalt to quartz basalt and have distinct affinities with the tholeiitic or plateau basalts... and appear to form a single basaltic province."

Estimates of thickness of the Volcanics at different localities range from 660 ft. by Jack to 4000 ft. by Mahoney. The greatest thickness measured by the writer is 3300 ft. at a locality west of Trig. Point T. 37, north of Turner Homestead. The Antrim Plateau Volcanics unconformably overlie the Upper Proterozoic sediments and appear to be conformably overlain by sediments of the Middle Cambrian Negri Group.

MIDDLE CAMBRIAN

Negri Group (Mahoney, in Hobson, 1936): Sediments of the Negri Group form the largest and most studied unit in the Cambrian sequence. Matheson and Teichert (1948) named the Argyle, Rosewood, and Hardman Basins of sediments of Negri Group. Further mapping has shown that there are at least seven isolated areas of sediments of this Group, most of which form geographical basins. The Hardman Basin contains the greatest thickness and best exposures, and in this area the group was split into eight formations (Traves, 1955), most of which can be recognised in the other areas of outcrop.

They are in ascending order: Headleys Limestone, Nelson Shale, Linnekar Limestone, Panton Shale, Shady Camp Limestone, Negri River Shale, Corby Limestone, and Hudson Shale.

Headleys Limestone (Traves, 1955): This formation forms the base of the Negri Group and consists of 60 ft. of thickly bedded grey crystalline limestone with abundant tuberous bodies of chert along the bedding planes, overlain by 50-60 ft. of thinly bedded grey crystalline limestone. The chert decreases in abundance from the base and very little, if any, is present in the thinly bedded limestone. No fossils have been found in this unit but the stratigraphic position of the formation suggests an age of either the top of Lower Cambrian or the base of Middle Cambrian.

Nelson Shale (Traves, 1955): The Nelson Shale consists of about 500 ft. of red, grey, and green shales with some thin bands of mudstone, limestone, and siltstone. Some shales are gypseous, and gypsum plates up to 8" long are found at the bottom of shale slopes. The Nelson Shale has not yielded any fossils, but as it conformably underlies the fossiliferous Linnekar Limestone, its age is lower Middle Cambrian.

Linnekar Limestone (Traves, 1955): The typical section of the Linnekar Limestone contains 5-10 ft. of poorly bedded grey and brown crystalline limestone with abundant chert nodules overlain by 50-60 ft. of thinly bedded grey limestone with intercalated thin shale beds. The upper part of the formation contains abundant *Redlichia, Biconulites,* and *Girvanella.* From examination of these fossils Öpik places the Linnekar Limestone in the lower part of the Middle Cambrian Epoch.

Panton Shale (Traves, 1955): The Panton Shale is the second shale unit of the Negri Group and it lies conformably between Linnekar Limestone and Shady Camp Limestone. It consists of approximately 200 ft. of red and grey shales, 120 ft. of which are exposed on the slopes of Mt. Panton.

Shady Camp Limestone (Traves, 1955): The Shady Camp Limestone, in most parts of the Hardman Basin, contains 10 to 20 ft. of grey crystalline limestone with *Girvanella* and pteropods, but in the Mt.

Panton area it is much thicker and contains at least 145 ft. of highly fossiliferous limestone and shale. Fossils from this locality include the trilobites *Xystridura* and *Redlichia*, the brachiopods *Wimanella* and *Billingsella* cf. *humboldti* (Walcott), the pteropod *Biconulites hardmani*, and *Girvanella*. Öpik has assigned them a lower Middle Cambrian age.

Negri River Shale (Traves, 1955): The Negri River Shale is the third unit of Negri Group and consists of 70 to 235 ft. of red and grey calcareous shale. No fossils have been found in this formation.

Corby Limestone (Traves, 1955): The Corby Limestone is a thin unit of about 10 ft. of dense laminated steel-grey crystalline limestone with sparse chert nodules. No fossils have been found in this formation.

Hudson Shale (Traves, 1955): The Hudson Shale forms the top unit of the Negri Group. It consists of about 650 ft. of red and grey shales, and at its top there is a rapid transition to the Elder Sandstone, which conformably overlies the cyclic limestone-shale formations of the Negri Group.

The Negri Group, particularly in the Hardman Basin, displays a rhythmic deposition of limestone and shale. Another interesting feature is the abundance of chert nodules at the base of each of the first three limestone formations.

Elder Sandstone (Mahoney, in Hobson, 1936): The Elder Sandstone conformably overlies the Negri Group and is about 1500 ft. thick. At Hudson Creek, overlying the transition beds from Hudson Shale, is fine sandstone which contains abundant mud pellets. Higher in the sequence is brown micaceous shaly sandstone exhibiting numerous shallow-water markings, which is overlain by poorly cemented, in places cross-bedded, well-sorted, medium- to fine-grained, reddish sandstone. No fossils have been recorded from the Elder Sandstone, but it is continuous in sedimentation with the fossiliferous Negri Group.

Ragged Range Conglomerate (Traves, 1955): This unit consists of at least 800 ft. of sandstone and conglomerate. There are three main beds of conglomerate, each approximately 100 ft. thick, with numerous lenses of sandstone. The conglomerate consists of poorly cemented, well rounded pebbles and boulders, ranging from 2 in. to 2 ft. in diameter, which are mainly quartzite, although some are highly weathered igneous rocks. The sandstones range from fine-grained to coarse-grained with pebbles and are ripple-marked and cross-bedded. Ragged Range Conglomerate in most places appears conformable with the underlying shales of the Negri Group, displaying a rapid transition from shale to sandstone similar to the one already described at Hudson Creek; but at one locality examined it overlaps on to the Antrim Plateau Volcanics. The Ragged Range Conglomerate is therefore thought to be a local marginal development of the Elder Sandstone, with which it is correlated.

Montejinni Limestone (Traves, 1955): The Montejinni Limestone consists of 40 ft. of thickly bedded to massive, fine- to coarse-grained, grey, cream and brown, crystalline limestone containing abundant chert nodules and plates along the bedding planes, overlain by 20 to 40 ft. of thinly bedded, fine-grained, grey crystalline limestone with very few, if any, chert nodules. The unit outcrops in a long, almost meridional strip passing through Montejinni Station. At one locality the thinly bedded grey limestone contains abundant *Girvanella,* the only fossils found in the formation so far. In all observed contacts the Montejinni Limestone overlies the Antrim Plateau Volcanics and is overlain by the Mullaman Group of Cretaceous age. By its relationship to the Lower Cambrian volcanics and its marked resemblance in stratigraphic position and lithology to Headleys Limestone, the Montejinni Limestone is assigned to the base of the Middle Cambrian and is thought to be the eastern extension of Headleys Limestone.

MIDDLE AND UPPER CAMBRIAN

Carlton Group (Reeves, 1948): The Carlton Group has been divided into five formations, which are, in ascending order:

Hart Spring Sandstone, Skewthorpe Formation, Pretlove Sandstone, Clark Sandstone, and Pander Greensand.

The Pander Greensand is of Lower Ordovician age but as it appears to be conformably in the sequence it has been included in the Carlton Group.

Hart Spring Sandstone (Traves, 1955): The Hart Spring Sandstone consists of sandstone with some impure limestone and shale. At Hart Spring, about 500 ft. of reddish, fine sandstone crop out. The fossils found in the unit are brachiopods which probably belong, or are closely allied, to the genus *Billingsella;* an undescribed *Hyolithes* is present. In a low outcrop southwest of Skewthorpe Ridge rocks probably belonging to the Hart Spring Sandstone contain fragments of fossils which Öpik (personal communication) thinks are *Redlichia.* Palaeontology and stratigraphic position indicate a Middle Cambrian age for the Hart Spring Sandstone.

Skewthorpe Formation (Traves, 1955): The Skewthorpe Formation contains limestone, shale, and sandstone, and is characterised by fossiliferous oolitic limestone. It was from this formation that Reeves (1948) collected the first Cambrian fossils in the Carlton area. In all the localities examined, the formation is exposed either in fault blocks or in isolated ridges surrounded by sand, so that the complete section is not known, although it is estimated to be 600+ feet thick. Fossils include the trilobites *Solenoparia, Damesella,* and *Blackwelderia,* and the brachiopods *Acrotreta, Obolus,* and *Lingulella.* Öpik (1950) pointed out that the presence of *Damesella* and *Blackwelderia* indicates that the formation is in the Middle Cambrian and that it may be taken as the top of Middle Cambrian.

Pretlove Sandstone (Traves, 1955): This unit, of reddish well-bedded sandstone, crops out in Pretlove Hills near the junction of Nimbing and Legune tracks. Farther south the white to ironstained sandstone containing trilobites and brachiopods is included in the unit. The trilobites belong to the genus *Crepicephalus* or a closely related genus, which indicates an age early in the Upper Cambrian.

Clark Sandstone (Traves, 1955): The Clark Sandstone, approximately 600 ft. of dark, greenish to reddish, glauconitic sandstone and friable red sandstone, contains numerous trilobites and brachiopods; the trilobites are of the dikelocephalid type, indicating an age in the middle or upper portion of the Upper Cambrian. The Clark Sandstone is conformably overlain by Pander Greensand of Lower Ordovician age.

AGE AND RELATIONSHIP OF "EO-CAMBRIAN" AND CAMBRIAN UNITS

The stratigraphic table is shown in figure 2. The succession of the Carlton Group begins in Middle Cambrian and goes to the top of Upper Cambrian. The fossiliferous formations of the Negri Group are of Middle Cambrian age and, although no fossils appear till the third formation (Linnekar Limestone) of the Group, it is assumed that the Negri Group represents the lower portion of the Middle Cambrian. The

Elder Sandstone and its marginal development, the Ragged Range Conglomerate, are not fossiliferous, but as they conformably overlie the Negri Group they are placed in the Middle Cambrian. They have not been correlated with the base of the Carlton Group, although they may perhaps coincide in age with the Hart Spring Sandstone. The Montejinni Limestone contains only *Girvanella;* because of its similarity in lithology and stratigraphic position to the Headleys Limestone, it may be equated to this basal formation of the Negri Group.

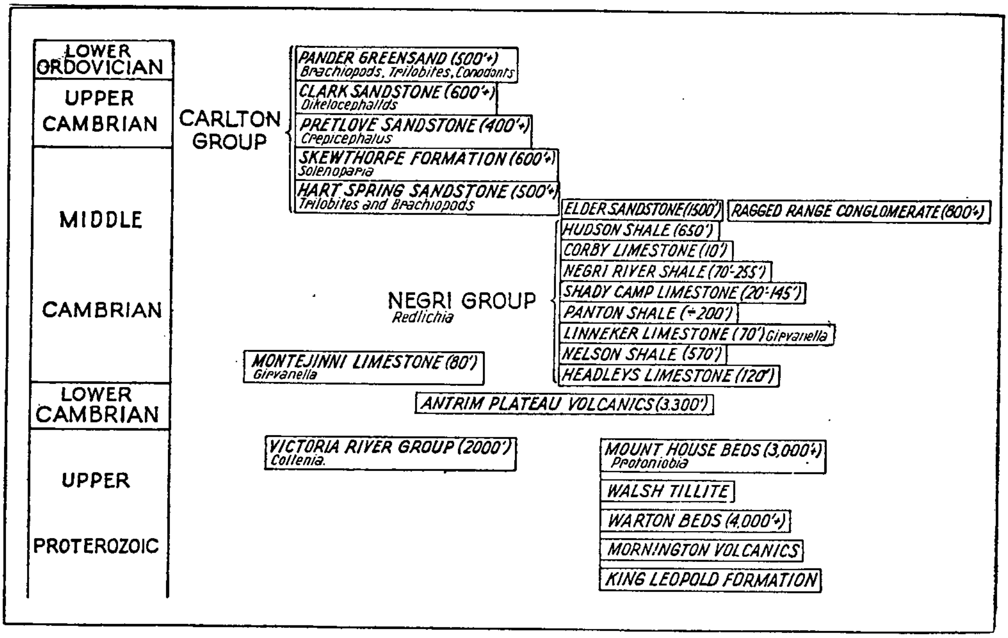

Fig. 2. Stratigraphic table.

Apparently conformably below the Negri Group in the west and the Montejinni Limestone in the east are the Antrim Plateau Volcanics which, because of the absence of any erosion at the top, are thought to be about the top of Lower Cambrian.

The contact of the Antrim Plateau Volcanics above with the Mt. House Beds and the upper portion of the Victoria River Group below shows deep erosional dissection, and the Volcanics, in places, are valley-fills.

Because of this erosional unconformity the Mt. House Beds and the top of the Victoria River Group are placed tentatively in the Upper Proterozoic but, if the Volcanics are high in the Lower Cambrian, it is possible that, with rapid erosion, they may be wholly or partly lower Lower Cambrian. Some fossils found in these units show a distinct similarity to forms described from the Lower Cambrian in other parts of the world.

The Walsh Tillite, Warton Beds, Mornington Volcanics, and King Leopold Formation, which underlie the Mt. House Beds, are thought to be Upper Proterozoic.

There is no doubt that with more detailed mapping many of the equivalents of the units of the Kimberley Block will be recognised in the Victoria River Group.

Another relationship which has been noted in the past is that of the Nullagine Formation with sediments of the Kimberley Block. In fact for many years the loose term Nullagine has been applied to the late Proterozoic sediments of the Kimberley Block. These two areas are separated by the large Palaeozoic and Mesozoic Canning or Desert Basin and although probably they are both of Upper Proterozoic age there is very little similarity in lithology or sequence.

The Upper Proterozoic sequence in South Australia appears to be similar to that of the Kimberley Block and if the term Adelaidean System is to be used throughout Australia, then the Upper Proterozoic sediments of the Kimberley Block and the Victorian River Group could be tentatively placed in the Adelaidean System.

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THE CAMBRIAN IN SOUTH AUSTRALIA

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SUMMARY

A comprehensive historical account of published work on the Cambrian and its relation to the Precambrian of South Australia is given. The stratigraphy of seven areas distributed over 340 miles in a north-south direction has been studied in detail and twelve faunal assemblages recognised by the author. Most of these assemblages are almost entirely new and the new elements comprising them as yet undescribed, but previously described faunas have been fixed in the stratigraphic succession for the first time. Cambrian rocks in South Australia have been shown to range from Lower Cambrian to middle Middle Cambrian. A new faunal province for the Lower Cambrian is indicated, but a lower Middle Cambrian fauna can be related to a comparable fauna in the Northern Territory. The base of the Cambrian is conventionally accepted as the base of the Pound Sandstone. The opinion that it might be found at the top of this formation is expressed.

Evidence of a slow but persistent regression within much of the Adelaidean Geosyncline during the Lower Cambrian is substantiated on faunal evidence, whilst in the southern part of the known limits of the geosyncline evidence of a Lower Cambrian orogeny has been found. This orogeny initiated renewed sedimentation giving rise to the unfossiliferous metasediments of the Kanmantoo Group which is assigned on structural evidence to a middle Lower Cambrian extending to a middle Middle Cambrian age. A short-lived lower Middle Cambrian transgression is evident in the Northern Flinders Range. Sedimentation within the geosyncline ended with a major orogeny which is dated as middle Middle Cambrian.

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HISTORICAL INTRODUCTION

Fossils subsequently recognised as Cambrian in age were first discovered in Australia in 1878 by J.G.O. Tepper at Ardrossan on Yorke Peninsula, South Australia. Tepper (1879) recorded this important discovery in a short paper on the geology of the Ardrossan area, in which he outlined the stratigraphic succession. A "variegated and a dark coloured limestone" in which the fossils occurred was named by him the Parara Limestone. Later Tepper (1881) somewhat modified his original ideas on the order of succession within this same region. Tate (1879) made a preliminary examination of the fauna Tepper had collected and tentatively held the opinion that it was Lower Silurian of Murchison in age. H. Woodward (1884) described two trilobites found by Tepper as *Dolichometopus tatei* and *Conocephalites australis* and also asserted their age to be Lower Silurian.

R. Etheridge Jun. (1890) was the first to demonstrate the Cambrian age of the Ardrossan fauna. He did so from an examination of Archaeocyatha from Ardrossan and three localities in the Flinders Range submitted to him by Tate. The discovery of Cambrian fossils at Curramulka some 20 miles to the south of Ardrossan was reported by Fletcher in a brief note (1890). Pritchard (1892) carried out a geological examination of the area and collected Cambrian fossils which were submitted to Tate for examination. In that year Tate (1892) described several new species. He enumerated the fauna described to that date, remarking that "at least twenty-three determinable species have been elaborated." Tate assigned the fauna to "the Lower Cambrian or *Olenellus*-zone" and thus was the first to recognise its Lower Cambrian age. Another Cambrian trilobite from Ardrossan was described by Etheridge (1898) as *Ptychoparia howchini.*

Of great interest was the discovery of Archaeocyatha and other Cambrian fossils in the Normanville-Sellick Hill region to the south of Adelaide as reported by Howchin (1897). Prior to this time the geological age of the rocks composing the Mount Lofty Ranges was a matter of conjecture, and this single discovery helped to clarify the issue although it was not until years later that stability of opinion regarding their age was reached. Howchin (1904; 1906) elucidated the geological succession on the western side of the Mount Lofty Ranges in the immediate neighbourhood of Adelaide and considered all the beds of this region which occurred above the Archaean Complex and which formed a conformable sequence, to be Lower Cambrian in age. These beds were later named the Adelaide Series but are known today as the Adelaide System, of Upper Proterozoic age. (These Adelaidean System rocks of the Mount Lofty Ranges continue northwards into the Flinders Range region where they are overlain conformably by fossiliferous Cambrian rocks.)

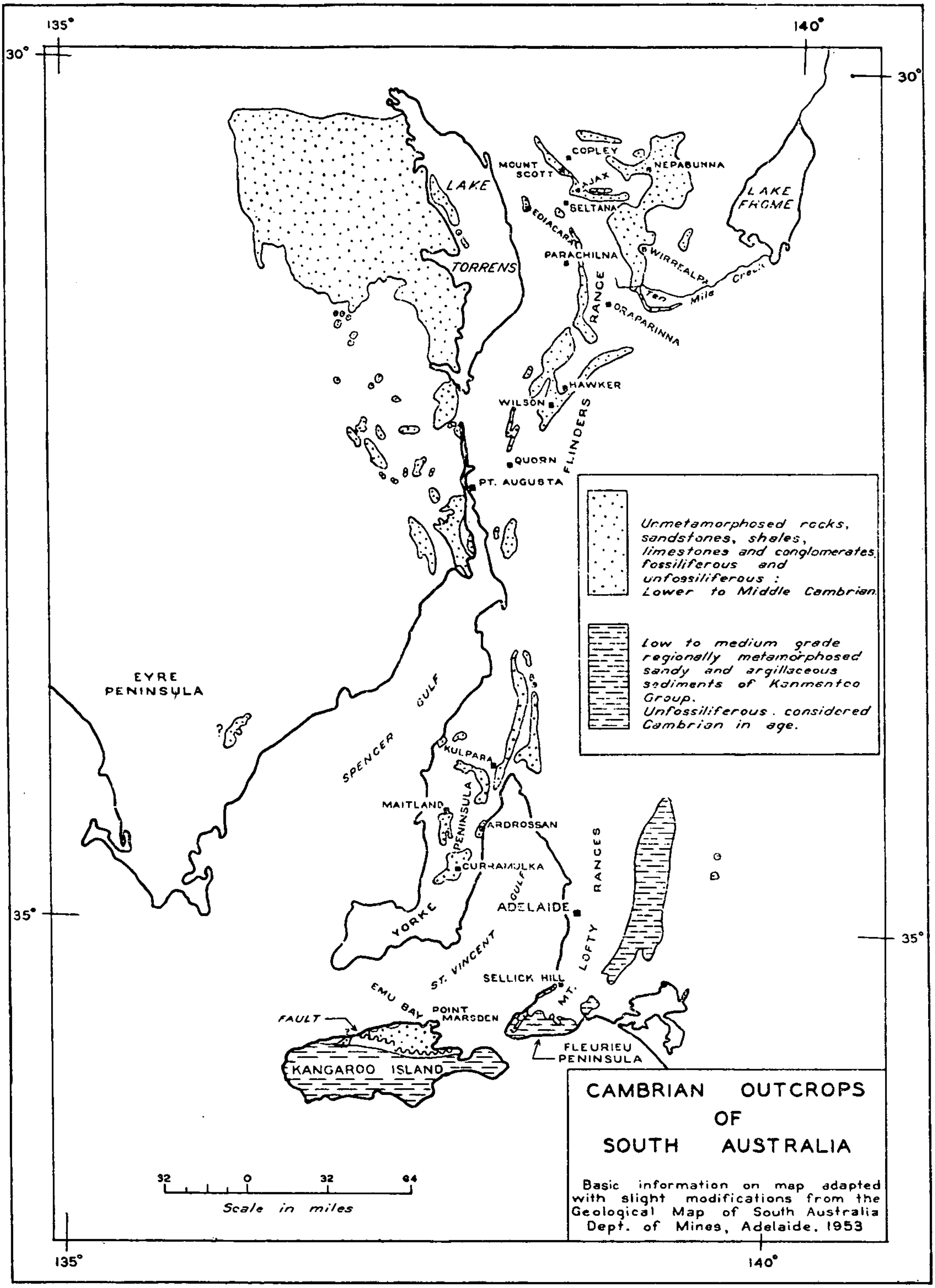
A number of Cambrian fossils collected by Howchin from two widely separated limestone formations in the vicinity of Wirrealpa in the Flinders Range were described by Etheridge Jun. (1905). Many of Etheridge's original generic references were later revised by Walcott (1912) who suggested Lower? Cambrian and Middle? Cambrian ages for the fossils concerned.

The so-called Cambrian rocks of both the Mount Lofty and Flinders Ranges were divided by Howchin (1907) into Lower and Upper Cambrian. The boundary was drawn at the top of the Brighton Limestone, since the beds above this formation are composed of red coloured rocks or as Howchin termed them "Purple Slates series" while those below are not coloured red. Only Howchin's Upper Cambrian rocks contained definite fossil remains.

The study of the Archaeocyatha which had figured so prominently in the assigning of a Cambrian age to the Ardrossan and related faunas was taken up by Griffith Taylor. A short note on them appeared in 1907, and this was followed by a comprehensive memoir in 1910 in which thirty-two new species were described, most of them coming from the now famous Ajax Mine locality of the Flinders Range. Taylor reported three forms, two from Ajax and one from Wirrealpa as specifically identical with forms described by Bornemann from the Lower Cambrian of Sardinia.

The geology of the Ardrossan Cambrian beds was re-investigated and discussed by Howchin (1918), who revised the order of succession as given by Tepper (1879; 1881). Howchin demonstrated that the lowest bed of the sequence was in part the Ardrossan Sandstone of Tepper, which the latter author showed on his map as conformably overlying the Parara Limestone. Howchin considered that the conformable sequence from the basal grits up to the top of the fossiliferous Parara Limestone was Upper Cambrian in age, in accordance with his views as stated in 1907. The Cambrian sequence in this region rests unconformably on the Archaean complex.

Fig. 1. *Cambrian outcrops of South Australia.* Areas where Cambrian or presumed Cambrian rocks occur are shown in fig. 1. These rocks are divisible into two groups. Metamorphosed strata (Kanmantoo Group) occur in an arcuate belt on the southern side of Kangaroo Island and on the eastern side of the Mount Lofty Ranges. They have so far yielded no fossils but they are dated on structural evidence as ranging from middle Lower to middle Middle Cambrian. The remaining outcrops include both fossiliferous and unfossiliferous rocks ranging in age from Lower Cambrian to middle Middle Cambrian. They are essentially unmetamorphosed, except for small areas which occur within the metamorphic belt roughly delineated by the Kanmantoo Group metasediments. No fossils are known in the rocks shown outcropping west of Port Augusta and Lake Torrens but they have been dated by various workers as equivalents of the Pound Sandstone which is taken as basal Cambrian. Unfossiliferous limestones are known to overlie the sandstones west of Lake Torrens. Fossiliferous Cambrian rocks are known in practically all the remaining areas shown on the map. The Cambrian age for the isolated outcrop on southern Eyre Peninsula is indicated on the Department of Mines, Geological Map of South Australia.


135°
140°
30°
30°
35°
35°
135°
140°
LAKE
TORRENS
LAKE
FROME
MOUNT
SCOTT
COPLEY
NEPABUNNA
AJAX
SELTANA
EDIACARA
PARACHILNA
WIRREALPA
Ten Mile Creek
ORAPARINNA
RANGE
HAWKER
WILSON
FLINDERS
QUORN
PT. AUGUSTA
EYRE
PENINSULA
SPENCER GULF
KULPARA
MAITLAND
PENINSULA
ARDROSSAN
CURRAMULKA
YORKE
GULF
ADELAIDE
RANGES
LOFTY
MT.
ST. VINCENT
SELLICK HILL
EMU BAY
POINT
MARSDEN
FAULT
KANGAROO ISLAND
FLEURIEU
PENINSULA
Unmetamorphosed rocks, sandstones, shales, limestones and conglomerates, fossiliferous and unfossiliferous : Lower to Middle Cambrian.
Low to medium grade regionally metamorphosed sandy and argillaceous sediments of Kanmantoo Group. Unfossiliferous. considered Cambrian in age.
CAMBRIAN OUTCROPS OF SOUTH AUSTRALIA
Basic information on map adapted with slight modifications from the Geological Map of South Australia Dept. of Mines, Adelaide, 1953
32 0 32 64
Scale in miles

Etheridge (1919) in revising the Cambrian trilobites of Australia discussed the South Australian species and doubtfully referred all of them to the genus *Ptychoparia* (?) except one which he referred, again with doubt, to *Olenellus* (?). This latter form was referred by Walcott (*in* Howchin, 1920) to *Redlichia* whilst the reference of the remaining species to *Ptychoparia* was doubted. Etheridge considered these trilobites to be Cambrian in age and would not use the terms Lower and Upper Cambrian because of the lack of knowledge of the Cambrian within Australia at that time.

Howchin (1922) discussed more fully the Cambrian sequence met with in the Wirrealpa area which he had already referred to (Howchin, 1907) and illustrated his remarks with a geological cross-section of the beds concerned. This Cambrian sequence is of great importance as it is the most complete in the State, and it contains a great thickness of beds including fossiliferous limestones younger in age than the "Archaeocyathinae Limestone." The fauna from this former limestone—the "*Obolella* Limestone" of Howchin (Wirrealpa Limestone, this paper) —was described by Etheridge (1905).

David (1922) gave the title "Adelaide Series" to all the strata of the Adelaide region which occurred below the "Archaeocyathinae limestones" and above the Archaean Complex. He suggested a Proterozoic (?) age for the series.

A comprehensive review of the occurrences of Cambrian fossiliferous rocks in South Australia was given by Howchin (1925). Besides dealing with all the published occurrences to that date, a number of new localities were added and the geological features of each locality briefly discussed.

Madigan (1925; 1926) reported that whilst geologically mapping the coastline of Fleurieu Peninsula, "*Salterella*" was found at Myponga Jetty in limestone 340 feet below limestones with Archaeocyatha, whilst below the "*Salterella* beds" were abundant annelid trails in arenaceous and flaggy beds. However from his mapping of the Willunga Scarp, Madigan (1927) was able to demonstrate that the Cambrian beds and Adelaide Series of the Sellick Hill-Carrickalinga Head region, which form a conformable sequence, were overturned to the west. Thus the fossiliferous beds of Myponga Jetty are stratigraphically above the limestones with Archaeocyatha and not below as reported earlier by Madigan (op. cit.) and later by David (1928; 1932) and Kobayashi (1942). The so-called "*Salterella*" from Myponga Jetty must be referred to *Hyolithes* (unpublished observation).

From his world wide analysis of the age of the Archaeocyatha, David (1927) concluded that the Adelaide Series might well be Lower Cambrian and not Proterozoic as he had suggested in 1922. This was in close agreement with what Howchin had consistently asserted from the year 1907.

Howchin (1929) finally placed the Lower Cambrian boundary at the top of the Brighton Limestone and limited the term Adelaide Series to all the beds above the Archaean complex and below this boundary. However David (1932) was less definite in his opinion and assigned that part of Howchin's so-called "Purple Slates series" which occurs above the Brighton Limestone and below the "Archaeocyathinae limestones" to a "Newer Proterozoic (or possibly Lower Cambrian)" age.

The Cambrian beds of the Kulpara district, Yorke Peninsula, previously discussed by Howchin (1925), were remapped by Barnes and Kleeman (1934) with the result that a more precise understanding of the order of the succession was obtained. Trilobites which were collected from shale and limestone were examined by F. Chapman who referred them to two species of the genus *Ptychoparia* and assigned a Middle Cambrian age to the beds.

In 1924 fossiliferous Cambrian rocks were discovered by Mawson in the vicinity of Mount McKinlay in the northern part of the Flinders Range. Details of two sections crossing these Cambrian beds, the Italowie and Nepabunna Sections, were given by him in 1937. Algae, Archaeocyatha and "pteropods" were the only fossils recorded. He included the thick quartzite formation underlying the fossiliferous beds of this region in the Cambrian. In 1938 he expressed a similar opinion when discussing the Cambrian sequence of Parachilna Gorge in the central part of the Flinders Range. He named the quartzite, which was conformable with the fossiliferous beds above, the "Pound Quartzite" "as this quartzite is responsible for the physiographic feature known as Wilpena Pound and other pound formations in the Flinders Range." The base of this formation he took as the base of the Cambrian and referred all the beds below and conformable with it to the sub-Cambrian or Proterozoic. Archaeocyatha were the only fossils recognised in the 3500 feet of calcareous beds above the Pound Quartzite (1500 feet) at this locality. A re-investigation of the Cambrian beds in the Wirrealpa region was carried out by Mawson who (1939) clearly outlined the stratigraphy of this important region.

Segnit (1939) considered the top of his "Flinders Range Sandstone-Quartzite Series" (Mawson's Pound Quartzite) to be the top of the Upper Precambrian on the evidence of a supposed stratigraphic break between it and the overlying fossiliferous Cambrian limestones. Segnit mapped and discussed a number of areas of Cambrian, Precambrian and supposed Cambrian rocks within the state, but as he failed to realise the immense thickness and variety of the rocks belonging to the two systems, he made correlations on the basis of similar lithology which resulted in serious errors in his work.

The Precambrian-Cambrian stratigraphy and structure of the Central Flinders Range in the vicinity of Oraparinna was discussed in summary by Mawson (1942). He showed that a conformable succession existed from the Late Proterozoic glacial sediments into the Cambrian. An unconformity at the base of the glacial beds was suggested.

In discussing the Cambrian succession and faunas of South Australia, Kobayashi (1942) has misinterpreted some and neglected to use others of the published works on the Cambrian succession and has been led to erroneous conclusions particularly in regard to his tentative zonation of the South Australian Cambrian.

Howchin's type area for the Adelaide Series on the western Mount Lofty Ranges was mapped and revised by Sprigg (1942), who divided the series into a lower, middle and upper Adelaide Series. Later Sprigg (1947; 1949) described Lower Cambrian jellyfish found near the top of the Pound Sandstone at Ediacara in the Flinders Range. He also reported algae from the same horizon.

The Pound Sandstone which underlies the limestones with Archaeocyatha contains the lowest fossiliferous horizon yet recorded in the State, apart from algae and traces of worms which have been reported in Adelaide System rocks. Organic remains from the latter described by David and Howchin (1896), Chapman (1927; 1929), David (1922; 1928), and David and Tillyard (1936) are no longer considered as identifiable organic remains.

The Adelaide Series, a term originally suggested by David (1922) and later modified and adopted by Howchin (1929) was referred to by Mawson (1948) as the Adelaide System. Mawson and Sprigg (1950) reaffirmed this latter opinion and subdivided the system (28,000 feet) into three series, namely, the Torrensian Series at the base (9450 feet), the Sturtian Series (12,600 feet) and the Marinoan Series at the top (5920 feet). Details of the formations encountered in each series are listed. The type area was the succession as met with in the Adelaide Region previously described by Howchin (1904; 1906; 1929) and more recently by Sprigg (1942; 1946). David and Browne (1950) independently elevated the Adelaide Series to the rank of System and following Howchin drew the Precambrian-Cambrian boundary at the top of the Brighton Limestone. The Marinoan Series of Mawson and Sprigg was placed in the Cambrian. The System was divided into a Lower and Upper Series, each of which in turn was divided into Stages. However this latter subdivision is incorrect as pointed out by Mawson and Sprigg (1950) and today the current views as put forward by the latter authors on the status of the system are widely accepted, with the addition that another Series, the Willouran Series (10,000 feet), [Sprigg (1952), Dickinson et al. (1954; 1955)], occurs below the Torrensian in the more north-westerly parts of the Adelaidean Geosyncline.

A feature of the southern extremity of the Adelaidean Geosyncline is a sequence of mainly metasediments which occurs on the eastern side of the Mount Lofty Ranges and which continues as a broad arc through Fleurieu Peninsula into Kangaroo Island. These rocks constitute what is known as the Kanmantoo Group. The Group was reviewed by Sprigg and Campana (1953). On structural and stratigraphic evidence, they assigned to it a Cambrian age, with a possible upward extension into the Ordovician, although no fossils have so far been found in it. The rocks of the group consist dominantly of greywackes, phyllites, mica schists and schistose sandstones and quartzites, which according to Sprigg and Campana may attain a thickness of 30,000 feet. In general the grade of metamorphism is low. Igneous intrusions and granitized sediments also occur in some areas.

The Kanmantoo Group sediments are different in character from the remainder of the Cambrian sediments of the mainland. According to Sprigg and Campana (1953) "its dominant facies are comparable with the Alpine Flysch." This would also be implied by the nature of the greywackes described by Campana, Wilson and Whittle (1954). It is suggested in the present paper that the sediments composing this group resulted from an orogeny predating the major orogeny which terminated sedimentation within the known limits of the Adelaidean

Geosyncline. Evidence of this postulated early orogeny has already been discovered on Kangaroo Island (see discussion on Kangaroo Island Region). Various opinions have been expressed on the age of the sediments now recognised to belong to the group. Woolnough (1908) and Hossfeld in part (1935) regarded such rocks as Precambrian in age, whereas Howchin (1907) favoured a Cambrian age as he considered them metamorphosed equivalents of the Adelaidean System rocks on the western side of the Ranges, which at that time were thought to be Cambrian. From his mapping on the Fleurieu Peninsula, Madigan (1925) reasonably demonstrated that the limestones with Archaeocyatha which occur at Sellick Hill continued to the south where they were represented by marbles. On this evidence he assigned a Cambrian age to the rocks of the region.

Campana, Wilson and Whittle (1954; 1955) have shown that on Fleurieu Peninsula "the Kanmantoo beds form the top horizon of both limbs of an overturned anticline, the core of which consists of metamorphosed Cambrian slates and limestones (Rapid Bay marble), the latter overlying rocks of the Adelaide System." Thus the base of the Cambrian in this region has been adjusted to the base of the "Archaeocyathinae Limestone" or its metamorphosed equivalent. A transition sequence of quartzites and slates has been suggested as the equivalent of the Pound Sandstone which is regarded as basal Cambrian in the Flinders Range. The base of the Kanmantoo Group is taken at the top of the slates or phyllites with phosphatic nodules which lie directly on the fossiliferous limestones or the Rapid Bay marble.

In the vicinity of Macclesfield, Sprigg and Wilson (1954) place the Lower Cambrian boundary at the base of a "quartzite and sandstone quartzite" formation. This is overlain by phyllites and schists with the Macclesfield Marble at the top. All the beds above this marble, which is equated with the "Archaeocyathinae Limestone," are placed in the Kanmantoo Group.

In 1952 R. C. Sprigg discovered a Cambrian fauna at Emu Bay, Kangaroo Island. *Redlichia*, *Lusatiops*, *Hyolithes* and a possible *Acrothele* were identified by Glaessner (*in* Sprigg, 1955), who provisionally placed the fauna in the uppermost Lower Cambrian. On his map, Sprigg (1954) shows a belt of Cambrian rocks in the central and northern part of the island overlying Adelaide System rocks. The southern edge of this belt is shown faulted against? Adelaide System phyllites and quartzites which are in turn directly overlain by Kanmantoo Group rocks, or, as is shown in one locality, by possible Cambrian rocks. Thus the base of the Kanmantoo Group in this region rests on ?Adelaide System rocks.

Howchin (1899) suggested a Middle or Upper Palaeozoic age for the Cambrian beds of Point Marsden whereas Madigan (1928), after finding boulders with Archaeocyatha in a conglomerate on Cape D'Estaing, assigned a post-Cambrian age to them, probably Ordovician, an age previously suggested by H. Y. L. Brown (1908). Wade (1915) considered these beds as Cambrian in age.

Since 1953 the writer has studied a number of Cambrian sequences in South Australia. All the areas studied, except for a small area between Wilson and Quorn, have been reported on, at least in part, by various other authors as outlined previously. The correlation chart, figure 2, briefly portrays the results of these stratigraphic studies within the areas examined. Correlation with other known Cambrian areas within the state is not feasible yet because of the insufficiently known fossil record in these places.

At least twelve sufficiently distinct faunal assemblages have been recognised in the areas examined. The faunas described by the earlier workers fall into some of these assemblages but other assemblages are completely new. All the new elements of these faunas are as yet undescribed and preliminary examination of the trilobites in particular shows the existence of a new province for the Lower Cambrian in this state. The fauna will be discussed in a later section of this paper and in subsequent publications.

STRATIGRAPHY

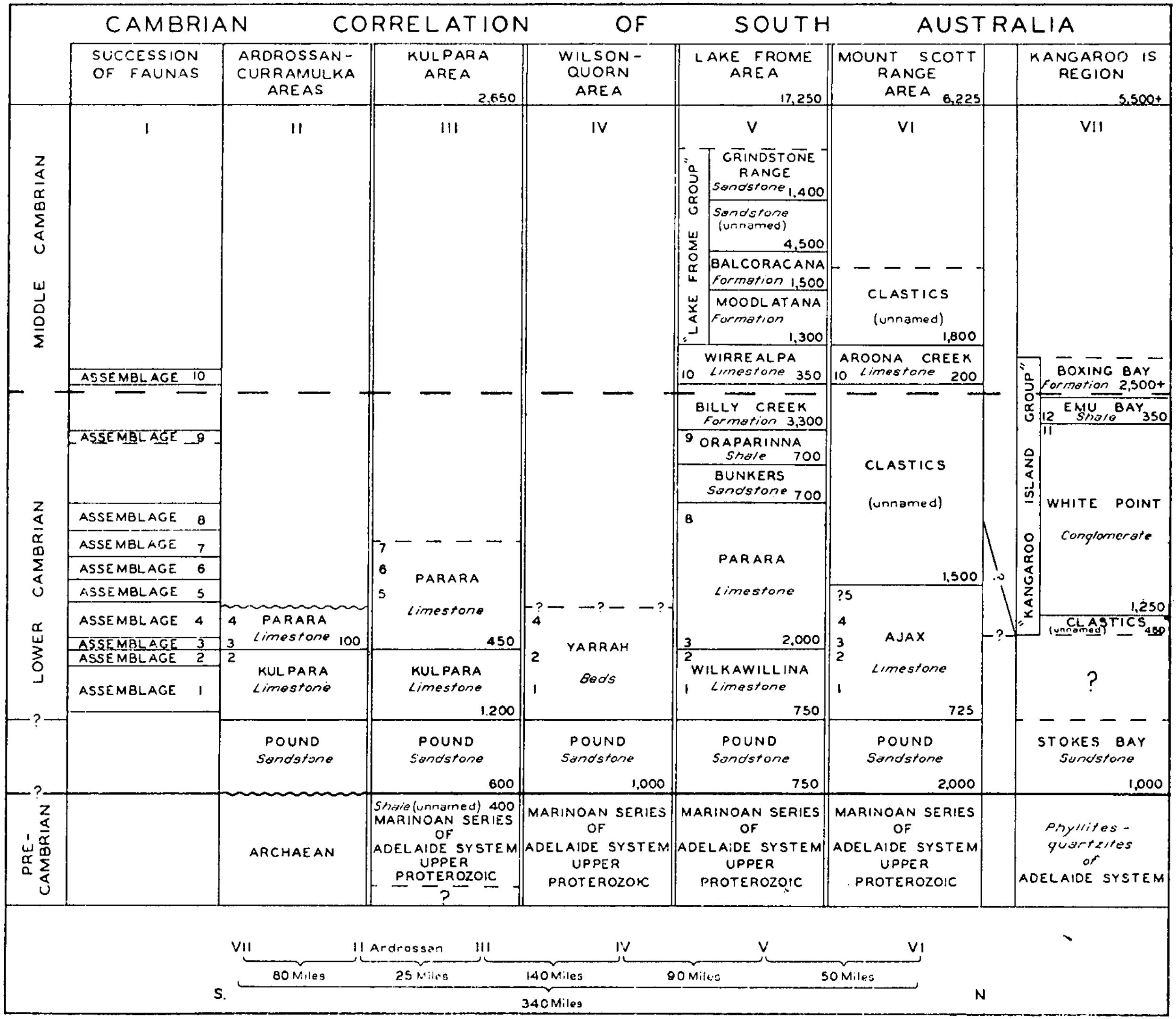
A study of the Cambrian geology of South Australia by the present writer has shown that the environment of deposition on the mainland was quite different from that recorded on Kangaroo Island. On the mainland, correlation of the formations recognised can generally be carried from one area to another with relative ease but none of these formations can be linked satisfactorily with those so far recognised on Kangaroo Island. For this reason it is proposed to discuss these two regions separately.

Most of the formational names used in this paper are new and as yet unapproved. They are used primarily to facilitate description.

Fig. 2. *Correlation chart of selected areas of Cambrian rocks in South Australia.* Apart from the Pound Sandstone, Stokes Bay Sandstone, Parara Limestone, Ajax Limestone and the Grindstone Range Sandstone, all the formational names shown in columns II to VII are presented here informally. Two separate regions of Cambrian rocks are covered by the correlation chart, namely the Mainland Region, which embraces six separate areas arranged from south to north and covered by columns II to VI, and the Kangaroo Island Region in column VII where the southernmost occurrence of Cambrian in South Australia is known. The base of the Cambrian is provisionally taken as the base of the Pound Sandstone or as is indicated in one case by Stokes Bay Sandstone, although as yet no conventional Cambrian fossils are known from these formations.

The Cambrian sequences are shown as conformable with Upper Proterozoic Adelaide System rocks in columns III to VII whilst in Column II, in the Ardrossan area only, Archaean rocks unconformably underlie the Cambrian. The "Kangaroo Island Group" (column VII) is a conformable sequence but its base is eliminated by faulting. A gap is shown between it and Stokes Bay Sandstone which is taken as basal Cambrian in this region. Sediments which might bridge this gap are as yet unknown owing to our lack of knowledge within this region. Evidence has enabled us to place the lower limit of the Group above faunal assemblage No. 2 but this limit may occur much higher than is indicated on the chart. The top of the Cambrian sequence is eroded in II, faulted against Precambrian in VI and possibly faulted in III and V. Thicknesses of the beds in feet are given in the columns where possible together with total thicknesses for individual areas at the head of these columns.

The succession of faunas is given in column I and their presence is indicated in the various columns by corresponding numbers. The Lower Cambrian-Middle Cambrian boundary is shown by a broken line occurring in unfossiliferous rocks in columns V and VI below faunal assemblage 10 whereas in column VII the boundary is indicated as occurring in the Boxing Bay Formation above faunal assemblages 11 and 12. The faunal assemblages 1 to 12 are listed in the text in as much detail as can possibly be given at this stage of the investigation.


CAMBRIAN CORRELATION OF SOUTH AUSTRALIA
SUCCESSION OF FAUNAS
ARDROSSAN - CURRAMULKA AREAS
KULPARA AREA 2,650
WILSON - QUORN AREA
LAKE FROME AREA 17,250
MOUNT SCOTT RANGE AREA 6,225
KANGAROO IS REGION 5,500+
I
II
III
IV
V
VI
VII
MIDDLE CAMBRIAN
LOWER CAMBRIAN
PRE-CAMBRIAN
"LAKE FROME GROUP"
GRINDSTONE RANGE Sandstone 1,400
Sandstone (unnamed) 4,500
BALCORACANA Formation 1,500
MOODLATANA Formation 1,300
CLASTICS (unnamed) 1,800
ASSEMBLAGE 10
WIRREALPA Limestone 350
10
ARROONA CREEK Limestone 200
10
BOXING BAY Formation 2,500+
"KANGAROO ISLAND GROUP"
EMU BAY Shale 350
12
11
BILLY CREEK Formation 3,300
ASSEMBLAGE 9
9 ORAPARINNA Shale 700
BUNKERS Sandstone 700
CLASTICS (unnamed) 1,500
WHITE POINT Conglomerate 1,250
ASSEMBLAGE 8
ASSEMBLAGE 7
ASSEMBLAGE 6
ASSEMBLAGE 5
ASSEMBLAGE 4
ASSEMBLAGE 3
ASSEMBLAGE 2
ASSEMBLAGE 1
4 PARARA Limestone 100
3
2
KULPARA Limestone
7
6
5
PARARA Limestone 450
KULPARA Limestone 1,200
4
2
1
YARRAH Beds
8
PARARA Limestone
3 2,000
2
WILKAWILLINA Limestone 750
1
?5
4
3
2
1
AJAX Limestone 725
CLASTICS (unnamed) 450
?
POUND Sandstone
POUND Sandstone 600
POUND Sandstone 1,000
POUND Sandstone 750
POUND Sandstone 2,000
STOKES BAY Sandstone 1,000
ARCHAEAN
Shale (unnamed) 400
MARINOAN SERIES OF ADELAIDE SYSTEM UPPER PROTEROZOIC
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Phyllites - quartzites of ADELAIDE SYSTEM
VII
II Ardrossan
III
IV
V
VI
80 Miles
25 Miles
140 Miles
90 Miles
50 Miles
S.
340 Miles
N

I. THE MAINLAND REGION

The Cambrian deposits studied on the mainland occur along a north-south belt, between Curramulka and Mount Scott, over a distance of 280 miles. The three southern localities occur on Yorke Peninsula in the Curramulka, Ardrossan and Kulpara areas, whilst the remaining three occur in the Flinders Range between Wilson and Quorn, in the Lake Frome area and in the Mount Scott Range.

A. *Kulpara Area*

The most complete sequence of Cambrian beds on Yorke Peninsula occurs in The Hummocks near Kulpara, situated 25 miles N.N.E. of Ardrossan. Howchin (1925), and Barnes and Kleeman (1934) have previously investigated this sequence. The total thickness of beds considered to be Cambrian in age is 2250 feet.

Pound Sandstone. The lowest beds seen in the area were examined along a creek that flows east through sections 497, 498 Hundred of Kulpara (see map, Barnes and Kleeman (1934)). Below the Pound Sandstone is an extensively drag folded sequence of chocolate coloured micaceous shales with thin interbedded quartzites and red- to chocolate-coloured siltstones. The sequence occupies the core of an anticline which plunges to the south at a low angle. A band of grey to brown sandstone, 20 feet thick, occurs in the lowest portion of this shale sequence which is estimated to be at least 400 feet thick. No formational name has been assigned to this shale sequence. It is regarded as belonging to the upper part of the Proterozoic Marinoan Series.

Conformably above is a sequence of red- to brown-coloured sandstones and quartzites, 600 feet thick, which I correlate with the Pound Sandstone of the Flinders Range. The formation is best examined on the eastern limb of the south plunging anticline. The formation on the western limb is extensively faulted. The lower members of the formation are massive and cross-bedded, show occasional slumping and contain appreciable amounts of dark minerals ("ilmenite"). The more strongly "ilmenitic" bands are nearly black. In the upper division there are brown-grey fine-grained sandstones and quartzites with appreciable amounts of feldspar. Small, rounded quartz pebbles are not infrequent in some bands. Above are thin flaggy red and brown sandstones containing clay gall impressions. At the top of the Pound Sandstone are beds which consist of calcareous shales and argillaceous sandstones through which are scattered limonite, haematite and quartz developments. The formation of iron oxides at the top of the Pound Sandstone has been observed in six localities in the Flinders Range. Howchin's faults in the north and south west portions of the area, postulated on the presence of limonite and quartz developments, are not correct. However some faulting does occur in the northern part of the area concerned. No fossils have been found in this formation in this area.

Kulpara Limestone. Conformably overlying the Pound Sandstone is a sequence of limestones about 1200 feet thick which I propose to call the *Kulpara Limestone.* The formation is best examined in The Hummocks in the second creek north of the main road connecting Kulpara and Port Wakefield. The formation consists dominantly of limestone but also contains dolomitic and siliceous limestones and at least one prominent band of yellow dolomite in the upper part. The siliceous limestones contain chalcedony nodules. One of these horizons occurs 400 feet above the base and another near the top of the formation. The limestones are variously coloured blue-grey, brown, yellow and pink-white.

The well defined yellow dolomite in the upper half of the formation is overlain by light blue-grey limestone, dark blue-grey siliceous limestone and intraformationally brecciated limestone. The latter is the highest bed recorded in the formation along the line of traverse, as the top part of the formation is obscured. No fossils have as yet been found in the formation in this area. The sequence from the yellow dolomite to the brecciated limestone is similar to that encountered in the Ardrossan area. Fossils of faunal assemblage No. 2 occur in this formation in the Ardrossan area between the upper part of the brecciated limestone and the base of the Parara Limestone. Beds in a corresponding position occur to the north of the line of traverse but have not yet been investigated.

Parara Limestone. This formation was examined in the first creek in The Hummocks south of the main road linking Kulpara and Port Wakefield. The base of the formation is not exposed here but is seen in section 235, a mile to the north-east. 400 feet of the formation is visible, and as the lowest bed to outcrop is estimated to be at least 50 feet above the true base of the formation 450 feet may be taken as the approximate thickness for the formation. The top is not seen because of soil cover and possible faulting.

The formation consists predominantly of blue-grey mottled and rubbly limestones, the limestone nodules being set in a yellow-green dolomitic and argillaceous matrix which on leaching forms a yellow shale. Massive limestone bands and shales are also present. The formation in this area is decidedly more argillaceous than the same formation at Curramulka and Ardrossan but it is still a dominantly calcareous formation. No fossils were collected in the first 70 feet of outcrops. Three distinct faunal assemblages were collected between 70 feet and 345 feet above the first outcropping bed, most of the forms being trilobites, but as yet unidentified. These forms constitute faunal assemblages Nos. 5, 6 and 7. Faunal assemblages Nos. 3 and 4, which occur in the basal part of the Parara Limestone or its equivalent elsewhere, have not been recorded by the author in this formation at Kulpara, but in this area M. F. Glaessner has collected *Helcionella* sp., which belongs with one of these assemblages. Faunal assemblages Nos. 5, 6 and 7 are unknown elsewhere, except for fragments of one trilobite in faunal assemblage No. 5 which are believed to be allied to an undescribed genus occurring with and above assemblage No. 4 in the Mount Scott Range area.

B. *Ardrossan Area*

The geology of this historically important area has been discussed by Tepper (1879; 1881) and Howchin (1918; 1925). My own observations are in close agreement with those of Howchin except that his deduced thickness of 300 feet for the sequence is probably much less than the true thickness which is indeterminable as the older beds of the sequence are mainly obscured by younger rocks. The sequence is traceable from a point three-quarters of a mile north-west of Ardrossan to Rogues Gully, 5 miles to the south of Ardrossan. The lowermost beds occur to the north of the area where they are covered by Tertiary beds. From a point a mile south-west of the town, to Horse Gully 2 miles to the south, progressively younger beds occur in a low escarpment of a plunging anticline which runs parallel to the coast, half a mile inland, but south of Horse Gully a reversal in plunge brings older beds to the surface.

Pound Sandstone. The oldest beds, which I correlate with the Pound Sandstone of the Flinders Range, outcrop in shallow quarry faces in section 77, Hundred of Cunningham (see Tepper's map, 1879). They consist of reddish coloured coarse grits and conglomerates rich in feldspar and mica which pass upwards into more normal sandstones. Archaean schists and pegmatites occur a short distance to the west. The contact between the two groups of rocks is obscured, but there is no doubt whatsoever that the formation rests unconformably on the schists as they do in the Winulta Creek, 10 miles to the north, and in the Maitland area as proved by boring. No thickness for this formation can be obtained in this area because of Tertiary cover but in the Winulta area it is at least 300 feet thick. No fossils have been found in the formation here. Tepper (1879) considered the above outcrops as stratigraphically above the Parara Limestone. He called these beds the Ardrossan Sandstone; but as the term was also applied to Tertiary sandstones it is best diregarded.

Kulpara Limestone. Above the Pound Sandstone and below the Parara Limestone is a sequence of limestones which contains a prominent band of yellowish coloured dolomite. These limestones are correlated with the top members of the Kulpara Limestone which occurs some 25 miles to the north. Only the top 300 to 350 feet of the formation can be examined, its lower contact with the Pound Sandstone being nowhere visible. The yellow dolomite is the lowest bed visible and crops out in the crest of an anticline which forms the escarpment to the south of Ardrossan. The anti-cline plunges at a low angle to the south just north of Horse Gully and in so doing exposes younger beds. The dolomite is overlain by 60 feet of a fine-grained blueish grey limestone similar in appearance to limestones in a similar stratigraphic position which carry Archaeocyatha elsewhere but no fossils have been found in it here. A thick sequence of grey siliceous limestones occurs above and passes upwards into brecciated limestones and limestones with Archaeocyatha and other fossils. These are best seen in the eastern part of Horse Gully where they are conformably overlain by the Parara Limestone. Over the whole length of the gully the beds are folded into very broad and gentle folds. The section seen in Horse Gully is as follows:

1. At the base of the section: 38 feet of a light blue-grey to yellowish-brown mottled and intraformational brecciated limestone

similar to that occurring in a similar stratigraphic position in the Curramulka and Kulpara districts. Fragments of Archaeocyatha are the only fossils present.

2. 26 feet of mottled grey to pink-and-white limestone, moderately coarse-grained due to recrystallization. Archaeocyatha, *"Micromitra (Paterina)" etheridgei* (Trate); *"Nisusia" compta* (Tate); *"Ambonychia" macroptera* Tate; other undescribed brachiopods, and *Hyolithes conularoides* Tate occur in this bed (Faunal assemblage No. 2).

Parara Limestone

3. Conformably above is the Parara Limestone which has an exposed thickness of 75 feet but it possibly attains a thickness of 100 feet. It is overlain by fossiliferous Tertiary rocks. The formation consists of dark blue-grey massive and rubbly limestones with an interstitial argillaceous and dolomitic matrix. Only the massive bands form good outcrops. The base is marked by a massive band 3 feet thick. *Yorkella australis* (Woodward), is the only trilobite so far found in this band. Associated with it are Archaeocyatha, the gastropods *Helcionella tatei* Resser and *"Ophileta" subangulata* Tate, hyolithids including *Hyolithes communis* Billings, numerous Conchostraca and undescribed brachiopods. (Elements of this fauna are contained in faunal assemblage No. 3.) 29 feet of rubbly limestone occur above this massive basal band but outcrops are poor. Faunas collected in both massive and rubbly bands between 32 and 75 feet above the base of the formation include trilobites allied to *Pararaia* Kobayashi; more than one species is represented, *Yorkella* is absent. The associated fossils include *Helcionella* sp., *"Ophileta" subangulata* and several hyolithids including *H. planoconvexa* (Tate). Apart from the trilobites the remainder of the fauna is similar to that from the basal 3 feet. Fragments of trilobites much larger than *Pararaia* occur at the exposed top of the formation (Faunal assemblage No. 4).

C. *Curramulka Area*

Geological notes on the Cambrian rocks of the Curramulka Basin, which lies 25 miles to the south-west of Ardrossan, have been published by Pritchard (1892) and Howchin (1925). Outcrops in the region are poor because of thick soil and kunkar cover, and the stratigraphy has been pieced together from both surface and subsurface (caves) data. The beds over the whole area are horizontal to slightly undulating. Howchin (1925) has delineated the areal extent of the Cambrian on his map but some exposures do occur outside his limits. Tate (1892) lists most of the fauna described so far from this area. Chapman (1918) has also described three species of Conchostraca from the same area.

Pound Sandstone. No exposures of this formation are known in the area. The nearest known locality for the formation is in Yorke Valley some miles to the west.

Kulpara Limestone. Limited exposures of this formation occur on the surface in the Curramulka township. The lowest beds are exposed in the Curramulka town well, where according to D. J. Taylor (personal communication), the sequence consists of 11 feet of blue-grey siliceous limestone, 15 feet of yellow dolomite, and 65 feet of intraformationally brecciated limestones at the top. These latter limestones outcrop on the surface just south of the town where they are overlain by 30 feet of limestone which includes a bed of mottled grey and buff coloured somewhat crystalline dolomitic limestone. In this latter bed are found Archaeocyatha, "*Micromitra (Paterina)*" *etheridgei*, "*Ambonychia*" *macroptera* and other brachiopods (Faunal assemblage No. 2). It is best seen adjacent to the well itself.

Thus approximately 120 feet of the top of this limestone formation occurs in the Curramulka area. Its similarity to the top of the Kulpara Limestone in the Kulpara and Ardrossan areas, its position in the sequence and its faunal content leave no doubt about this.

Parara Limestone. Approximately 100 feet of the formation occur in the area. Outcrops are limited to small exposures on the side of an escarpment and in and at the mouth of a cave, ½ and 1½ miles to the south-west of the town respectively. At the base of the formation at the former locality massive bands of dark-blue-grey limestone contain "*Salterella*" *planoconvexa*, *Yorkella australis*, *Hyolithes communis* and brachiopods (Faunal assemblage No. 3). *Yorkella* is still present 30 feet above the base of the formation.

The top beds of the formation are seen at the entrance to the cave where dark blue-grey mottled and rubbly limestones are horizontally bedded. *Pararaia, Lingulella* and abundant sponge spicules are the only forms found here so far. *Pelagiella* and *Pararaia* occur together well below the surface in the cave. (All these forms belong to faunal assemblage No. 4.)

Thus in the Curramulka area the exposed Cambrian sequence is about 220 feet thick. The top part of the Kulpara Limestone and the Parara Limestone are the only formations seen.

In summary the Cambrian System on Yorke Peninsula is represented by three formations, namely, Pound Sandstone, Kulpara Limestone and Parara Limestone. The Pound Sandstone is everywhere transgressive onto the Archaean except in the Kulpara area where it is conformable with a shale sequence which is considered as part of the Marinoan Series of Upper Proterozoic age. The Pound Sandstone thins westwards as is evidenced by comparing its thickness at Kulpara and Maitland, 600 feet and 71 feet respectively. The Kulpara Limestone is fossiliferous only in its upper part and contains the distinctive faunal assemblage No. 2. The Parara Limestone is the youngest formation represented. Five faunal assemblages can be recognised within it in the region.

Most of the known localities where Cambrian rocks occur on Yorke Peninsula are listed in Howchin (1918). The occurrences are quite scattered but they indicate the former continuity of Cambrian rocks in the region. In the Kulpara area there is a moderate amount of folding but elsewhere it is slight.

D. *Wilson-Quorn area*

In company with Dr. A. W. Kleeman and students of the Geology Department, University of Adelaide, the author discovered a small area of fossiliferous Cambrian rocks 18 miles north of Quorn in the Flinders Range. These rocks are an extension of the Cambrian rocks of the Wilson area, 20 miles to the north-west, which were discussed by Howchin (1925). The beds are folded into tight anticlines and synclines which plunge northwards. The structure is complicated by an overthrust fault from the west which cuts across the strike of the beds and limits the succession seen on either side of it. The stratigraphy is as follows:

Pound Sandstone. This formation is recognised as the basal bed of the Cambrian in the Flinders Range. In this area it attains a thickness of at least 1000 feet and is composed mainly of red to white sandstones and quartzites. Strong developments of red and yellow ochres and manganiferous iron occur in the 200 to 250 feet of interbedded sandstone and shale at the top of the formation. Red- to purple-coloured shales and siltstones of the Marinoan Series of the Adelaide System conformably underlie the Pound Sandstone. A thick sequence of somewhat arenaceous dolomitic limestones occurs in the Marinoan Series a short distance below the Pound Sandstone.

Yarrah Beds. Overlying the Pound Sandstone is a sequence of limestones and shales here designated the Yarrah Beds. The stratigraphy of these beds has not yet been fully investigated but the following information has been ascertained from work already done in the area.

The lower members of this sequence were examined east of the overthrust about 2 miles south-west of the Willochra Creek. The basal 200 feet of beds consists mainly of dolomitised limestones in which no fossils have been found. These are overlain by an undetermined thickness of blue-grey mottled limestones faulted below younger greenish slates. These limestones contain at least two distinct faunal assemblages. The older assemblage contains only archaeocyathids (faunal assemblage No. 1), whereas the younger assemblage contains besides archaeocyathids, the brachiopods *Kutorgina peculiaris* (Tate), and *"Micromitra (Paterina)" etheridgei* (Tate) (faunal assemblage No. 2).

Adjacent to the Willochra Creek on the western side of the overthrust is a strongly folded sequence of dark blue-grey mottled limestones which pass upwards into greenish coloured calcareous slates with layers of limestone nodules parallel to the bedding. Fragments of trilobites and hyolithids were noted in the limestones at this locality. Adjacent to the Yarrah-Wilson road due west of the above locality an assemblage of trilobites was found in limestones similar to the above but their position in the sequence is not yet clear. All the trilobites are *Pararaia*-like forms except one which is a proparian trilobite, similar to *Pagetia* but combining features which recall both *Dipharus* and *Calodiscus*. Conchostraca, *Lingulella* and Archaeocyatha are also present. This fauna is placed in faunal assemblage No. 4.

E. *Lake Frome Area*

A large area of Cambrian rocks occurs in The Bunkers, in the vicinity of Wirrealpa and Oraparinna in the Flinders Range, about 90 miles north-east of the Wilson-Quorn area. Previous accounts of the geology of the area have been given by Howchin (1907; 1922) but more particularly by Mawson (1939) who has listed thicknesses, fauna and lithology encountered along two traverses across the strike of the beds some 5 miles apart. Howard (1951) has produced a map of portion of the area under discussion. This, while useful for its structural value, does not show the true nature of the succession between the Pound Sandstone and the Wirrealpa Limestone. Etheridge (1905), Walcott (1912) and Chapman (1940) have contributed to the palaeontology of the area. 17,250 feet of Cambrian beds are represented in the area. Mawson (op. cit.) gave 16,500 feet as the thickness of the sequence.

The Ten Mile Creek Section. A section was made across the strike of the beds in the vicinity of the Ten Mile Creek. All the formations recognised along this line of section have an areal extent and can be traced for several miles along the strike. A faulted belt occurs along the line of section in what is here termed the Balcoracana Formation. The data for this formation was obtained further north, just south of the Balcoracana Creek. Apart from this minor break the easterly dipping succession as revealed in the Ten Mile Creek section is complete.

Pound Sandstone. This formation has a thickness of 750 feet. It consists dominantly of red- to chocolate-coloured micaceous, flaggy and cross-bedded sandstones. Red- to chocolate-coloured micaceous shales are prominent throughout the formation. Two thin but conspicuous bands of greyish-white quartzite are also present. Ripple markings, clay galls and slumping were noted in the formation. The Pound Sandstone in this area is notable in that its members are soft and easily eroded. For this reason it does not form high strike ridges which characterise it elsewhere. No fossils have been found in this formation. It is conformably underlain by the Marinoan Series of the Adelaide System.

Wilkawillina Limestone. Conformably succeeding the Pound Sandstone is a sequence of limestones 750 feet thick which are herein termed the Wilkawillina Limestone, the name being derived from the Wilkawillina Gorge in which the limestones are well exposed. The formation contains faunal assemblages Nos. 1 and 2. The basal member, 120 feet thick, consists of unfossiliferous siliceous and dolomitic limestones. Above are light blue-grey, white and pink coloured massive limestones, 465 feet thick which contain a fauna consisting of archaeocyathids only (Faunal assemblage No. 1). These make an appearance 10 feet above the base, are sporadic at first, but become exceedingly abundant from 60 feet above the base. Thin bands of oolitic limestones are present near the base of these massive limestones which are mottled due to thin argillaceous partings within them. The remainder of the formation consists of 165 feet of pink, buff, light blue-grey and white limestones. The are mottled and similar to those below. Besides containing an abundant archaeocyathid fauna they contain *"Micromitra (Paterina)" etheridgei* throughout. *"Ambonychia" macroptera* and *"Huenella" etheridgei* are also present in these beds (Faunal assemblage No. 2). The Wilkawillina Limestone is correlated with the Kulpara Limestone and the basal part of the Ajax Limestone but as it is significantly different from both in lithology a new formational name has been proposed.

Parara Limestone. A sequence of limestones, 2000 feet thick, is conformable with the Wilkawillina Limestone. They are so similar to the Parara Limestone of the Ardrossan area that without hesitation the term can well be applied to them. The formation is scantily fossiliferous throughout.

Lower Member. The lower 500 feet of the formation consists of grey to dark blue-grey limestones, variously mottled and rubbly, flaggy or massive. Some of the limestones are quite sandy and contain blue-grey chalcedony nodules. Thin laminae of dark coloured calcareous shale are interbedded with the limestones. The lower 110 feet of these beds contain the trilobite *Yorkella*, hyolithids, brachiopods and occasional Archaeocyatha (Faunal assemblage No. 3). The remaining 390 feet of limestone are sparingly fossiliferous. *Helcionella, Pelagiella, Hyolithes* Conchostraca and indeterminate fragments of trilobites have been found 260 feet above the base of the Parara Limestone. These fossils are found in both faunal assemblages Nos. 3 and 4 but to which assemblage they belong I am not prepared to say.

Upper Member. The upper 1500 feet of the Parara Limestone consists of a monotonous sequence of dark blue-grey flaggy and thin-bedded aphanitic limestone split by thin laminae of calcareous shales. The lower 240 feet of this aphanitic limestone contain occasional nodules of coarse-grained dark blue-grey limestone. These nodules are ragged in outline and parallel the bedding. The limestones are scantily fossiliferous. *Lingulella,* hyolithids, occasional Archaeocyatha, Conchostraca, siliceous sponge spicules and fragments of trilobites occur in the lower 875 feet of this upper member. In the top 625 feet of the member Archaeocyatha, sponge spicules and hyolithids occur together with trilobites and brachiopods. Small lenses within a limestone band 3 feet thick, 250 feet below the top of the formation, are crowded with trilobite and brachiopod remains. One of these trilobites is related to the *Pararaia* group of trilobites. The associated atrematous brachiopod is new. This fauna is referred to as faunal assemblage No. 8. It has not been recognized elsewhere in the State.

Bunkers Sandstone. Approximately 600 to 700 feet of a dominantly sandstone formation, here referred to as the Bunkers Sandstone, overlies the Parara Limestone. The basal 45 feet consists of siliceous limestone, calcareous shale and quartzite. The remainder of the formation is made up of white- to buff-coloured sandstones which weather red. Weathered feldspar is common in these beds which show both ripple marks and cross-bedding. No fossils have been found in this formation.

Oraparinna Shale. 700 feet of greenish coloured micaceous shales which includes 60 feet of dark blue-grey rubbly limestone at its top are here referred to as the Oraparinna Shale. The shales make poor outcrops because of their softness and because they break down into splinter like fragments. Both shale and limestone are fossiliferous but to date only the upper 35 feet of shales have been investigated. Heads and thoracic segments of a trilobite, as yet unidentified, and *Hyolithes* are the only fossils found so far. This fauna is referred to as faunal assemblage No. 9. Nothing comparable has been found elsewhere in South Australia.

Billy Creek Formation. Conformable with the Oraparinna Shale is a sequence of red-beds 3300 feet thick. These beds are referred to as the Billy Creek Formation. It consists dominantly of chocolate coloured micaceous shales, sandstones and siltstones. The shales occupy most of the thickness and are often ripple marked. Pseudomorphs after halite occur in the shales in the upper parts of the formation. Thin buff coloured dolomites and calcareous shales are common in the lower 1200 feet. No fossils have been found in the formation.

Wirrealpa Limestone. Above the Billy Creek Formation is a sequence of fossiliferous limestones 350 feet thick which I propose to call the Wirrealpa Limestone. The formation is generally referred to as "*Obolella limestone.*" It was in this formation that Howchin first found fossils younger in age than the fossiliferous limestones immediately above the Pound Sandstone. Etheridge (1905; 1919), Walcott (1912) and Whitehouse (1939) have contributed to the palaeontology of this formation. The beds consist dominantly of grey massive and mottled rubbly limestones. The rubbly limestones have a greenish-grey argillaceous matrix. Grey-green shales are present near the base of the formation whilst thin oolitic limestones are present in the top half.

Redlichia aff. *nobilis* Walcott, *Helcionella* aff. *rugosa chinensis* Walcott, sponge spicules and "*Obolella*" *wirrialpensis* Etheridge occur in the lower 60 feet of the formation. This assemblage is faunal assemblage No. 10. Archaeocyatha are abundant from 190 feet to 245 feet above the base of the formation. Associated with them are brachiopods, sponge spicules, *Girvanella* and fragments of trilobites. "*Biconulites*" aff. *hardmani* (Foord) and *Girvanella* are common in the top parts of the formation. The brachiopod referable to "*Obolella*" *wirrialpensis* occurs throughout most of the formation. Previous collections from this formation contain *Eoorthis tatei* (Etheridge), but its exact stratigraphic position is unknown. Faunal assemblages younger than those contained in the Wirrealpa Limestone are unknown elsewhere in the Cambrian of South Australia. Faunal assemblage No. 10 has also been recognized in the Mount Scott Range area. It is regarded as a lower Middle Cambrian assemblage.

Lake Frome Group. Conformable with the Wirrealpa Limestone is a great thickness of "red beds" totalling 8700 feet, which are here referred to as the Lake Frome Group. Four separate formations have been recognized in it, all of which have so far proved to be unfossiliferous except for "trilobite" trails in what is here termed the Balcoracana Formation.

Moodlatana Formation. The oldest formation of the group is a 1300-foot sequence of chocolate coloured micaceous shales and argillaceous sandstones, here called the Moodlatana Formation. The beds are soft and weather readily and outcrops are poor. The sandstones are variously cross-bedded, flaggy or massive. Occasional thin dolomites with included chert or chalcedony nodules occur near the base.

Balcoracana Formation. Conformably succeeding the Moodlatana Formation is a 1500-foot sequence of interbedded red- to chocolate-coloured micaceous shales, cross-bedded micaceous sandstones and numerous thin buff dolomites, some of which contain chalcedony nodules. These beds are here termed the Balcoracana Formation. Data for this formation were obtained 1 mile south of the Balcoracana Creek because in the Ten Mile Creek section, some 5 miles to the south, the same formation is extensively faulted. Trails ascribed to trilobites occur in this formation in the vicinity of the Ten Mile Creek.

Sandstones (Unnamed). 4500 feet of red, purple and chocolate coloured micaceous sandstones and subordinate shales occur above the Balcoracana Formation. The soft beds weather readily to red sands. Large scale cross-bedding is a feature of these sandstones. Slump structures are also common.

Grindstone Range Sandstone. Above the soft sandstones (unnamed) are more resistant sandstones and quartzites which constitute the Grindstone Range, a prominent topographical feature trending north-south between the Ten Mile and Balcoracana Creeks. This 1400-foot arenaceous formation was designated by Mawson the Grindstone Range Sandstone. It is the youngest formation in the area. Hard quartzites with slump structures occur in the basal parts of the formation. Above are softer red- to white-coloured sandstones, often feldspathic. The sandstones are ripple marked and cross-bedded. Rounded quartz pebbles are abundant in quartzites in the top-most visible beds of the formation. Any upward extension of the formation is lost below the boulder beds of the Lake Frome Plains.

Thus in the Lake Frome area the Cambrian succession attains a thickness of 17,250 feet. Six faunal assemblages have been indicated as occurring between the Wilkawillina limestone and the Wirrealpa Limestone. The 8700 feet of red-beds of the Lake Frome Group above the Wirrealpa Limestone are unfossiliferous. Faunal assemblages Nos. 1, 2, 3, 8 and 9 are all regarded as Lower Cambrian. Faunal assemblage No. 10 is a lower Middle Cambrian assemblage and can be correlated with the *Redlichia* fauna of the Gum Ridge Formation (see Öpik, *in* Ivanac, 1954) and similar faunas in the Northern Territory and Western Australia. The Lower Cambrian-Middle Cambrian boundary is indicated as occurring in a 3300-foot unfossiliferous red bed sequence, the Billy Creek Formation. The Lake Frome Group of red beds, although unfossiliferous, is considered as having been deposited in a very short period of time. The sedimentary structures associated with these beds, particularly the extensive and large-scale cross-bedding are suggestive of deposition in a deltaic environment. Deposition of this Group is considered to have continued to Middle Cambrian time at which time an orogeny occurred which ended sedimentation in the Adelaidean geosyncline.

F. *Mount Scott Range area*

Rocks of Cambrian age form a belt trending in a north-west to south-east direction immediately to the south of Copley in the Flinders Range, some 50 miles north-west of the Lake Frome area. The earliest known occurrence of Cambrian strata in this area was in the vicinity of Ajax Mine 9 miles S.S.E. of Copley. Taylor (1907; 1910) and the Bedfords (1934-39) have described Archaeocyatha from the Ajax Limestone. Howchin (1925) has contributed short geological notes on the same area, the most significant points of which are the extensive faulting and alteration of the beds occurring there. Segnit (1939) has reported on the geology of an area 7 miles north-west of Ajax Mine. Parkin and King (1952) have delineated on their map the areal extent of the Cambrian sequence in the Ajax-Mount Scott Range area and have shown its relationships to the Adelaide System rocks.

The present writer examined the Ajax area and found it to be so extensively faulted, and its rocks so altered by metasomatism that the task of carrying out systematic work there was dismissed. Instead the Cambrian sequence was examined in detail in the immediate vicinity of Mount Scott, 7 miles to the north-west. A conformable sequence from the base of the Pound Sandstone up to dolomitic limestones at the top of the sequence was demonstrated. Approximately 6225 feet of strata were measured in this sequence. The top of the sequence is faulted against the Copley Quartzite of the Torrensian Series (Adelaide System). This is in close agreement with the ideas of Parkin and King (op. cit.). It differs from the ideas of Segnit (op. cit.) in three aspects:

(1) No strike fault exists to the immediate south of the Mount Scott Range.

(2) No evidence of a disconformity could be found between the Pound Sandstone and the Ajax Limestone.

(3) Segnit's "Flinders Range Sandstone-Quartzite Series," here called the Pound Sandstone, is not repeated by strike faulting as the Mount Aroona Range. Instead the quartzite forming this range is the Copley Quartzite of Parkin and King (op. cit.), the "Thick" Quartzite of Mawson (1941) of Proterozoic age.

The sequence measured by the author is discussed in detail below.

Pound Sandstone. In the area under review the scarp of the Mount Scott Range where the section was run consists of massive and cross-bedded white to reddish-brown sandstones and quartzites, but below these are red to purple sandstones, siltstones and shales, and occasional bands of quartzite and fine-grained quartz-feldspar conglomerates. These latter beds I am including in the Pound Sandstone and take as its base the top of the last dolomitic band in the underlying and conformable Marinoan Series of the Adelaide System. The Pound Sandstone in this area is approximately 2000 feet thick. This is in agreement with the figure given by Mawson (1947, p. 273). The succession from the base is as follows:

1. 310 feet of red to purple micaceous shale grading into flaggy siltstones and sandstones. Occasional thin red quartzites with clay galls are present. Ripple marks are common in these beds.
2. 35 feet of purple to white feldspathic quartzite. Thin cross-bedded and flaggy micaceous sandstones and bands of fine-grained quartz-feldspar conglomerate occur near the top.
3. 65 feet of chocolate micaceous flaggy sandstone with some shale.
4. 15 feet of quartzite with a thin conglomerate band near the top.
5. 90 feet of purple micaceous sandstones, flaggy siltstones and shales.
6. 75 feet of purple and white micaceous flaggy sandstones. Some are feldspathic. The beds are strongly cross-bedded.
7. 145 feet of cross-bedded and massive white to red-brown feldspathic sandstones and quartzites. These form the top of the Mount Scott Range scarp. Clay gall inclusions are common in the quartzites.
8. 135 feet of massive purple and white quartzites and grey to white cross-bedded and flaggy sandstones. Green clay galls are common.

9. 120 feet of purple flaggy sandstones and siltstones. These are often micaceous and feldspathic. Minor purple quartzites and shales are also present.
10. 250 feet of grey to purple feldspathic quartzites and minor feldspathic sandstones. Ripple marks and clay gall impressions are common.
11. 510 feet of purple and white sandstones, generally feldspathic. Some lenses of small well-rounded quartz pebbles are present in these beds, which exhibit ripple marks and cross-bedding. Thin quartzites are also present in these beds.
12. 75 feet of white massive coarse sandstone.
13. 35 feet of blue-grey massive quartzite riddled with clay gall inclusions.
14. 100 feet of sandstones and calcareous shales. Limonite, haematite and manganese minerals occur in these beds which form the top member of the Pound Sandstone. No fossils have been found in the formation in this area, but at Ediacara, 18 miles south-west of Mount Scott, fossil jelly fish and algae occur in the upper parts of the same formation. The jellyfish have been described by Sprigg (1947; 1949).

Ajax Limestone. Conformably overlying the Pound Sandstone is a sequence of limestones 725 feet thick, here designated the Ajax Limestone. The name has previously been used and restricted to the fossiliferous "Archaeocyathinae Limestones" of the Ajax Mine area. As the upper extensions of these limestones have been eliminated from the sequence by faulting in the Ajax Mine area, it is proposed to expand the term Ajax Limestone to include all the limestones of the Mount Scott Range area, above the Pound Sandstone and below an unnamed group of clastics. Observations made by the author disagree with Segnit's data for this formation. Segnit recorded over 2000 feet for the formation as against 725 feet by the author. Our descriptions of the rocks types present are also at variance. The Ajax Limestone in the Mount Scott area contains the following members. Base:

1. 70 feet of grey to blue-grey siliceous limestone which contains numerous chalcedony nodules. Some cross-bedding noted in these

beds. A thin quartzite band with possible worm castings occurs near the base. Some dolomitisation noted.

2. 65 feet of grey oolitic and siliceous limestones. Minor flaggy calcareous shales are present. The top of this member is marked by a 3-foot band of pisolitic limestone. Ripple marks and possible sun cracks were noted in these beds.

3. 50 feet of grey aphanitic flaggy limestones and dolomites. Siliceous limestones, oolitic limestones and intraformational brecciated limestones are also present in these beds.

4. 105 feet of grey siliceous limestones with intercalated flaggy limestone and dolomite. Chalcedony nodules up to 3 feet thick parallel the bedding near the base of this member.

5. 90 feet of yellow dolomitised limestone; the beds are mottled, rubbly and massive. The first evidence of a fauna occurs in these beds. Archaeocyathids make their appearance 30 feet above the base and occur sporadically to the top. Patches of partially silicified archaeocyathids occur in some beds. An unidentified atrematous brachiopod is the only other fossil recorded in these beds. This fauna is grouped in faunal assemblage No. 1.

6. 205 feet of light red to pink argillaceous limestone. Some mottled and rubbly limestone bands are present in these otherwise massive limestones. Archaeocyathids are abundant throughout these beds. Occasional specimens show partial silicification. "*Micromitra (Paterina)*" *etheridgei* occurs from the base to within at least 20 feet of the top of this member. "*Nisusia*" *compta* occurs in the basal 5 feet of the member but has not been recorded higher in the section. "*Ambonychia*" *macroptera* has been recognized in a number of beds whilst "*Huenella*" *etheridgei* occurs 40 feet below the top of the member. Sponge spicules, unidentified tubular organisms and unidentified brachiopods are also present in these beds. The whole of the fauna is included in faunal assemblage No. 2.

7. 66 feet of purplish to greyish-red argillaceous limestone. The more argillaceous bands weather to a rubble. Some of the limestones are recrystallised. The trilobite *Yorkella australis* appears at the base and is associated with *Hyolithes conularoides*, *Helcionella tatei*, *Ophileta*" *subangulata*, unidentified brachiopods, and concho-

stracans. This assemblage is included in faunal assemblage No. 3. This fauna is succeeded by one containing species of *Pararaia*, Conchostraca and an unidentified brachiopod genus (Faunal assemblage No. 4). This assemblage was recognized from 23 to 32 feet above the base of the member. The remainder of the beds are fossiliferous and contain Archaeocyatha, hyolithids including *H. conularoides*, brachiopods and fragments of a large trilobite similar to a trilobite contained in faunal assemblage No. 5 at Kulpara. For this reason it is suggested here that this assemblage is possibly a correlate of the faunal assemblage No. 5.

8. 6 feet of reddish-coloured argillaceous limestone.
9. 70 feet of white to yellowish-brown dolomitic and siliceous limestone. Large chalcedony inclusions occur in these beds.

Unnamed Clastics. Conformable with the Ajax Limestone is a sequence of red beds 1500- to 2000-feet thick consisting chiefly of chocolate coloured micaceous shales becoming grey and calcareous at the top. Micaceous sandstones and siltstones are also present. The shales are ripple marked and the sandstones show slump structures and cross-bedding. Outcrops are poor and other rock types may possibly be present. No fossils occur in these beds.

Aroona Creek Limestone. Conformably above the "Unnamed Clastics" is a sequence of limestones 200 feet thick which I propose to call the Aroona Creek Limestone. The formation is best examined where it cuts the Aroona Creek. The basal part of this formation contains a fauna which can be correlated with that occurring in the lower 60 feet of the Wirrealpa Limestone and must therefore be correlated with it. Because the lithology of the Aroona Creek Limestone is significantly different from that encountered in the Wirrealpa Limestone a new name for the formation is warranted. The sequence from the base is as follows.

1. 10 feet of grey coloured, well-bedded argillaceous limestone. Calcite is disseminated throughout these beds as a recrystallization effect.
2. 45 feet of grey to blue-grey argillaceous limestone which weathers to a rubble, and banded oolitic limestones. These beds are fossiliferous and contain *Redlichia* aff. *nobilis*, *Helcionella* aff. *rugosa chinensis*, *Girvanella* and hyolithids (Faunal assemblage No. 10).

3. 140 feet of purple, pink and grey-coloured well-bedded limestones. Many are argillaceous whilst others may possibly be dolomitic limestones. Many of the limestones contain disseminated calcite. Slump structures are also present.

Unnamed Clastics. Conformably overlying the Aroona Creek Limestone is a sequence of red-beds 1800 feet thick. Possible trilobite trails are the only indications of former life found in these clastics. The top of these beds is faulted against the Copley Quartzite of the Adelaide System by a prominent fault known as the Norwest Fault. The sequence from the base to the Norwest Fault is as follows:

1. 300 feet of chocolate-coloured shales. The lower members are grey and calcareous. A 6-foot band of blue limestone occurs at the top.
2. 240 feet of flaggy and cross-bedded, soft chocolate micaceous sandstone. Thin interbedded shales are also present.
3. 450 feet of chocolate-coloured sandstones and shales. A 7-foot band of blue-grey limestone occurs at the top.
4. 260 feet of chocolate-coloured flaggy and cross-bedded micaceous sandstone. Some shale is present.
5. 270 feet of interbedded chocolate-coloured micaceous sandstones and shales. Thin dolomites and some limestone are present.
6. 80 feet of mainly chocolate shales, in part green, with thin interbedded chocolate micaceous sandstones. Possible trilobite tracks occur in some of the beds.
7. 120 feet of micaceous sandstones and shales.
8. 100 feet of badly fractured greyish-red limestone, possibly dolomitic. This limestone is the highest bed recorded in the Cambrian sequence in this area. The top is not seen because of faulting.

To conclude: 6225 feet of Cambrian strata are present in the Mount Scott Range area. Two fossiliferous formations are present in the sequence. The older with Lower Cambrian fossils contains five faunal assemblages (Nos. 1 to 5), and the younger with lower Middle Cambrian fossils (faunal assemblage No. 10) can be correlated with the fauna in the lower 60 feet of the Wirrealpa Limestone. Faunal assemblage No. 1 is poorly represented in the area and is much better represented in the Ajax Mine area where the archaeocyathids are silicified. The unnamed clastics above the Aroona Creek Limestone are correlates of the lower part of the Lake Frome Group. They are faulted below Adelaide System rocks.

II. KANGAROO ISLAND REGION

Rocks of known Cambrian age cover a considerable area in the northern parts of Kangaroo Island. Sprigg (1954) has delineated the extent of these rocks and has demonstrated their relationships to older and younger sediments. As mentioned previously, Sprigg discovered fossils in the Emu Bay area in 1952. These fossils were subsequently identified by Glaessner *(in* Sprigg, 1955) who recognized their upper Lower Cambrian affinities. Ages previously suggested for these rocks by Howchin, Brown, Wade and Madigan range from Cambrian to Upper Palaeozoic. Howchin (1899) originally referred to all the Palaeozoic rocks (Cambrian) which occurred beneath the (Permian) glacial beds, as the Point Marsden series. Madigan (1928) also used this term in the same sense. He also referred to conglomerates on Point Marsden as "Point Marsden conglomerates" and attempted to relate these beds with the Precambrian Sturtian Tillite. Sprigg (1955) has used the term Point Marsden Group for all the rocks of Cambrian age which occur north of the Cygnet and Snelling Faults and has outlined the order of the succession within this "Group." The present writer disagrees with the order of the succession put forward by Sprigg and is disregarding the term "Point Marsden Group" because of ambiguity and evidence indicating a break in its lower part. The fossiliferous Emu Bay Shale does not underlie the White Point Conglomerate (White Point Limestone of Sprigg) as he suggests but lies conformably above it. This is seen 6 miles east-north-east of Emu Bay. The same can be inferred in the Emu Bay-Cape D'Estaing area where the Emu Bay Shale occurs above the extensively faulted White Point Conglomerate.

The Cambrian rocks outcrop over much of the coastline between Middle River and Point Marsden, a distance of some 40 miles. I have examined only 15 miles of this coastline from Smith Bay to Point Marsden. Major and minor faults are present over this interval of coastline and have complicated the structure. Nevertheless, along one stretch of coastline just east of Emu Bay, between what is locally known as the "Bald Rock" and White Point, a conformable succession of strata totalling about 4500 feet has been inspected. The base of this sequence is eliminated by faulting. Two faunal assemblages have been recognized in this sequence, the younger being correlated with the Emu Bay Shale fauna.

Our present knowledge of the Cambrian succession in the Kangaroo Island region is indeed limited. It may well be summarised as follows. At least 5500 feet of Cambrian rocks can be recognized.

Stokes Bay Sandstone. According to Sprigg (1954; 1955) a sequence of red and white sandstones and quartzites about 1000 feet thick conformably overlies phyllites and quartzites attributed to the Upper Proterozoic Adelaide System. This sandstone-quartzite sequence is called by Sprigg, the Stokes Bay Sandstone of Cambrian age. No fossils have yet been found in it. Sprigg (1955) has stated that the formation "is characterized by marked internal slumping and normal and pseudocrossbedding." The Stokes Bay Sandstone has not been recognized in the area examined by the author. Sandstone and quartzite sequences of unknown stratigraphic position occur between Smith Bay and "Bald Rock" but in every instance the bases of these sequences are bounded by major faults. Some of these sequences may possibly be Stokes Bay Sandstone.

Kangaroo Island Group. A conformable sequence of strata about 4500 feet thick was inspected by the writer between "Bald Rock" and White Point. Three named and one unnamed formations make up this sequence which is herein named the "Kangaroo Island Group."

1. Quartzite sandstone and Shale: Unnamed. Just east of "Bald Rock" a faulted contact occurs between east dipping shales and west dipping quartzites. These purple to chocolate-coloured micaceous shales, 100 feet thick, are the lowest beds of the "Kangaroo Island Group," and are part of an unnamed shale, sandstone, and quartzite sequence 450 feet thick. These shales are ripple marked and contain trails ascribed to trilobites. The top 350 feet of beds are made up of red to purple quartzites, sandstones and micaceous shales. The quartzites are cross-bedded and show slump structures. Minor faults, all with measurable throws, are present in the quartzites.

2. White Point Conglomerate. Conformably overlying the unnamed formation is a sequence of conglomerates calculated to be about 1250 feet

thick, which is here termed the White Point Conglomerate. The same formation has been called by Sprigg (1954; 1955) "White Point Limestone" but the formation is composed dominantly of conglomerate beds. Thin red and green-coloured shales and red quartzites with slump structures are interbedded with the conglomerates. They may be aptly termed polymictic conglomerates. The boulders and pebbles composing them include abundant blue-grey and pink limestones some of which contain Archaeocyatha, dolomites, quartzites (mainly red), quartz, and igneous and metamorphic rocks. Most of these boulders, some of which attain 3 feet in length, show some degree of rounding. The matrix is generally arenaceous but in some instances it is practically lacking, in which case, the boulders and pebbles are merely stacked one upon the other, with their long axes elongated parallel to the bedding.

Sprigg (1955) has suggested that the numerous limestone boulders of this formation have been derived as talus from archaeocyathid reefs. The present writer does not subscribe to this view but considers them as normal conglomerates derived from the active erosion of an adjacent land mass. They are taken as positive evidence of a minor Lower Cambrian orogeny which folded and elevated the southern portion of the Adelaidean Geosyncline. This elevation postdated the main period of archaeocyathid development (time of faunal assemblages Nos. 1 and 2) because the Lower Cambrian archaeocyathid limestones were involved in the movements and later contributed as erosive products to the White Point Conglomerate. No boulders ascribed to beds younger in age than the archaeocyathid limestones have been seen in the White Point Conglomerate. More than one pulse of this orogeny is reflected in the "Kangaroo Island Group" as is evidenced by the presence of conglomerates in the formations stratigraphically above the White Point Conglomerate.

The formation has not been fully investigated for fossils. Numerous cephala of an undescribed trilobite have been found in shale near the top of the formation. No other fossils have been found with this trilobite. Complete specimens of the same genus of trilobite have been found in shale in the equivalent of the White Point Conglomerate just west of Cape D'Estaing, but as the formation there is extensively faulted, the exact stratigraphic position of the fossil there is unknown. This trilobite is assigned to "faunal assemblage" No. 11. The above two localities are the only occurrences of the White Point Conglomerate known to the writer. The formation at Cape D'Estaing however contains many more interbedded quartzites and shales than at the type locality 1 mile W.S.W. of White Point.

Emu Bay Shale. Conformably overlying the White Point Conglomerate is a 350-foot sequence of brown and purple-coloured micaceous shales and flagstones, and minor interbedded reddish-coloured quartzites, and occasional conglomerate lenses up to 3 feet thick. These beds are correlated with the Emu Bay Shale of Sprigg (1955), because comparable faunas occur in both these shales which occupy the same stratigraphic position, relative to the White Point Conglomerate, at both localities. An upper Lower Cambrian fauna which includes *Redlichia* n.sp., a genus of trilobites c.f. *Lusatiops*, *Isoxys* n. sp., an unidentified crustacean and annelids occur in the basal 20 feet of the formations about 1 mile W.S.W. of White Point. This fauna is called here, faunal assemblage No. 12. Trilobite trails occur in higher horizons at the same locality. R. C. Sprigg has found two fossiliferous beds in the formation at the type locality 200 yards north-west of the Emu Bay Jetty. The fauna which has been preliminarily examined by Dr. M. F. Glaessner includes *Redlichia* n.sp., *Lusatiops* n.sp., a possible *Acrothele* and *Hyolithes* sp.

Boxing Bay Formation. The Emu Bay Shale is conformably overlain by a 2500-foot sequence of red coloured quartzites and interbedded shales, flagstones and conglomerates. This sequence is here referred to as the Boxing Bay Formation. Its upper limit is seen on the eastern side of White Point. A feature of the quartzites is that they are cross-bedded and show slump structures. Occasional thin conglomerate bands are interbedded with the quartzites in the middle parts of the formation but on White Point itself and a little to the west numerous bands of conglomerate are present in the quartzites. These conglomerates contain abundant red gneissic granite boulders and other rock types including occasional archaeocyathid limestone. No indigenous fossils have yet been discovered in this formation. The Lower Cambrian-Middle Cambrian boundary has been drawn through this formation.

The Boxing Bay Formation is the top formation of the "Kangaroo Island Group." The upper limits of this north-east dipping formation are seen on the western side of Boxing Bay between White Point and Point Marsden. No outcrops occur in the centre of this bay but on the western side of Point Marsden a sequence of red-coloured quartzites dipping to the north-east occurs. These quartzites are cross-bedded and show slump structures. They outcrop as far as Point Marsden and in their upper limits contain interbedded conglomerates similar to those on White Point. This sequence which is about 1200 feet thick represents either an upward continuation of the Boxing Bay Formation or is a faulted repetition of the same formation.

Thus on Kangaroo Island the Cambrian sequence as far as we know it is represented by at least 5500 feet of strata. The oldest formation, the Stokes Bay Sandstone is, according to Sprigg (1955), 1000 feet thick and rests conformably on Adelaide System phyllites and quartzites. This formation is tentatively correlated in this paper with the Pound Sandstone of the Flinders Range. It is unfossiliferous. Above is a conformable sequence of strata designated the "Kangaroo Island Group" at least 4500 feet thick. The base is not seen because of faulting. The top of the group dips below a cover of Permian and Quaternary deposits. A quartzite sequence with interbedded conglomerates occurs on Point Marsden. This sequence is 1200 feet thick and is either the upward continuation of the "Kangaroo Island Group" or a faulted repetition of the top formation of the Group.

The upper Lower Cambrian faunal assemblages (Nos. 11 and 12) have been located by the writer in the Kangaroo Island Group. The older assemblage occurs near the top of the White Point Conglomerates and the younger at the base of the overlying Emu Bay Shale. This latter assemblage contains the Lower Cambrian *Isoxys* and a protolenid-like trilobite which recalls *Lusatiops.* A species of *Redlichia* different from all other known species is associated with *Isoxys* and cf. *Lusatiops.* Neither of these faunas can be correlated with those so far recorded on the mainland. As the assemblage (No. 12) is of uppermost Lower Cambrian age it is considered that the boundary between Lower and Middle Cambrian would fall in the Boxing Bay Formation, though as yet no fossils have been found in it. Alternatively the boundary may occur in the Emu Bay Shale itself above the known faunas. In the correlation chart a gap between the Stokes Bay Sandstone and the "Kangaroo Island Group" is indicated. Rocks which might bridge this gap have not yet been recorded on Kangaroo Island. Faunal assemblages Nos. 1 and 2 are missing and younger assemblages are also possibly included in the gap. Evidence of a Lower Cambrian orogeny with at least two pulses is recorded in the "Kangaroo Island Group." It is interesting to note that as one passes from the base of the White Point Conglomerate to the top of the "Kangaroo Island Group" the proportion of archaeocyathid limestone and other limestone and dolomite boulders in the conglomerate decrease and the proportion of granite (red gneissic granites in particular), quartzite and metamorphic rocks increase. This would imply the erosion through a Cambrian sequence into an underlying complex similar to the Archaean as seen in the Ardrossan area on Yorke Peninsula (see column II of the Correlation Chart).

THE CAMBRIAN FAUNAL SUCCESSION IN SOUTH AUSTRALIA

Twelve Cambrian faunal assemblages have been recognized in the areas discussed above. Of these all are Lower Cambrian assemblages except faunal assemblage No. 10. This latter assemblage according to A. A. Öpik (this Symposium) is comparable with similar faunas of lower Middle Cambrian age in the Northern Territory. It is recognised in both the Mount Scott Range and Lake Frome areas. In each instance unfossiliferous red-beds occur below this assemblage and below them are faunal assemblages considered to be Lower Cambrian. The Middle Cambrian-Lower Cambrian boundary is therefore placed in these unfossiliferous formations. Most of the assemblages occurring in the other areas studied on the mainland can be correlated with the Lower Cambrian faunas of the Mount Scott Range area and hence are regarded as Lower Cambrian. Some uncertainty exists regarding the age of the top of the Parara Limestone in the Kulpara area as neither faunal assemblage No. 6 nor No. 7 can be correlated with faunas elsewhere. Faunal assemblage No. 7 is shown on the correlation chart as older than faunal assemblage No. 8 but this must await verification.

In the Kangaroo Island region, evidence of a Lower Cambrian age for the Emu Bay Shale, and consequently the beds below, lies in the presence of *Isoxys* Walcott, and an ellipsocephalid-protolenid like trilobite which resembles *Lusatiops* R. and E. Richter. *Lusatiops* is an uppermost Lower Cambrian form, consequently the Lower Cambrian-Middle Cambrian boundary possibly falls in the Boxing Bay Formation, the youngest known formation in this region.

Two assemblages older than those recognized in the above areas are known to occur elsewhere. The older of the two is the Ediacara jellyfish assemblage described by Sprigg (1947; 1949). This assemblage occurs in the upper part of the Pound Sandstone at Ediacara, 16 miles south-west of the Mount Scott Range area and is the oldest Cambrian faunal assemblage recognized in South Australia. More recently Sprigg and Wilson (1953) discovered a new locality for these fossil jellyfish near the top of the Pound Sandstone 40 miles east-south-east of the Mount Scott Range area. Worm burrows and castings and possible algae have been reported in this formation elsewhere. The younger assemblage occurs in the Nepabunna and Italowie areas where Mawson (1937) reported the presence of cryptozoönic structures in dolomite and limestone below the first appearance of the archaeocyathids. In 1925 he had previously referred one of these Italowie algae to *Cryptozoön australicum* Howchin. This species which is a *Collenia*-type alga occurs in the Nepabunna area below fossiliferous limestones which contain faunal assemblages Nos. 1 and 2 and later assemblages not yet differentiated.

FAUNAL ASSEMBLAGE No. 1

This assemblage is the oldest assemblage recorded in the areas described above. It has been recognized in only three of these areas; the Mount Scott Range, Lake Frome and Wilson-Quorn areas. Archaeocyathids (and occasional sponge spicules) are the only fossils which I have observed in this assemblage except for an unidentified atrematous brachiopod found in association with them in the Ajax Limestone of the Mount Scott Range area. A large number of archaeocyathid genera are represented in this assemblage. Most, if not all, of the species described from the Ajax Mine area by Taylor and the Bedfords are believed to have come from beds containing only this assemblage, for it is significant that no fossils characteristic of faunal assemblage No. 2 have been reported by them. Such fossils would most certainly have been noticed if they were present. The Bedfords have also described sponges and algae from the Ajax Limestone; a brachiopod was also noted in their material from this area.

FAUNAL ASSEMBLAGE No. 2

This is a most characteristic assemblage and has been recognised in all areas except the Kulpara area and the Kangaroo Island region. Archaeocyathids are abundant and a large number of genera are represented, including many of the genera present in faunal assemblage No. 1. As far as is known the main period of archaeocyathid limestone development in South Australia is covered by the time of faunal assemblages Nos. 1 and 2. The brachiopod known as *Micromitra (Paterina) etheridgei* (Tate) is restricted to the assemblage. It cannot be referred to any known brachiopod genus. It is an atrematous brachiopod with two well defined teeth in the ventral valve; the other valve is unknown. "*Nisusia*" *compta* (Tate) and "*Huenella*" *etheridgei* Walcott are incorrectly assigned, both are new. "*Ambonychia*" *macroptera* Tate is not a pelecypod but is a new genus of brachiopod. *Kutorgina peculiaris* (Tate), *Hyolithes conularoides* Tate, unidentified brachiopods, tubular organisms and sponge spicules are also present in the assemblage.

FAUNAL ASSEMBLAGE No. 3

The trilobite *Yorkella australis* (Woodward), is characteristic of this assemblage. The species *australis* has been variously assigned to *Conocephalites*, *Ptychoparia*, *Solenopleura* and *Protolenus*. *Ptychoparia howchini* Etheridge is a synonym of *australis;* Kobayashi (1942b) has listed all synonyms of *australis*. *Howchinella* mentioned in David (1932) is a nomen nudum. Associated with *Yorkella* are *Helcionella tatei* Resser, *Hyolithes conularoides* Tate and *H. communis* Billings. "*Salterella*" *planoconvexa* Tate is a *Hyolithes;* "*Ophileta*" *subangulata* Tate is a *Pelagiella*. Conchostraca, unidentified brachiopods and occasional archaeocyathids are also present.

FAUNAL ASSEMBLAGE No. 4

Several species of trilobites occur in this assemblage. All of these species except one, have been referred to in this paper as belonging to, or allied to, the genus *Pararaia* Kobayashi. Woodward (1884) originally described *Dolichometopus tatei*, the genotype of *Pararaia*, as having a glabella, "nearly smooth, with only a slight indication of furrows." In his diagnosis of *tatei*, Kobayashi (1942b) stated that "no lateral furrows" are present. Faint furrows are also discernible on both *Microdiscus subsagittatus* Tate and *Olenellus pritchardi* Tate which Kobayashi has taken as synonyms of *Pararaia tatei;* he has listed all previous generic references under *Pararaia*. A species which I refer to *tatei* occurs in all areas where this assemblage has been recognised. Three lateral glabellar furrows are always present. Other species of *Pararaia* are also present in the assemblage. The remainder of the fauna includes a proparian trilobite, similar to *Pagetia* Walcott but combining features which recall both *Dipharus* Clark and *Calodiscus* Howell, *Helcionella, Pelagiella subangulata*, occasional archaeocyathids, *Lingulella* sp., hyolithids including *H. planoconvexa* and unidentified brachiopods and conchostracans.

FAUNAL ASSEMBLAGES Nos. 5, 6 AND 7

These assemblages occur in the Parara Limestone in the Kulpara area. All the species in these assemblages are as yet undescribed. They all belong to unrecorded genera. Faunal assemblage No. 5 is possibly represented in the Mount Scott Range area by a trilobite species comparable to one occurring in faunal assemblage No. 5 in the Kulpara area. Associated with it are archaeocyathids, *Hyolithes conularoides* and undescribed brachiopods. A trilobite in faunal assemblage No. 7 has some resemblance to *Micmacca* Matthew. Assemblage No. 7 is shown in the correlation chart as older than assemblage No. 8. This is subject to verification.

FAUNAL ASSEMBLAGE No. 8

This small fauna contains as least two undescribed trilobite genera, one of which shows some relationships to *Pararaia Kobayashi*. An undescribed brachiopod is associated with them.

FAUNAL ASSEMBLAGE No. 9

The only forms recognised in this assemblage are a species of trilobite having some protolenid affinities and *Hyolithes* sp.

FAUNAL ASSEMBLAGE Nos. 11 AND 12

These two Lower Cambrian assemblages are recognised only in the Kangaroo Island region. An opisthoparian trilobite is the only species present in "assemblage" No. 11. It is characterised by a bilobed and expanded frontal lobe of the glabella on either side of which are depressions anterior to the eye-line. The fifth and sixth thoracic segments are fused and macropleural. Its relationships are unknown. Faunal assemblage No. 12 contains *Redlichia*, and a trilobite with ellipsocephalid and protolenid relationships (cf. *Lusatiops)*, *Isoxys*, an unidentified crustacean and annelids. The trilobites are similar if not identical species to those examined by Glaessner *(in* Sprigg, 1955) from the Emu Bay Shale. The *Redlichia* is distinguished from all other known species of the genus by its long stout occipital spine.

FAUNAL ASSEMBLAGE No. 10

This fauna is a lower Middle Cambrian assemblage and is found only in the Lake Frome and Mount Scott Range areas. *Redlichia* aff. *nobilis* Walcott, *Helcionella* aff. *rugosa chinensis* Walcott, *Girvanella* Nicholson and Etheridge and calcareous sponge spicules occur in both areas. The brachiopod known as "*Obolella*" *wirrialpensis* Etheridge is found in the assemblage in the Lake Frome area. As it has a calcareous shell it does not belong with *Obolella*. *Biconulites* aff. *hardmani* (Foord), which is a Hyolithes (unpublished observation), archaeocyathids, *Girvanella*, "*Obolella*" and *Eoorthis tatei* (Etheridge), occur above assemblage No. 10 in the Wirrealpa Limestone in the Lake Frome area but on present knowledge they are not assigned to a separate faunal assemblage.

David, Whitehouse and Kobayashi have attempted to define the Cambrian faunal succession in South Australia. David (1932) and Kobayashi (1942a) have erroneously indicated "*Salterella planoconvexa*" as representative of the oldest Cambrian horizon in South Australia. This error stems from a report by Madigan (1926) on the presence of "*Salterella*" below the archaeocyathid limestone at Myponga Jetty, but this is not so as the beds at this locality are overturned as Madigan (1928) later indicated. The so-called "*Salterella*" is a *Hyolithes* and belongs with *H. communis* Billings and not *H. planoconvexa* (Tate) or

Biconulites as Spath (1936, p. 436) suggested. David (1932) has given *Howchinella* (a nomen nudum) and Whitehouse (1936) *Protolenus* as the characteristic trilobite of the "*Protolenoid* Stage" which occurs above the "*Archaeocyathus* Stage"; this trilobite does not belong with *Protolenus* but is *Yorkella* Kobayashi. In his zonation of the South Australian Cambrian Kobayashi considered the Lower Cambrian *Pararaia-Yorkella* fauna of Yorke Peninsula as an early Middle Cambrian fauna and consequently placed it above the *Redlichia* fauna of the Flinders Range, despite stratigraphic evidence to the contrary; his youngest zone, the *Huenella* zone (not *Huenella* but a new genus of brachiopod) was wrongly placed because of Walcott's incorrect generic determination.

THE BASE OF THE CAMBRIAN IN SOUTH AUSTRALIA

The question of what marks the base of the Cambrian System in South Australia has long been a matter of controversy. The various opinions of workers regarding this issue have already been expressed in the historical introduction. The reason for all this uncertainty is that in all areas, except those of marginal overlap such as at Ardrossan, fossiliferous Cambrian rocks pass down conformably into very thick rock sequences which are either unfossiliferous, or if fossiliferous do not contain conventional Cambrian fossils.

The Pound Sandstone of the Flinders Range which attains a vast thickness in some areas (Reyner and Pitman, 1955) have estimated 9000 ft for it in the Mundy Waters area and Sprigg (1949) 7000 ft in the Gammon Ranges to the east of Mundy Waters), is everywhere conformably overlain by limestones containing Archaeocyatha of definite Lower Cambrian age whilst below and conformably with it are red beds (Marinoan Series) of the Adelaide System. Isolated occurrences of fossil jellyfish and possible algae are the only fossils known within the Pound Sandstone which Mawson originally suggested was the basal bed of the Cambrian. It would appear that his chief reason for doing so, was because this formation which conformably underlies the Archaeocyatha limestone, formed such a striking marker bed throughout the Flinders Range. He (1940) also argued that "with it was certainly ushered in an entirely new cycle of deposition and a change in climate." Most present day workers including the State

Geological Survey, have followed Mawson's lead in regarding this formation as the basal Cambrian formation. Whether we are entitled to consider it as such on this evidence alone is indeed open to argument. Also where shall we place the boundary in areas such as at Sellick Hill where no Pound Sandstone can be recognised although in this area continuous sedimentation from Proterozoic times is the case.

In this paper I have tentatively followed Mawson, by including the Pound Sandstone and Stokes Bay Sandstone of Sprigg in the Cambrian for the following reasons. The Archaeocyatha are the first authentic Lower Cambrian fossils to appear in the sequence but their relationships to Lower Cambrian faunas in other provinces have not yet been satisfactorily fixed. In his review of this group David (1927) concluded that the South Australian forms occurred near the top of the Lower Cambrian, an opinion also shared by Whitehouse (1936). Their conclusions have undoubtedly influenced succeeding workers into placing the Cambrian boundary well below the first appearance of the Archaeocyatha. However we now know that this enigmatic group persisted into the lower Middle Cambrian Wirrealpa Limestone which is over 7000 ft stratigraphically above their first appearance. Choubert and Hupé *in* Hupé, 1952) have shown that in the Moroccan Cambrian Archaeocyatha occur from the "base" of the Lower Cambrian (Georgian) and are followed by trilobite faunas. This order of faunal succession is comparable to that occurring in this state, but no correlations between the two regions are yet possible. A study of the archaeocyathids from both regions may give correlations which will allow us to define the base of the Cambrian. Perhaps then we shall find that the base of the Archaeocyatha limestone will approximate the base of the Cambrian; Campana, Wilson and Whittle (1954) have already indicated this for the Sellick Hill area. I say approximate for two reasons. First no Archaeocyatha are known from the base of the limestones overlying the Pound Sandstone. In some areas algae bridge this gap, e.g. in the Italowie-Nepabunna areas. Secondly it would appear that the archaeocyathids first appear in the rock record at somewhat different times. For instance their appearance in the Lake Frome and Wilson-Quorn areas seems to be earlier than it is in the Mount Scott area. It is definitely earlier in these two areas than it is in the Ardrossan and Curramulka areas where faunal assemblage No. 1 is missing.

PALAEOGEOGRAPHY OF THE SOUTH AUSTRALIAN CAMBRIAN

The Adelaidean Geosyncline (Flinders Trough, David and Browne, 1950; Adelaide Geosyncline, Sprigg, 1952) in which the Proterozoic Adelaide System was deposited persisted into the Cambrian. Its suggested limits in early Cambrian times lay between the old land masses of Yilgarnia (Cotton, 1930) in the west and Willyamia (Sprigg, 1952) in the east and are shown in figure 3. The Yilgarnian shoreline is placed according to observed facts, but the position of the Willyamian shoreline is partly speculative through insufficient evidence. Willyamia as used in this paper is a gross extension of the term as used by Sprigg (1952) and also of Willyama originally proposed by Andrews (1937), both of whom derived the terms from the Precambrian Willyamia Complex of Mawson (1912). Generally a sea connection with the Amadeus Trough has been inferred by other Cambrian palaeogeographers, (Whitehouse, 1936; Andrews, 1937; Kobayashi, 1942a; David and Browne, 1950) although Cambrian sediments in South Australia are unknown north of latitude 30° South. It would appear that such a connection did exist for at least part of the Cambrian as archaeocyathids are present in the lower Cambrian of the Macdonnell Ranges (Madigan, 1932).

A great transgression of the sea onto the Archaean rocks of Yilgarnia in what is now the Yorke Peninsula region occurred at the beginning of Pound Sandstone time. Presumably this transgression also occurred in the region to the west of Lake Torrens and Port Augusta where sandstones and conglomerates believed to be the same age occur. A rapid thinning of the formation is seen on Yorke Peninsula, for in the Maitland area only 71 ft of the formation are present as against 600 ft of it in the Kulpara area 20 miles to the north-east. Rapid subsidence is dominant within most of the geosyncline during this time and vast thicknesses (as much as 9000 ft) of shallow water clastics were deposited over immense areas particularly in what is now the Northern Flinders Range. The formation is not recognisable on Fleurieu Peninsula where Campana, Wilson and Whittle (1955) have shown that Adelaide System beds thin rapidly to the South. Because of this thinning they have assumed "that the region formed the southern limits of the sedimentational trough." This seems unlikely in view of the nature of the sediments deposited there, and the present writer is interpreting this thinning, and even absence of parts of the sequence to the presence of a local isolated high within the geosyncline, which received little or no sedimentation during Late Proterozoic and Pound Sandstone time. Later in the Cambrian this area subsided, was then uplifted, and again subsided before the end of Lower Cambrian time. The Stokes Bay Sandstone of Sprigg is believed to have been deposited during this time.

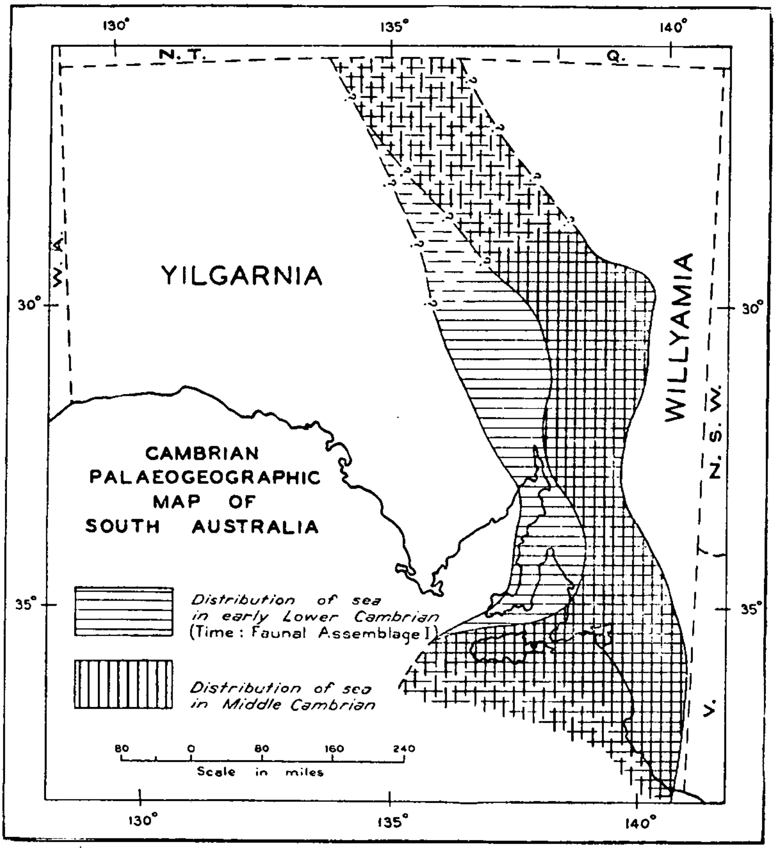

Fig. 3. *Cambrian Palaeogeographic Map of South Australia.* This map shows the postulated areas occupied by Cambrian seas in early Lower Cambrian (time of faunal assemblage 1) and early Middle Cambrian (time of faunal assemblage 10). The sea is shown stretching between two cratons, Yilgarnia and Willyamia. A connection to the north is postulated, this region being covered largely by Cretaceous and younger sediments. The positions of the Yilgarnian shorelines have been confidently plotted but the same does not apply for the position of the Willyamian shoreline. Nevertheless existing information necessitates this shoreline being placed as far east as is indicated.

Following the deposition of the Pound Sandstone came a period of limestone deposition covered mainly by the time of faunal assemblages 1 and 2. Algae were abundant early in some areas but were soon followed by archaeocyathids which in favourable areas, in the deeper parts of the geosyncline well away from shore, became practically rock forming, but never did they form reefs as so many people have suggested. They are true biostrome organisms. This has already been pointed out by Okulitch and de Laubenfels (1953). Shorewards these limestones often become siliceous whilst in some areas dolomites and dolomitic limestones were deposited. Fairly shallow seas are indicated within the various areas examined by the writer, during much of the time preceding the appearance of faunal assemblage 1, by the abundance of oolites, pisolites, intraformationally brecciated limestones and associated sedimentary structures. The shoreward dolomitic limestones seem to indicate chemical precipitation in saline, possibly barred basins. Little or no fauna is represented in these shoreward areas at this time, but later (in the time of faunal assemblage 2) conditions throughout the geosyncline favoured an abundance of life.

In *Yorkella* and *Pararaia* times (Faunal assemblages 3 and 4) conditions throughout the geosyncline were remarkably uniform, for the blue-grey generally mottled and rubbly Parara Limestone is easily recognisable despite the vast distances between its occurrences. In the Mount Scott Range area this formation is not recognised, but in the time interval represented by the *Yorkella* and *Pararaia* faunas in the Ajax Limestone, purplish-coloured, sometimes mottled and rubbly limestones were deposited. These limestones bear a superficial resemblance to Parara Limestone elsewhere, but as they are so much like the underlying red-coloured limestones it would be impractical to split them from the remainder of the Ajax Limestone. Much of the Parara Limestone consists of limestone nodules set in a calcareous-argillaceous matrix, which on weathering form rubbly limestones. Mawson (1925) has indicated that such rocks might be genetically related to algae, but their genesis is uncertain. In the Kulpara and Wilson-Quorn areas calcareous shale horizons containing isolated limestone nodules are present in the Parara Limestone or its time equivalent, whilst the upper part of the formation in the Lake Frome area contains no mottled limestone but consists of alternating bands of limestone and pencil thin laminae of calcareous shale.

Deposition of Parara Limestone continued in the Lake Frome area and the more central parts of the geosyncline while unfossiliferous dolomitic limestones and red-bed clastics were being laid down in the Mount Scott area. These dolomitic limestones and red-beds are taken as an indication of regression in this part of the geosyncline. The effects of this regression persisted in the Mount Scott area until Middle Cambrian times. On the mainland in the south, no sediments younger than the Parara Limestone at Kulpara are known. It is assumed here, through lack of evidence to the contrary, that sedimentation ceased with the Parara Limestone as the youngest Cambrian formation on Yorke Peninsula. To the south of Sellick Hill, in the vicinity of Myponga Jetty, *Hyolithes communis* and *Helcionella tatei* (discovered by M. F. Glaessner) occur in shaly mottled limestones above "Archaeocyathinae" limestones; these two species are elsewhere associated with the *Yorkella* assemblage (faunal assemblage 3). On their map (Yankalilla Sheet), Campana, Wilson and Whittle (1954) correlate these beds with the base of a shale and slate sequence containing phosphatic nodules of the Sellick Hill area. Hence we may assume that this sequence can be dated from the time of *Yorkella*, that it is a time-equivalent of part of the Parara Limestone but that the upper age limit of the sequence is unknown. It is assumed here that the termination of sedimentation in both the Yorke Peninsula and Sellick Hill regions was a result of the same regression which started earliest in the Mount Scott Range area, while the age of the marginal southern part of the regression is determined as much earlier than the end of Parara Limestone sedimentation in the more central parts of the geosyncline, such as the Lake Frome area. Moreover it is suggested that the regression in the southern part of the geosyncline is directly connected with a Lower Cambrian uplift accompanied by folding of the region. Evidence for this uplift rests on the presence of the thick Lower Cambrian White Point Conglomerate in the Kangaroo Island Group, which was derived partly from Lower Cambrian sediments. We know with certainty that the earliest possible date of these movements is after the time of faunal assemblages 1 and 2 because boulders containing these assemblages are known in the White Point Conglomerate. The latest possible date for these movements is well before the upper Lower Cambrian, as a fauna of this age rests conformably on the 1250-ft-thick White Point Conglomerate. It would seem that these movements can be fixed within even narrower limits if we are to include the Parara Limestone of the Kulpara area and the shales and slates of the Sellick Hill area in these movements, as the regression above would indicate. This then would place the base of the Kangaroo Island Group at a point on the correlation chart above faunal assemblage 7.

As pointed out previously (see above) the initiation of Kanmantoo Group sedimentation is believed to have resulted from an orogeny predating the major orogeny which terminated sedimentation in the Adelaidean Geosyncline. This early orogeny is identified with the movements just mentioned. It is believed that shoreline conglomerates, sandstones and shales as seen in the Kangaroo Island Group grade seawards into the "flysch-like" Kanmantoo sediments which were deposited in areas of rapid subsidence. Areas which were stable during much of the Proterozoic, such as the Yankalilla area, now became regions of active subsidence. The ideas mentioned above are substantiated by those of Campana and Horwitz (in press) who have now inferred a transgressive nature for the Kanmantoo sediments over eroded Lower Cambrian and Adelaide System rocks. This interpretation of the abnormal contacts seen on Fleurieu Peninsula and in the eastern Mount Lofty Ranges explains well the reasons why the base of the Kanmantoo Beds is seen resting on rocks of varying ages as mentioned in the historical introduction. It also eliminates the Nairne Fault, which after all is but an inferred major fault line separating the Kanmantoo Group rocks from metamorphosed Adelaide System and in one case supposed Cambrian rocks (Macclesfield Marble). Their arguments also apply in the Kangaroo Island region south of the Cygnet-Snelling Faults (interpreted by the present writer as overthrust faults) where Kanmantoo Group sediments are shown by Sprigg (1954) resting on both supposed Adelaide System and Cambrian rocks.

Marine conditions were maintained in the Lake Frome area for much of the time represented by the 1500 feet of red-bed clastics which were deposited in the Mount Scott Range area during the period of regression (see above). In the former area the fossiliferous green Oraparinna Shale rests conformably on the Bunkers Sandstone which may be interpreted as a shoreline facies. It would seem then that the rate of subsidence in this area was such that a full sea connection was continually maintained until upper Lower Cambrian times when the Billy Creek Formation was deposited at which time a general regression took place and the sea was partially or even completely excluded from the area. Subsidence was rapid but was not sufficient to allow a full sea connection in the region; dolomites and indications of high salinity (halite casts) are present within the formation indicating that deposition occurred in shallow saline basins (ripple marks). In the southern parts of the geosyncline marine conditions persisted and the fossiliferous Emu Bay Shale with its upper Lower Cambrian *Redlichia* fauna and Kanmantoo Group rocks were being deposited.

In early Middle Cambrian times a rapid and widespread transgression of the sea occurred (fig. 2) as is indicated by the fossiliferous basal parts of the Wirrealpa and Aroona Creek Limestones but another gradual regression in the Mount Scott area is indicated because marine fossils are absent in the upper part of the Aroona Creek Limestone. A return to red-bed deposition in this area is at this time evident. Meanwhile in the Kangaroo Island region sedimentation was continuous and uplift of the adjacent mainland continued for conglomerates were still being deposited within the Boxing Bay Formation. Final regression of the sea is seen in the Lake Frome area with the return of red-bed sedimentation. Temporary incursions of the sea are possibly indicated by trails ascribed to trilobites within the Balcoracana Formation and the 1800 feet of clastics in the Mount Scott Range area. Subsidence in both areas was considerable but sedimentation kept pace with it. Dolomite developments at this time are again possibly indicative of barred saline seas. The two uppermost formations of the Lake Frome Group are the youngest Cambrian formations represented on the Mainland. They were obviously deposited in a deltaic environment as would be indicated by the vast scale of the cross bedding which in ground plan gives the impression of faulted sediments. Sedimentation in the south continued during this time but now came a period of paroxysm which terminated the depositional history within the geosyncline. David and Browne (1950) have suggested that the folding of the Adelaidean Geosyncline was contemporaneous with the Tyennan movement which they date as early Upper Cambrian. The 8700 feet of the Lake Frome Group red-beds are by their deltaic nature believed to have been deposited in a relatively short period of time. Similar sediments comprising the Billy Creek Formation 3300 ft thick are the passage beds between the Lower and Middle Cambrian faunas. It would seem then that the folding took place about middle Middle Cambrian times. Öpik (this

Symposium) believes that the folding started in the time of *Ptychagnostus gibbus* (Linnarsson) and continued to the end of *Ptychagnostus punctuosus* (Angelin) time.

In South Australia the effects of this orogeny were widespread and varied. The sediments which were transgressive onto Yilgarnia were hardly effected by these movements but sediments in the deeper parts of the trough were folded into long parallel chains. Compressional thrusts were directed principally from the east and south-east as illustrated by Campana (1954); structures overturned to the west are evident in Fleurieu Peninsula. In the southern region of the geosyncline, Adelaide System rocks on the eastern side of the Mount Lofty Ranges and the Kanmantoo Beds which overlie them, were regionally metamorphosed by these same movements. Locally they were intruded by granite and dyke rocks. The only other Cambrian rocks which were metamorphosed were the Lower Cambrian rocks included in the same broad belt of metamorphism. Cleavage and recrystallizational effects are the only noticeable changes in Cambrian rocks elsewhere. Scattered occurrences of basic igneous rocks intruding the Cambrian of the Flinders Range are known.

This final orogeny welded the Adelaidean Geosyncline onto ancient Yilgarnia and Willyamia but a positive tendency for uplift has persisted even to the present day. Unfortunately no evidence of folding between the Middle Cambrian and the end of the Palaeozoic is known but this does not preclude such folding. We can show that the Cambrian history of the Adelaidean Geosyncline was quite complex, additional investigations will probably show that it was even more complicated than is now recognised. Large areas of Cambrian and Upper Adelaide System rocks have been stripped by erosion. Much of this cover was possibly removed by the end of the Palaeozoic but erosion in the Flinders Range and adjacent areas contributed to the thick cover of the Mesozoic sediments in the Great Artesian Basin, which obscure any Cambrian rocks which might occur below them. The Kanmantoo Group rocks of the eastern Mount Lofty Ranges pass below a cover of Tertiary and Quaternary deposits in the Murray Basin and their eastward extension is unknown. Mawson and Parkin (1943) and Mawson and Dallwitz (1944) have indicated that the unstressed granites and related igneous rocks which occur as outliers within part of this basin are genetically related to the Cambrian folding of the Adelaidean

Geosyncline. It would seem probable that these igneous rocks are intrusive into rocks of the Kanmantoo Group and possibly earlier Cambrian and Adelaide System rocks.

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THE CAMBRIAN STRATIGRAPHY OF VICTORIA

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INTRODUCTION

The history of the Tasman Geosyncline in Victoria began with intense submarine igneous activity, piling up not less than 5000 ft of basic lavas, pyroclastics, and cherts, whose base is nowhere exposed. With the waning of vulcanicity during the Middle Cambrian, the next phase, covering the remainder of the period, was the deposition of some 2000 ft of shales.

The base of the Ordovician is marked by the entry of normal terrigenous detritus. In central Victoria, Ordovician, Silurian, and Lower Devonian (Yeringian), totalling some 35,000 to 40,000 ft, consist of a conformable succession of greywackes, sandstones, shales, and mudstones, with occasional conglomerates and rare lenticular limestones. The only evidence of vulcanism during this time is the presence of decomposed basic material possibly interbedded in the Lower Devonian sediments of the Walhalla Synclinorium. It may be noted that the Lower to Middle Devonian Snowy River Porphyries of eastern Victoria post-date the main orogenic movements in that region. In central Victoria the main orogenic deformation occurred during post-Yeringian pre-Upper Devonian time.

Rocks considered to be Cambrian in age are restricted in outcrop to a number of narrow belts associated with major tectonic structures. In only three areas, at Heathcote, Lancefield, and the Dolodrook River, has their age been demonstrated. However the predominance of a characteristic suite of altered igneous and pyroclastic rocks (known locally as "diabases") and the virtual absence of such rock types in the later geosynclinal deposits has led to the assignment of all such outcrops to the Cambrian.

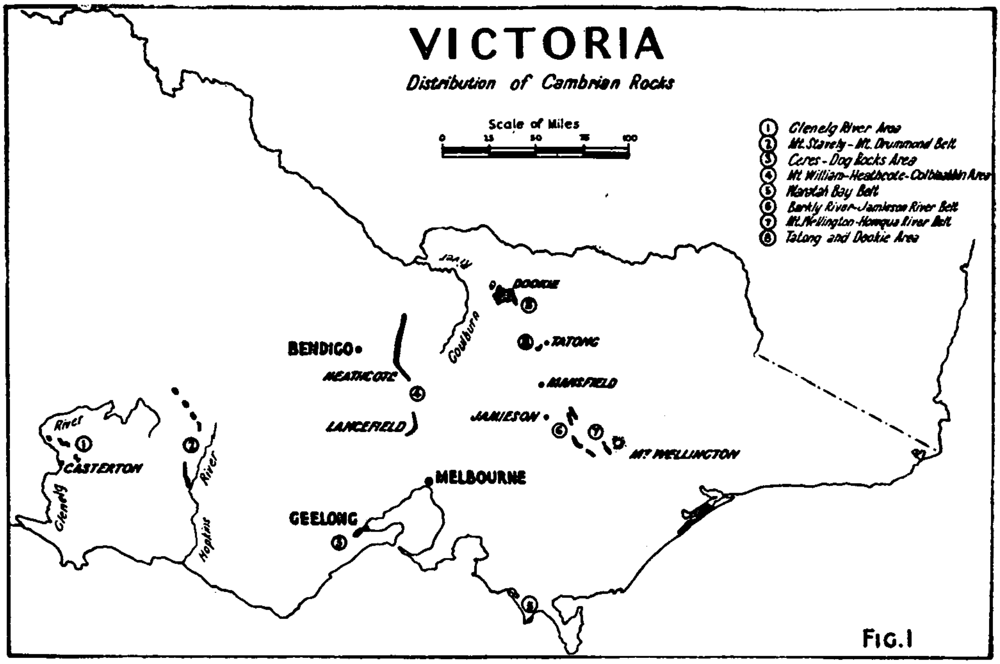


FIG. 1

From west to east across Victoria the outcrop lines are as follows (fig. 1):

1. Glenelg River Area.
2. Mt. Stavely-Mt. Drummond Belt.
3. Ceres-Dog Rocks Area.
4. Mt. William-Heathcote-Colbinabbin Belt.
5. Waratah Bay Belt.
6. Barkly River-Jamieson River Belt.
7. Mt. Wellington-Howqua River Belt.
8. Tatong and Dookie Areas.

It may be noted that the Wagonga Series, occupying a narrow meridional belt northwards from Narooma on the south coast of New South Wales, has also been referred to the Cambrian (Brown, 1933). In addition, a belt of serpentinous rocks along the Tumut River, also in southern New South Wales, may prove to be Cambrian in age.

STRATIGRAPHICAL SEQUENCES

MT. WILLIAM-HEATHCOTE-COLBINABBIN BELT (figs. 2, 3)

This belt, the bulk of which has been mapped by the senior author, is the best-known of all outcrop areas. Never more than two and a half miles wide, it outcrops in a general meridional direction for some seventy miles, except where transected by the Upper Devonian Cobaw granitic massif. It is obscured by younger rocks at both ends. Small deflections to the northwest at Heathcote and to the southwest near Monegeetta are significant. The eastern boundary is a high-angle reverse fault system, made up from south to north of the Mt. William, McIvor, and Mt. Ida Faults. The Mt. William Fault brings Cambrian rocks against Middle Ordovician to Lower Silurian, while on the other two faults Cambrian abuts against Upper Silurian and Lower Devonian, in this case involving a stratigraphical throw of some 45,000 ft. North of the Cobaw massif the western boundary is also a faulted junction, the Heathcote and Knowsley East Faults, against Lower Ordovician (Lancefieldian and Bendigonian). In the south there is a conformable passage from Cambrian to Ordovician. The structure within the belt is extremely complex, indicated among other things by the presence of infaulted lenses of Lower and Upper Ordovician sediments. It has thus proved impossible to work out the succession in detail.

The stratigraphical units recognised in the areas to south and north of the Cobaw granite are:

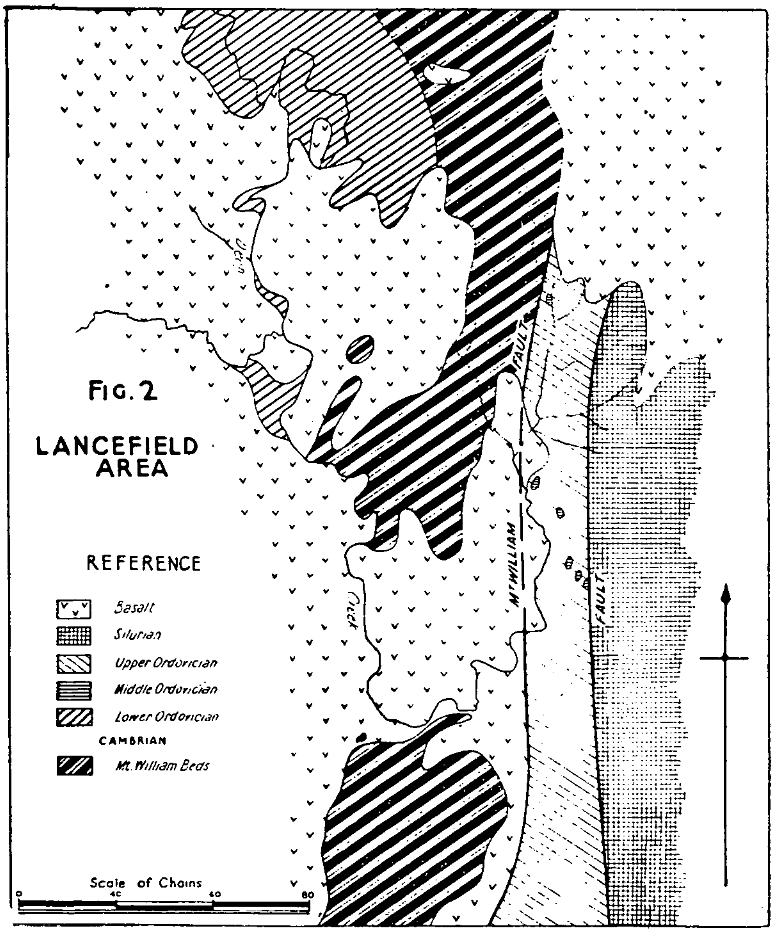
	Lancefield	Heathcote-Knowsley East
? Middle-Upper Cambrian	Goldie Shales	Goldie Shales
Middle Cambrian	Mt. William Group	Knowsley East Formation
Lower-? Middle Cambrian		Heathcote Greenstones

The Heathcote Greenstones (Heathcotian of authors) are altered basic to intermediate lavas, pyroclastics, minor intrusives, and lenticular bedded cherts containing *Protospongia* sp. and radiolaria. Their thickness has been estimated at not less than 5000 ft and they are considered to be largely, if not wholly, submarine. Pillow lavas have not been recognised. The greenstones, whose petrology has been described recently by Tattam (ms.) belong to the spilite-keratophyre association, being altered representatives of an original normal calc-alkaline suite characterised by an abundance of pyroxene and dearth of olivine. During the alteration, which pre-dated the main faulting, felspars were albitised, pyroxene largely converted to actinolite, chlorite and/or talc, and secondary minerals such as stilpnomelane and the epidote group introduced.

Dolerite was the dominant igneous rock type, with lesser amounts of augite andesite, augite porphyrite, felspar porphyrite, microdiorite, hornblende porphyrite, and quartz porphyrite. While many of the more basic rocks are undoubted lava flows, some at least, and most of the more acid types, are probably dykes or sills. Small masses of talc schist are considered to be altered pyroxenite and peridotite intrusions. Two small masses of microgranite, in part albitised, outcrop within the greenstones at Heathcote. The age of these is uncertain. They may be pene-contemporaneous with the greenstones which they intrude or belong to a later period of intrusion.

In general in the northern and southern portions of the belt lavas and cherts predominate while in the central Heathcote-Tooborac area pyroclastics and minor intrusives are more abundant. In this area particularly, many of the rocks have been strongly sheared during later tectonic movements. The pyroclastics, again largely altered rocks, include ashes, tuffs and lenticular agglomerates.

Younger Cambrian rocks occur in two areas which for convenience are discussed separately. In the south (fig. 2) the lavas, ashes, and cherts of the greenstone suite pass up gradationally into interbedded cherts, black shales, and thin ash beds. As no boundary can be mapped these beds are included with the greenstones in the Mt. William Group. Some of the black shales near Monegeetta contain the rich "dendroid" fauna listed below:



Inadvertently the Goldie Shales have been included under Mt. William Beds. They outcrop in the western half of the Cambrian belt.

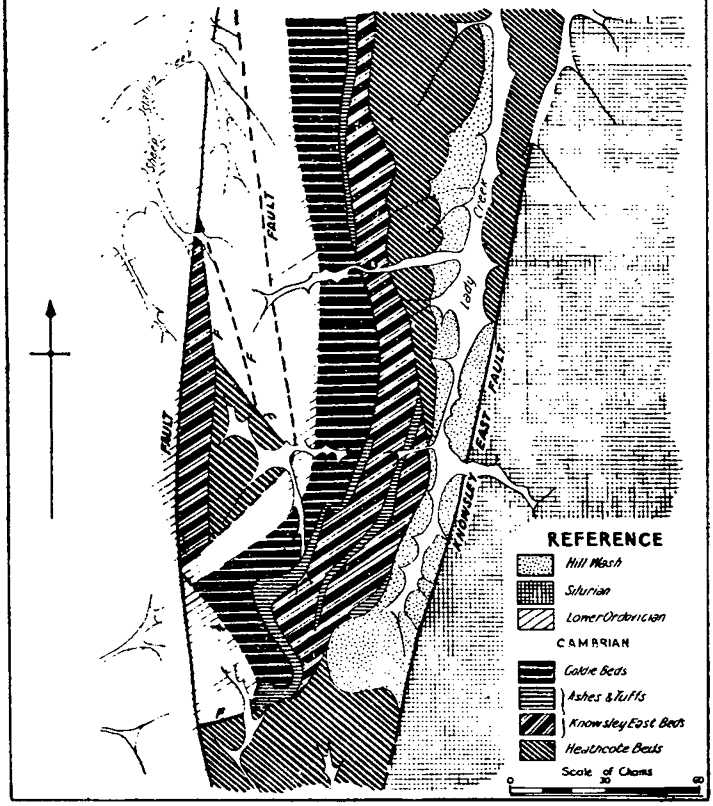
		Monegeetta	*Knowsley East*
Archaeocryptolaria	skeatsi Chapman, 1919	x	x
A.	recta Chapman, 1919	x	x
A.	recta flexilis Chapman and Thomas, 1936	x	x
A.	flabelloides Chapman and Thomas, 1936	x	

	Monegeetta	Knowsley East
Archaeolafoea longicornis Chapman, 1919	x	x
A. monegettae (Chapman, 1929)	x	x
A. serialis Chapman and Thomas, 1936	x	x
A. fruticosa Chapman and Thomas, 1936	x	x
Mastigograptus cf. gracillimus (Lesquereux, 1878)		x
M. tenuiramosus (Walcott, 1879)		x
M. circinalis Ruedemann, 1908	x	
M. arundinaceus (J. Hall, 1847)	x	
Protohalecium hallianum Chapman and Thomas, 1936		x
cf. Chaunograptus gemmatus Ruedemann, 1908	x	
Sphenoecium filicoides (Chapman, 1917)		x
S. discoidalis Chapman and Thomas, 1936	x	x
Cactograptus crassus Ruedemann, 1908	x	x
C. flexispinosus Chapman and Thomas, 1936	x	x
C. plumigerous Chapman and Thomas, 1936	x	
"Acanthograptus" candelabrum Chapman and Thomas, 1936	x	x
"Thallograptus" cf. succulentus (Ruedemann, 1904)	x	
Acrotreta antipodum Chapman, 1918	x	

The overlying unfossiliferous Goldie Shales, some 2000 ft in thickness, are black shales and mudstones, silicified in outcrop and with no ash bands. These are followed, apparently conformably, by the Ordovician. For convenience, the Cambro-Ordovician boundary is placed at the entry of greywackes which mark the first appearance of abundant detrital quartz and granitic accessory minerals. One hundred feet above this the first Ordovician graptolites, *Dictyonema campanulatum* Harris and Keble, *D. scitulum* Harris and Keble, and *Staurograptus diffisus* Harris and Keble occur. This fauna, Zone La 1 of the Lancefieldian Stage, is Tremadocian in age and is correlated with part of the *Bryograptus kjerulfi* Zone of Great Britain and Scandinavia.

In the Parish of Knowsley East, six miles north of Heathcote, the greenstones are followed conformably by the Knowsley East Formation, some 500 ft of interbedded shales and ash-bands, with several bands of agglomerate (fig. 3). Besides the "dendroid" fauna listed above, these beds contain two principal trilobite-bearing horizons separated by just over 100 ft of strata. The sequence is complicated by minor folding but

FIG. 3 KNOWSLEY EAST AREA



For "Silurian" read "Lower Devonian."

the field evidence indicates that the "*Dinesus* Band" lies beneath the "*Amphoton* Band." Recently an unidentifiable Ptychoparioid trilobite has been found apparently well below the former.

The "*Dinesus* Band" contains the following trilobites:

Peronopsis sp.
Dinesus ida Etheridge f., 1896.
Kootenia fergusoni (Gregory, 1903) (*Notasaphus* T.S.)
"*Amphoton*" sp.

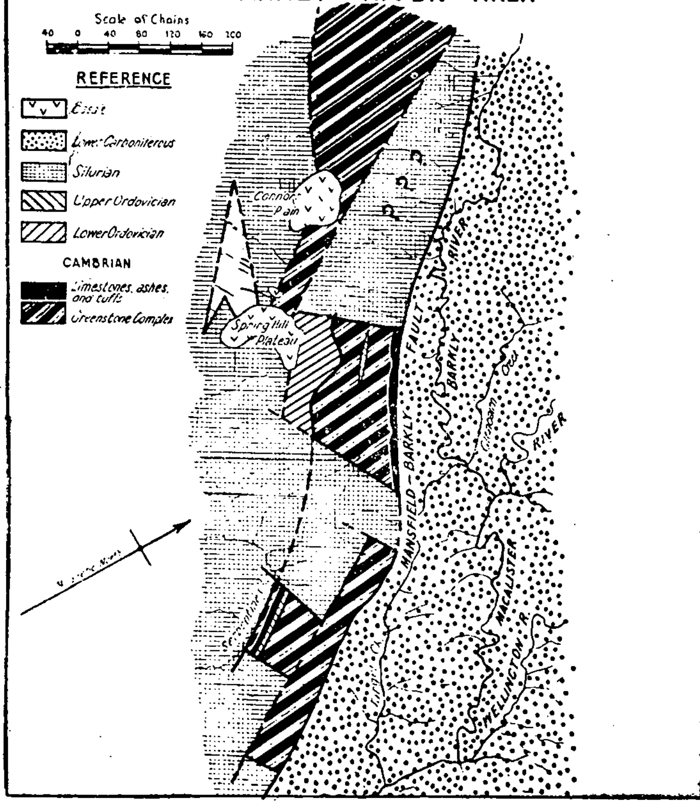
and fragments of a large trilobite described by Öpik (1949) as *Centropleura neglecta*. In addition Chapman (1917) has recorded a number of brachiopods from this band but these are in need of revision.

The "*Amphoton* Band" contains:

Peronopsis cf. *normata* (Whitehouse, 1936)
Dinesus sp.
Solenoparia n. sp.
Nepea narinosa Whitehouse, 1936.
Dorypyge n. sp.
"*Amphoton*" sp.
Fuchouia n. sp.

The Knowsley East Formation passes up, apparently conformably, into the unfossiliferous Goldie Shales, which in this area are faulted against Ordovician.

FIG. 4 BARKLY RIVER AREA



BARKLY RIVER-JAMIESON RIVER (fig. 4) AND MT. WELLINGTON-HOWQUA RIVER BELTS (fig. 5)

In east-central Victoria inliers of Cambrian rocks lie along two sub-parallel belts only a few miles apart which trend in a general NW-SE direction. The eastern Mt. Wellington-Howqua River belt outcrops along the Dolodrook River near Mt. Wellington and in the valleys of the Jamieson and Howqua Rivers, being obscured in between by Upper Palaeozoic rocks. The western belt outcrops on the western side of the Barkly River from near Licola to Mt. Shillinglaw where it is truncated, apparently by cross faulting, and is overlain by Silurian rocks. It reappears on the Jamieson River north of Mt. Skene and then veers in a more northerly direction, eventually terminating on the Howqua River close to the eastern belt. With one exception the boundaries of all outcrops with the Ordovician and Silurian are faulted and their internal structure is again extremely complex.

The most important inlier, that along the Dolodrook River, is faulted against Upper Ordovician and Silurian (Teale, 1920; Harris and Thomas, 1954) (fig. 5). The sequence begins with the sheared

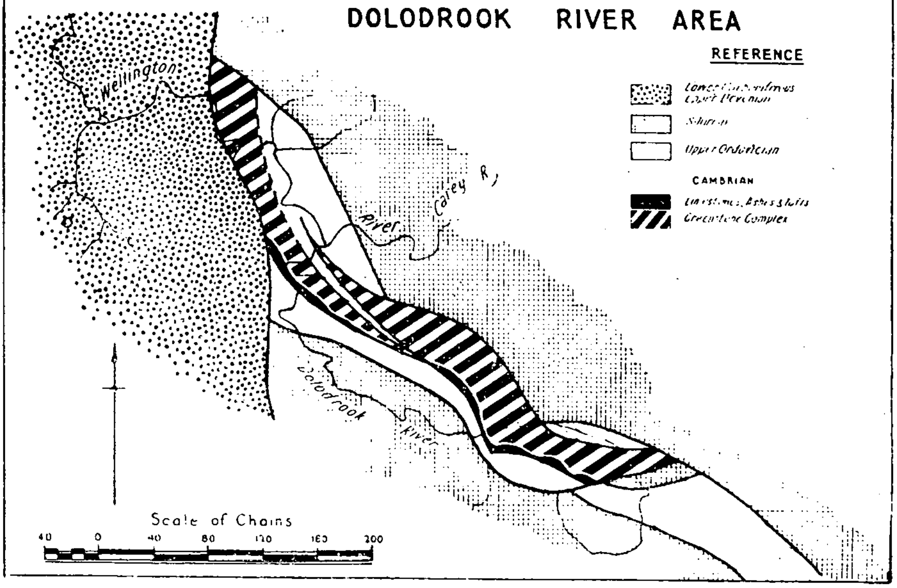


FIG. 5
DOLODROOK RIVER AREA

and partly serpentinised Mt. Wellington Greenstones, which include lavas, tuffs, and agglomerates. These were erroneously believed by Teale to be serpentinised peridotites and pyroxenites and to be separated from the later Cambrian rocks by an unconformity.

Following conformably upon the greenstones are the Garvey Gully Tuffs, well-bedded tuffs and ashes. Interbedded in these is a lenticular limestone, the Dolodrook Limestone, which contains two trilobite faunas determined by the junior author. This limestone appears as a series of lenses in outcrop but this is almost certainly the result of subsequent deformation. The older fauna, collected from localities on the Dolodrook River and Thiele's Creek includes:

Hypagnostus n. sp.
Ptychagnostus australiensis (Chapman, 1911)
Pseudagnostus vastulus Whitehouse, 1936.
Pseudagnostus sp.
Phoidagnostus sp.
Blountia n. sp.
Bynumia n. sp.
Crepicephalus etheridgei Chapman, 1911.
Corynexochus sp.
Eugonocare sp.
Thielaspis (n. gen.) *thielei* (Chapman, 1911)
Thielaspis minima (Chapman, 1911)
and other undescribed forms.

The second fauna, from the outcrop on Roan Horse Gully, contains:

Aphelaspis n. sp.

Chapman (1911) has also recorded the following species—?*Lingulella* sp., *Orthis (Plectorthis) platystrophioides* Chapman, and *Scenella tenuistriata* Chapman. In addition parts of the limestone are crowded with small algal pellets.

In the Barkly River inlier the greenstones are largely massive basic igneous rocks, with sheared tuffs and ashes (Harris and Thomas, 1954). Intimately associated with some of the ashes are thin marmorised limestones, brought into place by thrusting and probably equivalent to the Dolodrook Limestone.

The outcrop of the eastern belt on the Howqua River consists of albitised basaltic rocks, similar petrographically to those in the Heathcote Greenstones, agglomerates, and ashes (Teale, 1919; Harris and Thomas, 1938). On the west these Howqua Greenstones are faulted against Upper Ordovician, but on the east are succeeded by a belt of cherts half a mile in outcrop, the Howqua Cherts, which contain *Protospongia* sp. and near the top Lancefieldian graptolites (Zone La 2). Part at least of these cherts may be Cambrian in age.

The Jamieson River inlier differs somewhat in lithology from the last, being largely agglomeratic, with some bedded cherts. Tuffs and ashes are also present.

A small extremely dislocated inlier of phosphatic shales at Phosphate Hill, two miles west of Mansfield, has in the past been referred to the Cambrian (Howitt, 1923). Neglecting Upper Ordovician graptolites present in faulted wedges of black chert, the only diagnostic fossils, *Tetragraptus approximatus* Nicholson, *T. decipiens* T. S. Hall and *Dictyonema* sp., indicate a Lancefieldian (Zones La 2-3) age, so that these beds are best placed in the Ordovician.

Tatong

Thirty miles N.N.W. of the Howqua River outcrops, an inlier of greenstones and chert at Tatong is considered to be Cambrian (Summers, 1908), but details are wanting.

Dookie

In the Dookie area, thirty miles further to the northwest, hills of Lower Palaeozoic rocks rise out of the alluvial plains of northern Victoria. A greenstone series, believed to be Cambrian in age, has a dominant E-W trend and is faulted on the south against Lower Ordovician (Castlemainian) and Silurian sediments. The succession consists of altered dolerite lavas and probably sills, interbedded with tuffs, ashes, and cherts.

Waratah Bay Belt

A narrow strip of greenstone with a NE-SW trend crops out on the western shore of Waratah Bay in South Gippsland (Lindner, 1953). On the east it is faulted against another faulted strip of limestone, the

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Digger Island Limestone, containing a Tremadocian trilobite fauna, while on the west it is unconformably overlain by Middle Devonian limestone. The greenstones, probably Cambrian in age, include albitised basic lavas and pyroclastics, with insignificant amounts of sheared limestone and shale.

Ceres and Dog Rocks

Small outcrops of epidiorite at Ceres, Dog Rocks, and the You Yangs, all in the Geelong District, are considered to be remnants of a belt of Cambrian greenstone which have been subsequently metamorphosed to epidiorite by Devonian granites.

Mt. Stavely-Mt. Drummond Belt

A number of outcrops in the alluvial flats to the east of the Grampian Ranges in Western Victoria indicate the presence of yet another belt of probable Cambrian rocks. In the largest exposure at Mt. Stavely the belt, up to two miles wide, consists of interbedded basic lavas and cherts. On the western side there is a gradual transition, with no observed structural break, into sandstones and shales believed to be Lower Ordovician in age.

Glenelg River Area

Several outcrops of basic rocks at Wando Vale on the Wando River, and Dergholm on the Glenelg River are believed to be Cambrian in age. They are mainly amphibolites, serpentines, and talc-chlorite schists, surrounded by regionally metamorphosed sediments of probable Ordovician age (Wells, in press). The trend here is NW-SE.

The Dimboola Nº 1 Bore in the Wimmera struck greenstone of possible Cambrian age at 370 feet (Gloe, 1947).

AGE AND CORRELATION

Direct evidence for the age of the rocks described above is found in only two areas, near Heathcote and on the Dolodrook River. The two trilobite faunas in the Knowsley East Formation are medial Middle Cambrian in age. The "*Dinesus* Band" fauna is correlated with the European *Ptychagnostus gibbus* zone. *Dinesus* occurs in the same zone in Queensland and in Middle Cambrian beds in Siberia. *Kootenia* is long-ranging and the identification of *Centropleura* is in doubt.

The association of genera in the "*Amphoton* Band"—"*Amphoton*," *Fuchouia, Dorypyge, Solenoparia, Nepea*—appears rather later in the Middle Cambrian in Queensland. Close comparison of Victorian and Queensland species has not been possible as yet. However, the rare presence of *Dinesus* in this fauna suggests that the "*Amphoton* Band" does not differ greatly in age from the "*Dinesus* Band."

The older fauna in the Dolodrook Limestone is significant because it contains genera restricted to the Middle Cambrian in Europe—*Hypagnostus, Ptychagnostus, Phoidagnostus, Corynexochus*—associated with North American early "Upper" Cambrian genera—*Blountia, Bynumia, Crepicephalus.* There is no evidence to suggest that the European genera linger on into the Upper Cambrian in Australia, although Whitehouse (1939) assigned the association of *Pseudagnostus, Corynexochus,* and *Eugonocare* to the early Upper Cambrian. This association however has been recorded from late Middle Cambrian beds in Eastern Asia. This fauna is definitely younger than the New Zealand Cobb River fauna which is correlated with the *Solenopleura brachymetopa* zone of Scandinavia, and it is therefore correlated with the succeeding *Lejopyge laevigata* zone. The *Aphelaspis* fauna in the Dolodrook Limestone is correlated with the Dresbachian *Aphelaspis* zone of North America which appears to be equivalent to part of the European *Olenus* zone.

The Knowsley East Formation covers much of the Middle Cambrian. From their conformable relationships the Goldie Shales must represent the Upper Cambrian and probably part of the Middle Cambrian as well. The Dolodrook Limestone apparently straddles the Middle Cambrian-Upper Cambrian boundary so that the containing Garvey Gully Tuffs must cover part of both Middle and Upper Cambrian. Although no lavas occur in any of these formations the presence of pyroclastics in the Knowsley East and Garvey Gully Formations indicates that volcanic activity was still going on when these were deposited. It is probable that this activity ceased earlier in the Heathcote-Lancefield area than in the Dolodrook River area.

For convenience the whole of the Heathcote and Wellington Greenstones are included in the Cambrian. The bulk of them are without doubt Lower Cambrian but they probably continued into the Middle Cambrian. The reasons for correlating the other occurrences of greenstones with these have been set out above.

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THE MIDDLE AND UPPER CAMBRIAN SERIES (DUNDAS GROUP AND ITS CORRELATES) IN TASMANIA

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ABSTRACT

Over 10,000 feet of greywacke and sub-greywacke breccia, conglomerate and sandstone, argillite, chert, and lavas and pyroclastics of the spilitic suite were deposited in Tasmania between the time of the Middle Cambrian ***Ptychagnostus gibbus*** Zone and that of the Upper Cambrian ***Glyptagnostus reticulatus*** Zone. These rocks are the Dundas Group and its correlates. Trilobites, brachiopods, dendroids, cystoids and worms have been found in these sediments. Basic and ultrabasic rocks were intruded during the Upper Cambrian as dykes through the Precambrian and as slightly transgressive sheets into the Dundas Group. Granite was also emplaced during the Jukesian Movement before the Lower Ordovician. The trough, in which deposition occurred, was part of a eugeosyncline.

RÉSUMÉ

Plus de trois milles trois cents mètres de grauwacke et sous-grauwacke brèches, conglomérats et grès, d'argillite, de pierre de corne, et des laves et des roche pyroclastiques de la type spilitique ont été déposés en Tasmanie pendant l'intervale de la Zone de **Ptychagnostus gibbus** (Cambrien moyen) à la Zone de **Glyptagnostus reticulatus** (Cambrien supérieur). Cettes roches-ci constituent la "Dundas Group" et ses corrélatives. On a trouvé des trilobites, des brachiopodes, des dendroides, des cystoides et des annelides dans ces sédiments. Pendant le Cambrien supérieur des roches basiques et ultrabasiques ont introduit de force à travers les roches Ante-Cambrien comme des dykes et à travers la "Dundas Group" comme les filons couches transgressives. Du granite s'est aussi mis en place pendant le Mouvement jukesien auparavant l'Ordovicien inférieur. Le fond de bateau, dans lequel les dêpots se sont formé, était une partie d'un eugeosynclinal.

INTRODUCTION

Evidence that Cambrian rocks occur in Tasmania was first given by Twelvetrees (1905, p. 10), although rocks now known to be Cambrian were first described by Gould in 1867. The first definite evidence of the age of these rocks was the report of the discovery of dendroids in 1945 by Thomas and Henderson at Dundas. Since then Elliston and others have found trilobites in many places, and most of these have been identified by Opik. The discovery of these trilobites and the mapping of a number of formations of the Dundas Group at Dundas by Elliston mark an important advance in the knowledge of the Cambrian System in Tasmania. Since the discovery of dendroids many geologists have added greatly to the knowledge of the system and the time is opportune for a comprehensive review.

The author wishes to acknowledge the assistance of Mr. J. G. Symons, Director of Mines, who made available unpublished material from the Mines Department files, Mr. F. Blake, geologist with the Mines Department, Miss E. Smith, who provided lists of literature and criticized the preliminary manuscript, and Dr. A. A. Öpik and Professor S. W. Carey who criticized the manuscript.

DISTRIBUTION

The distribution of the Dundas Group and its correlates in Tasmania is shown on the map (fig. 1). This can be summarized as a major synclinorium of Dundas Group rocks extending from the Mainwaring River on the West Coast, north to the Pieman River, thence through an arc to Sheffield and Deloraine where it disappears trending southeasterly below Permian sediments. Correlates of the Dundas Group outcrop at Beaconsfield on the eastern edge of an anticlinorium and probably trend south as part of a major synclinorium beneath Permian sediments east of the Tyennan Anticlinorium (approximately the Tyennan Block of Carey [1953]). They occur at Adamsfield and extend sporadically to New River Lagoon. Another synclinorium containing sediments correlated with the Dundas Group trends northwesterly from the Arthur River south of Smithton, through Smithton to King Island, where it swings to the north or even northeast (Waterhouse, 1916a). In some places Ordovician rocks directly overlie pre-Dundas Group rocks, always unconformably. These areas are shown on the map (fig. 4) as Tyennan Unconformities. They occur on the Tyennan Anticlinorium or its margins, and on the outer margin of the main synclinorium at Zeehan and Penguin. It is not known whether the lack of Dundas Group correlates on the Tyennan and Rocky Cape Anticlinoria (see Carey, 1953, fig. 3) is a sedimentational feature or is due to Upper Cambrian erosion. This question is discussed further under STRUCTURE.

HISTORICAL REVIEW

The earliest reference to rocks now known to be Cambrian was by Gould (1867) who described the sequence near Penguin. During the next twenty years the system received little attention even from Johnston (1886), but from about 1895 (Officer, Balfour and Hogg), onwards there has been more or less constant addition of new information. This has been greater during the early part of this century and within the last ten years than in the intervening period.

The term "Dundas Group" was introduced by Waller (1905a) but the same rocks have also been called "Dundas Slates" and "Dundas Series." Following work by Elliston (1954) the term "Dundas Group" is now used. The age assigned to rocks considered coeval with the Dundas Group has varied. Twelvetrees (1902) considered them Middle to Upper Silurian but in 1905 and 1909b the same author regarded them as Cambrian as they were overlain by the Owen Conglomerate of Ordovician age. Twelvetrees and Ward (1910) considered them as

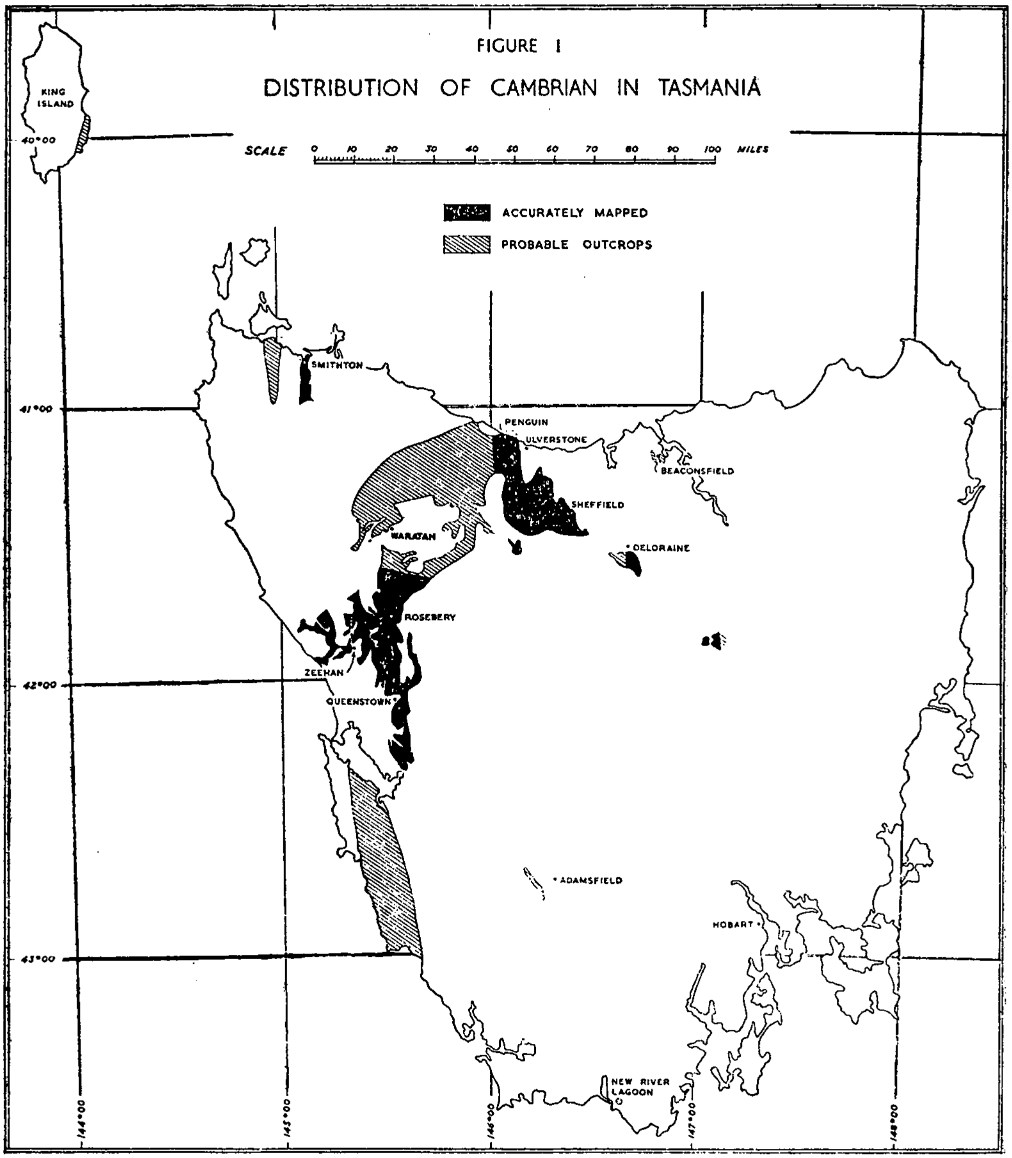

Fig. 1. Map of Tasmania showing the distribution of the Dundas Group.

Cambro-Ordovician, as did Hills (1924), but this latter author also included rocks not now considered as coeval. In 1928, Nye and Lewis restricted the known Cambrian to the Hatfield Plains Slate and placed the Dundas Group in the Ordovician because of a supposed intrusion of Gordon Limestone (Ordovician) by a dyke of porphyroid at Paloona. The so-called intrusion is a flow or sill in contact with a bed of chert of Cambrian age. Nye (1932) considered the Dundas Group as Upper Cambrian to Ordovician, a conclusion based on Hall's identification of graptolites from the North-East Dundas Tram (1902), an identification later rejected by Thomas (1945). Only the Hatfield Plains and Arthur River Slates were considered to be Cambrian by Nye and Blake (1938) and the Dundas Group was placed in the Devonian. Thomas (1944) placed the Dundas in the Cambrian with an epi-Cambrian orogeny followed by Ordovician sedimentation. Then in 1945, Thomas and Henderson demonstrated, on the evidence of dendroids, that part of the Dundas Group was Middle Cambrian. Later, Thomas (1947) included the Dundas "Series," the Farrell Slate and Arthur River and Hatfield Plains Slates in the Cambrian. Hills and Carey (1949) included rocks now correlated with the Dundas in their Pieman Group of Upper Precambrian and Cambrian age. Finally, Elliston (1954) redefined the Dundas Group, defined its constituent formations, and summarized the evidence showing it to be of Middle and Upper Cambrian age.

The first palaeontological work on the Dundas Group was the erroneous identification of graptolites by Hall (1902). Chapman (1926) described a phyllocarid and later (1929) a worm from the Dundas Group. In 1945, Thomas and Henderson made an important contribution with the discovery of dendroids from Dundas. In 1950, Elliston, B. G. May, and others, while carrying out a survey of the Dundas district, discovered trilobites. Later, Taylor and Elliston found trilobites in the Huskisson River area, and R. J. Cooper and the author found trilobites in the Leven Gorge. Trilobites from all areas were sent to A. A. Öpik, who identified them and showed them to be of Middle and Upper Cambrian age.

A vexing question has been the age and nature of the "porphyroids", a name introduced into Tasmanian literature by Twelvetrees and Petterd (1899) following a letter from Rosenbusch. These authors regarded them as sheared eruptive rocks and Twelvetrees (1902) gave their age as Middle and Upper Silurian. Later, Twelvetrees (1909b) recognized volcanic rocks in the Dundas but thought that the porphyroids were intrusive and Cambrian as they did not intrude the Ordovician Owen Conglomerate. Hills (1924) also considered the porphyroids Cambrian because the Owen Conglomerate unconformably overlies them on Mount Darwin. He also considered them to be highly metamorphosed plutonic, effusive and fragmental rocks. In 1928, Nye and Lewis placed the porphyroids in the Ordovician because of MacIntosh Reid's erroneous interpretation of the situation at Paloona, mentioned above. Finucane (1932) postulated that the porphyroids were entirely intrusive, basing his ideas on observation of dykes near Rosebery, and of Devonian age. This view was followed by Nye and Blake (1938) and other writers until Carey (1946), who reverted to earlier views that the porphyroids were effusive, basing his ideas on observations east of Rosebery. Carey (1953) postulated that the porphyroids were due to hydrothermal alteration of Cambrian lavas and sediments during the Devonian. This idea was followed by Scott (1954) who considered the porphyroids as sheared, silicified and albitized Cambrian spilites. Bradley (1954) advanced the view that some of the porphyroids were originally keratophyres but that the quartz and some of the feldspar porphyries were albitized and silicified sediments, especially greywackes and greywacke-conglomerates, the alteration having taken place in the Devonian.

The ultrabasic rocks of Tasmania have been considered co-magmatic with the Devonian granites since Twelvetrees (1909b) wrote on them, but earlier he had considered them Middle to Upper Silurian. Hills and Carey (1949) were the first to suggest that some of the serpentine might be older than the Lower Ordovician Owen Conglomerate, and Carey (1953) showed this to be the case.

In an unpublished report, Nye (1928) suggested that the cherts are silicified argillites, a view followed by all later writers.

Hills, in 1924, remarked on the similarity between the Dundas Group and the Heathcotian Series of Victoria, a similarity which has since been strengthened by the discovery of dendroids by Thomas and Henderson in 1945.

The first writer to consider the tectonic conditions under which the Dundas Group was deposited was Carey (1950; 1953), who, following a suggestion by the author, postulated deposition in a eugeosyncline. In 1950, Carey postulated the presence of a number of cycles of sedimentation in the Dundas Group, an idea developed further in this paper. Carey considered that the cycles were initiated by orogenic

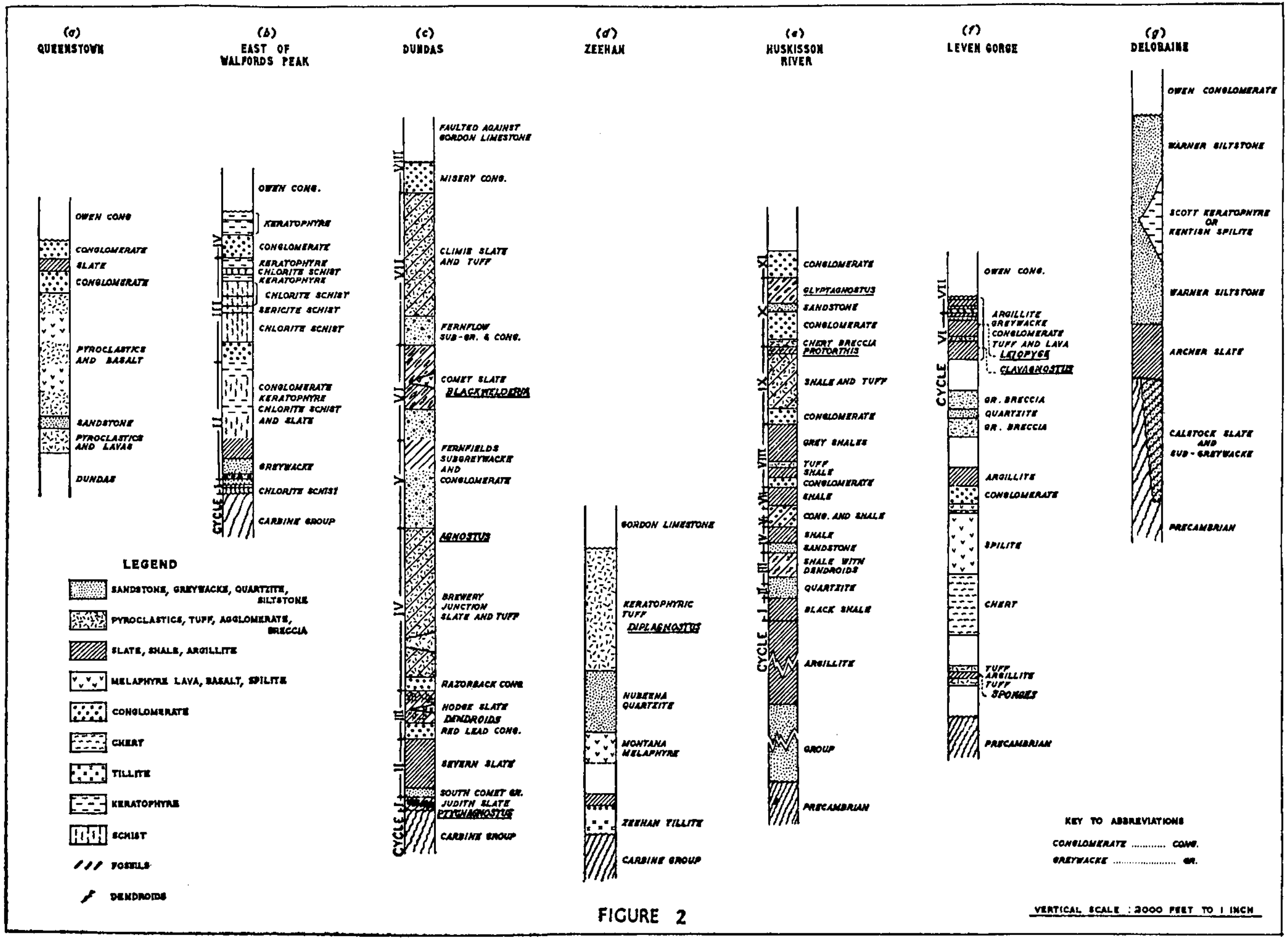

Fig. 2. Columnar sections:
(a) Lynch Creek, South Queenstown section;
(b) Lake Dora section;
(c) Dundas section;
(d) Zeehan section;
(e) Pieman and Huskisson River section;
(f) Leven Gorge section;
(g) Deloraine section.

movements, but Elliston (1954) considered that vulcanism was the controlling factor.

STRATIGRAPHY

In this paper the term Dundas Group will be used in a strict sense when referring to the sediments in the type area, and in the sense of those rocks correlated with the Dundas Group, *sensu stricto*, when referring to rocks outside the type area. The reason for the correlation will be given in each case where the term is used in the loose sense.

THE DUNDAS SECTION

The section at Dundas is summarized below and as figure 2 (c):

Formations:	*Thickness in feet:*
Gordon Limestone (Ordovician)	
fault	
Misery (Sub-greywacke) Conglomerate	500
Climie Slate and Tuff	2000
Fernflow Sub-greywacke and Conglomerate	470
Comet Slate and Sub-greywacke, with *Blackwelderia*, etc.	1050
Fernfields Sub-greywacke and Conglomerate	1950
Brewery Junction Slate and Tuff, with trilobites, = Curtin Davis Volcanics (1000)	2450
Razorback (Sub-greywacke) Conglomerate	225
Hodge Slate, with *Archaeocryptolaria*, etc.	530
Red Lead Conglomerate	250
Severn Slate	800
South Comet Greywacke	150
Judith Slate and Sub-greywacke, with *Ptychagnostus*, etc.	200
	10,575
unconformity	
Carbine Group	

This section is essentially that of Elliston (1954, p. 163), but the author considers that many of Elliston's tuffs are sub-greywackes (in Pettijohn's [1949] sense) as will be seen from the descriptions which follow. In addition, the Curtin Davis Volcanics are considered as probably contemporaneous with the Brewery Junction Slate and Tuff, as both overlie the Razorback Conglomerate, and both are volcanic.

The basal formation, the Judith Slate and Greywacke has a micaceous greywacke (or tuff) at the base and this contains *Lorenzella*, *Pachyaspis, Peronopsis, Ptychagnostus, Pagetia* and *Triplagnostus.* Öpik (1951a and c; and pers. comm.) correlated it with the Scandinavian Middle Cambrian Zone with *Ptychagnostus gibbus.* The South Comet Greywacke contains small angular fragments of grey and black chert and feldspar. The Severn Slate consists of interbedded slates and greywackes or sub-greywackes with intraformational brecciation. Some of the greywackes are dolomitic. The Red Lead Conglomerate belongs to the sub-greywacke suite as it contains angular, sub-angular and rounded fragments, from a fraction of a millimetre up to three feet across, of banded chert, chert, greywacke, quartzite, banded slate and jasper in a silt grade matrix. The feldspar content is low. Graded and cross bedding occur in this formation. Elliston suggested (1954, p. 168) that this may be in part glacial.

An important horizon is the Hodge Slate, a micaceous carbonaceous slate with thin beds of greywacke and tuff. This formation contains trilobites, cystoids and dendroids such as *Archaeolofoaea serialis, Archaeocryptolaria skeatsi,* etc. (Thomas and Henderson, 1945) and is considered (Öpik, 1951c) to be upper Middle Cambrian. Thin basic flows occur in this formation northeast of Dundas. *Solenoparia,* Bathyuriscids, and perhaps *Homagnostus* occur in tuff on the power line 100 yards west of Bonnie Point on the North-East Dundas Tram which is shown on Elliston's map as part of the Hodge Slate.

The Razorback Conglomerate is a sub-greywacke conglomerate with angular and rounded fragments, up to 6 inches in diameter, of chert, jasper, quartzite, black slate, and, rarely, basalt. A striated pebble collected by Waller near Montezuma Falls (see Elliston, 1954, p. 166) possibly came from this formation.

In the type area, the Razorback Conglomerate is overlain by the Brewery Junction Slate and Tuff which is composed of grey, light greenish or black slate with thin tuff bands which become rarer near the top. A relatively thick bed of keratophyric tuff occurs near the base of the formation and outcrops on the track to the Comet Mine about a quarter of a mile from Dundas township. It consists of angular fragments of keratophyre in a matrix of angular fragments of albite and quartz. Recently, the author found trilobites and cystoids just below the top of this formation on the South Comet Tram several hundred yards east of Brewery Junction. They were badly deformed and Öpik was unable to identify any genera other than *Agnostus* (or *Homagnostus* ?) and *Ptychagnostus* ?.

Above the Razorback Conglomerate near Montezuma Falls is a thick sequence of porphyritic basalts and associated pyroclastic rocks (see Scott, 1954, p. 134) called the Curtin Davis Volcanics. Because of their position they are correlated with the Brewery Junction Slate and Tuff which also contains pyroclastic rocks.

The succeeding formation, the Fernfields Conglomerate and Greywacke is a sub-greywacke conglomerate near the base and becomes finer-grained upwards where sparse boulders occur in a sub-greywacke matrix. Higher still it passes into slates with occasional pebbles which have been suggested to be of glacial origin. The top of the formation is a sub-greywacke conglomerate.

Light grey slates with thin bands of sub-greywacke comprise the Comet Slate and Sub-greywacke. This formation contains *Blackwelderia* cf. *biloba* Kobayashi, *Conocephalites* (?), *Oidalagnostus* and *Anomocarella* (?) (see Öpik, 1951a). These are still only upper Middle Cambrian. A lava flow occurs in this formation to the southeast of Dundas.

The Fernflow Conglomerate and Sub-greywacke consists of siliceous and slaty fragments in a slate matrix. It has been suggested by Elliston (1954, p. 171) that this also is glacial.

The succeeding formation is dominantly slaty, with some tuff (?) or sub-greywacke beds and rare conglomerate. This is the Climie Slate and Tuff and is followed by the Misery Conglomerate which consists of graded and cross-bedded sub-greywacke conglomerates with boulders of quartzite, chert, jasper, basalts, etc., in a matrix of angular quartz, chert and jasper grains. The contact with the overlying Ordovician Gordon Limestone is probably a fault and several thousands of feet more of sediment could well occur above the Misery Conglomerate. Younger formations, at least basal Upper Cambrian in age (Öpik, 1955, letter) are apparently present on the North-East Dundas Tram, as shown by the occurrence of *Coosia* and *Pseudagnostus*, a Dikelocephalid and *Aphelaspis* (?) in a greenish mudstone in the first re-entrant east of Bonnie Point. The erroneous allocation of this bed to the Hodge Slate by Elliston (1954, map) apparently arose from misinterpretation of earlier conversation and correspondence with Öpik.

The succession at Dundas could be regarded as consisting of parts of at least eight cycles, as indicated in the columnar section (fig. 2 [c]). A perfect cycle would commence with a coarse sub-greywacke conglomerate, pass upwards into alternating conglomerate and sub-greywacke, sub-greywacke, alternating sub-greywacke and slate, and then into slates with subordinate sub-greywacke, and finally perhaps into slate. Volcanic and pyroclastic rocks would be accidental interruptions to these cycles, although vulcanism seems to occur at intermediate stages in three of the cycles. Elliston (1954, p. 165) regarded rough alternation of conglomerate and finer beds as due to periods of vulcanism and non-vulcanism, but the author disagrees with this and points out that the lava flows seem, from Elliston's description, to occur in his finer-grained formations, e.g. Hodge Slate, Brewery Junction Slate and Tuff, and Comet Slate and Tuff. The author's interpretation of the succession as consisting of eight cycles differs considerably from Elliston's and the author (following Carey, 1950) suggests that each cycle is initiated by a rise in the area supplying the sediments to the trough, due to an orogenic movement, part of the Tyennan Orogeny, and that each cycle represents the erosion of these uplifted areas. Vulcanism seems to occur at an intermediate stage in the cycles. In at least one case the beginning of a new cycle is marked by a sharp change, e.g. between the Brewery Junction Slate and Tuff and the Fernfield Formation (Elliston, 1954, p. 171).

Dundas Group rocks also occur east of Dundas (Elliston, 1954, p. 177) and provide a link with the slates, tuff and breccias of the Williamsford and Rosebery area (Hall et al., 1953, p. 1147). Many of the Dundas Group formations can be traced north to Renison Bell (Loftus Hills, pers. comm.) where quartzite, slate, conglomerate and tuff occur. Elliston remarked (1954, p. 177) that purple slates, tuffs, breccias and conglomerates like those in the Dundas Group occur northwest of Renison Bell in the Poiseidon-Bon Accord area.

SOUTH OF MACQUARIE HARBOUR

The farthest area south in which Dundas Group rocks have been studied on the West Coast is in the vicinity of the Wanderer and Mainwaring Rivers. Here Blake (1936) recorded slates, quartzites, breccias, chlorite and talc schists, chert, feldspathic breccia and basic porphyries. Scott (1954, p. 129) recorded a spilite from the Mainwaring River area.

On the coast south of the Spero River area, Taylor (1949) found tuff and impure limestone, and near Asbestos Point, Macquarie Harbour, sericite and quartz sericite schists, slates, schisted tuffs and fine conglomerates. Scott (1954, p. 129) noted spilite at Double Cove, on the southern shore of Macquarie Harbour.

No fossils have been found yet in these rocks south of Macquarie Harbour, but on lithological grounds they are correlated with the Dundas Group.

WEST COAST RANGE

There are almost continuous outcrops of the Dundas Group from Mount Sorell north to Mount Murchison. In the Mount Darwin area Hills (1913, p. 32) recorded felsites, keratophyres, tuffs and breccias, and noted the presence of purple schist, quartz chlorite schist, black slate and coarse-grained feldspathic sandstone. Bradley (1954, p. 235) noted the presence of black, fine-grained greywacke hornfels, black fine-grained laminated greywacke and sericite schist on Mount Darwin. Bradley also recorded (1954, p. 232) feldspar porphyry and chlorite sericite pyrite schist from Snake Spur.

The section along Lynch Creek, south of Queenstown, as computed from a section kindly supplied by M. Solomon, of the Mount Lyell Mining Company, is given below and as text-figure 2 (a):

Owen Conglomerate (Ordovician)	
unconformity	
Conglomerate	200-300 ft.
Slate	200 ft.
Conglomerate	350 ft.
Pyroclastics Porphyritic Pyroxene Basalt Pyroclastics Lava (missing in places) Pyroclastics	2000 ft.
Grey sandstone	200 ft.
Pyroclastics	400 ft.
Lava (spilitic)	

Bradley (1954, p. 231) provided a different section on the assumption of a sequence of formations dipping steeply west but recent detailed work by Solomon has demonstrated the presence of two anticlines and an intervening syncline.

The Lyell Schists in which the main copper bodies occur at Queenstown were regarded by Hills (1927, p. 130) as metamorphosed tuffs and he observed that they passed westward into lava flows and volcanic breccias. Later the schists were considered as schisted intrusive porphyries by Edwards (1939) and others. Alexander (1953, p. 1134) quoted Connolly as noting porphyries, rhyolite breccias, conglomerates and well-bedded slates in the Lyell Schists. Bradley (1954) regarded the

Lyell Schists as metamorphosed Dundas Group rocks with some of the schists due to metamorphism of the Owen Conglomerate, a view also expressed earlier by Hills (1927, p. 130). Along the Comstock Tram north of Queenstown there is a section of the Dundas Group with slates, spilites, a keratophyre with flow structure, cherts, greywacke conglomerates and greywackes. Bradley (1954, p. 228) equated a greywacke conglomerate at the King River Bridge with the Dora Conglomerate (see later), but without adequate evidence. This unit also contains slate bands near the road at the mouth of Linda Creek. It appears to be overlain unconformably by the Owen Conglomerate.

At Mount Sedgwick, Bradley (1954, p. 228) recorded conglomeratic quartz porphyry, i.e. quartz porphyry fragments in a quartz porphyry matrix (= aa keratophyre perhaps), and thin hornfels.

East of Walford's Peak and near Lake Dora a number of sections were measured by Dr. F. Ahmad and the author. One cross-section, taken just north of Lake Dora is summarized below and as text-figure 2 (b); (thicknesses are approximate only):

	Owen Conglomerate (Ordovician)	
	unconformity	
u.	Scoriaceous quartz biotite keratophyre	125 ft.
t.	Scoriaceous quartz keratophyre	250 ft.
s.	Quartz chlorite schist with bed of greywacke conglomerate	375 ft.
r.	Quartz keratophyre	160 ft.
q.	Quartz chlorite schist	110 ft.
p.	Quartz biotite keratophyre	110 ft.
o.	Quartz chlorite schist	235 ft.
n.	Chlorite schist	160 ft.
m.	Conglomeratic quartz chlorite sericite schist	110 ft.
l.	Pebbly quartz feldspar chlorite schist	470 ft.
k.	Sub-greywacke conglomerate	
j.	Biotite keratophyre	
i.	Quartz chlorite schist with slate bands	1900 ft.
h.	Keratophyre	
g.	Quartz chlorite schist	
f.	Black slate	
e.	Greywacke	250 ft.
d.	Greywacke conglomerate	80 ft.
c.	Feldspathic sandstone	100 ft.
b.	Quartz chlorite schist	< 40 ft.
a.	Crenulated chlorite schist with limestone lenses	100 ft.
	TOTAL	4600 feet.
	unconformity	
	Carbine Group	

This section may be regarded as composed of at least four cycles, as shown in figure 2 (b), but detailed stratigraphy may reveal the presence of more. The volcanic rocks occupy an intermediate position in the cycles except in the case of the biotite keratophyre (unit j.) which is followed by a sub-greywacke conglomerate (unit k.). The succession quoted above is capped, a little south of Walford's Peak, by a sub-greywacke to greywacke conglomerate, called by Bradley (1954, p. 228) the Dora Conglomerate. This passes transitionally up into the Owen Conglomerate. Correlation of units in four sections of the Dundas Group just west of Lake Dora suggests that the Dora Conglomerate is unconformable on the underlying beds and this in turn indicates that the Dora Conglomerate may be equivalent to the Jukes Breccia at the base of the Junee Group of Lower Ordovician age.

North of Walford's Peak another section of the Dundas Group is partially exposed between the Sticht Range and Anthony Creek. The basal beds consist of a coarse siliceous conglomerate with very large boulders of Precambrian quartzite and quartz schist. The next rock type exposed is a keratophyre, followed by a chloritic schist, by several keratophyres, and then by a haematitic quartzite.

To the west of the Tyndall Range, Blake (1931) recorded green-grey and dark grey slates, green quartzite and acid and basic porphyries near the Langdon River, the quartzites containing an echinoderm stem. Later, the author found a hornblende keratophyre near Basin Lake, described by Scott (1954, p. 142), associated with slates, greywackes and greywacke conglomerates. At Red Hills, southwest of Mount Murchison, the Owen Conglomerate unconformably overlies a greywacke conglomerate dipping steeply west and about 150 feet thick. This is succeeded to the west by a keratophyre with flow structure, and aa or brecciated keratophyres, then by feldspar chlorite schists and then by quartz keratophyre on the flanks of the Gooseneck.

About two miles south of the Gooseneck, and west of Lake Julia, greywackes, greywacke conglomerates, keratophyres and aa keratophyres occur.

These rocks along the West Coast Range are correlated with the Dundas Group on grounds of lithological similarity and their position unconformably beneath the Junee Group of Ordovician age. In fact there is a continuous outcrop of these rocks from Dundas east to Mount Murchison and south to Macquarie Harbour. Thus, although individual formations have not been traced throughout this area, the probability of all the rocks mentioned in this section being part of the Dundas Group is high.

ZEEHAN

Beneath the Junee Group on the western side of the Zeehan Syncline, the Dundas Group outcrops and isolated observations have been made on it. Three miles east of Trial Harbour, Waterhouse (1916b, p. 100) recorded sub-greywacke breccia, slate, sandstone and tuff. According to Elliston (1954, p. 175) the Zeehan Tillite occurs at the Swansea Mine, Zeehan, and, in the vicinity, Taylor (1953) reported an argillaceous sandstone, a sub-greywacke conglomerate and a black shale. Just north of Zeehan, the Zeehan Tillite (Waller, 1905b; Twelvetrees and Ward, 1910, p. 41) outcrops just below or at the base of the Dundas Group (Spry, pers. comm.) but its structural relationships are still obscure. Low in the Dundas section north of Zeehan is the Montana Melaphyre, a formation of spilitic lavas, tuffs and breccias with some development of spherulitic felsites (see Scott, 1954). The Montana Melaphyre is overlain by the Nubeena Quartzite and Slate from which indistinct gasteropods, brachiopods and echinoderms have been recorded by Waller (1905b). The Nubeena Quartzite and Slate is followed by the so-called "Keratophyric Tuff" described by Twelvetrees and Ward (1910, p. 15). This latter formation consists of vitric and lithic keratophyric tuffs and breccias with interbedded slates and sandstones and contains fossils in the Summit Cutting on the Comstock Tram west of Zeehan, in a black slate. Öpik (1951c) recorded *Diplagnostus* sp., and cystoids, and suggested correlation with the Hodge Slate. The section is summarized as figure 2 (d).

NORTH PIEMAN, ROSEBERY AND MOUNT FARRELL DISTRICTS

Taylor (1954a), in an important contribution, gave the succession from the mouth of the Stanley River to Rosebery. This is summarized below and as text-figure 2 (e):

Conglomerate	420 ft.
Black shales with *Glyptagnostus*	420 ft.
Sandstone	130 ft.
Conglomerate	450 ft.
Chert Breccia	120 ft.
Black slate with *Protorthis* and dendroids	110 ft.
Shales and tuffs	890 ft.
Conglomerate	260 ft.
Grey shales	610 ft.
Tuff	90 ft.
Shale	160 ft.
Conglomerate	160 ft.
Shale	300 ft.
Conglomerate and shale	350 ft.
Shale	260 ft.
Sandstone	170 ft.
Dark grey shales with dendroids	390 ft.
Quartzite with some shale and conglomerate	350 ft.
Black shale	380 ft.
	6020 feet.
Argillite	12,000 feet.
unconformity	
Group of jasper, shale, quartzite and tuff	13,000 feet.
unconformity	
Davey Group	

The unconformity with the Davey Group occurs west of the mouth of the Stanley River. The basal beds are jasper followed by quartzite with interbedded shale and tuff, shale, quartzite, and a shale with some breccia beds. Taylor correlated this with the Carbine Group (Elliston, 1954) but the presence of tuff bands is not usual in the Carbine.

The argillite which outcrops roughly from the mouth of the Wilson to the mouth of the Ring River along the Pieman, overlies the lower group unconformably and is about 12,000 feet thick. The formation consists of deep red to purple or blue-green to deep-green argillites with subordinate pyritic grey to black shale and bands of pyroclastics throughout, but commoner towards the top. Near the top of the formation is a flow, thirty feet thick, of vesicular basalt consisting of labradorite, biotite and some interstitial albite in a glassy groundmass. Taylor also equated this formation with the Carbine Group but the presence of volcanic material in it and the lithology of the slates suggest correlation with the Dundas Group rather than with the Carbine.

Overlying this formation on the Huskisson River are 6000 feet of conglomerate, breccia, greywacke, slate and volcanics, with formations higher in the column than any recorded so far from Dundas. The basal formation consists of thinly-bedded black shales, followed by a formation of coarse, green-grey quartzite, dark shales, fine-grained conglomerates and then light-grey quartzites at the top. The present author would prefer to split this formation beneath the conglomerate and regard this conglomerate as the beginning of a new cycle. The next unit on Taylor's scheme is a fine-grained, thinly-bedded, dark grey shale containing dendroids, which Taylor equated to the Hodge Slate. This is followed by a coarse-grained blue-grey sandstone. A thickly-bedded yellow-brown to grey shale follows, and this is succeeded by a unit containing three conglomeratic members with two interbedded shaly members. The present author prefers to regard these as five separate formations. The next unit in Taylor's succession is a thinly-bedded blue-grey shale, and this is followed by a dark-grey conglomerate with quartz and chert pebbles in a coarse sandy matrix. A thinly-bedded shale follows and is succeeded in turn by a massive feldspathic tuff and then thinly-bedded grey shales. The next cycle commences with a cherty conglomerate which is overlain by thinly-bedded shales with tuffaceous bands and then a unit of black slate with *Protorthis, Otusia* (?), *Sphenoecium* and *Archaeolofoaea* (Öpik, 1951b). Öpik (1951b; and letter, 1955) correlated this with the Hodge Slate. This view requires the non-deposition or erosion in this area of all the formations above the Hodge Slate in the Dundas area.

Taylor's next three units comprise the lower part of the next cycle and are a chert breccia, a coarse conglomerate and a brown sandstone with some conglomerate. The higher beds of this cycle are black pyritic shales with thin sandy laminae and contain *Glyptagnostus reticulatus* and *Protospongia* (Öpik, 1951b). The top unit is a greywacke conglomerate with pebbles of sandstone and chert in a sandy matrix.

The topmost group thus consists of eleven cycles ranging from upper Middle Cambrian to lowermost Franconian in age. A notable contrast with the section at Dundas is the paucity of volcanics. In addition, the sediments of this group appear to be finer-grained on the whole than those of the Dundas Group at Dundas.

West of Rosebery, Taylor recorded chlorite sericite schist, black shale, tuff, devitrified rhyolite, quartzite, slate, fuchsitic agglomerate and purple slate. Tuffs, slate and slate breccia occur on Colebrook Hill (Ward, 1911).

In the Rosebery area, slates, breccias, chloritic keratophyres and chloritic, calcareous, talc and sericitic schists occur (Hills, 1915a and b). A fuchsitic "breccia conglomerate" occurs in several places west and northwest of Rosebery (Finucane, 1932; Taylor, 1954a). At Rosebery and Williamsford, chlorite and sericite schists containing the zinc ore are overlain by a black slate which increases in thickness to the north, and this in turn is overlain by the "Eastern Massive Fragmentals," a group of porphyritic lavas (or intrusive rocks, see Finucane, 1930), breccias and tuffs which extends north beyond Farrell Junction and east to Tullah (Hall et al., 1953; Carey, 1946). Black and grey slates occur near Tullah and near Mount Farrell a conglomerate occurs which is overlain by the Owen Conglomerate (Ward, 1908, p. 20).

Just north of Farrell Siding on the Hatfield Plains, in the cutting on the Emu Bay Railway between 49.9 and 50.25 miles from Burnie, *Hurdia davidi* was found in thin-bedded, black, fissile slate, similar to that underlying the "Eastern Massive Fragmentals" at Rosebery (Finucane, 1932, p. 24). Later mapping suggests that the Hatfield Plains Slate is continuous with the slate at Rosebery (Taylor, 1954). If Elliston's correlations are correct, this would be in the upper beds of the Climie Slate.

These rocks in the Rosebery and Tullah areas are correlated with the Dundas Group on the grounds of lithological similarity, and structural continuity (see Elliston, 1954, p. 177).

Porphyries and felsites, probably keratophyres, occur in the Que River district where they are associated with chlorite schists, quartz sericite schists and buff-purple fine-grained breccias (Henderson, 1938).

Near the Pinnacles, keratophyre, conglomerate, slate, breccia and feldspathic tuff (or greywacke) have been noted (Reid, 1918, pp. 28-30). The Que River and Pinnacles rocks are correlated with the Dundas Group because of lithological similarity.

WARATAH

Slates, tuffs, lavas, greywackes and a chert (the Cleveland Chert) occur at Mount Cleveland near Waratah (Hughes, 1953a). Just west of Waratah, red, buff, grey and black slates, red and white cherts, volcanic breccias, and tuff or greywacke are associated with a hornblende basalt (Nye, 1932). *Tasmanadia twelvetreesi* occurs in slates on the Arthur River a few miles northwest of Waratah (Chapman, 1929). The Magnet Dyke (see Cottle, 1953) was considered by Scott (1954, p. 129) to be a sequence of spilitic flows. South of Waratah in the Mount Ramsay area Finucane and Blake (1933) noted the presence of purple, black, and grey slates, black cherts, and fine-grained green or grey breccias (or greywackes). These rocks are correlated with the Dundas Group on the basis of lithological similarity.

SMITHTON AND KING ISLAND

In the Smithton area Carey and Scott (1952) placed 5000 feet of slates, breccias, tuffs, spilites and perhaps tillite in the Dundas Group on grounds of lithological similarity. The tillite occurs at the base of the section. A little west of Smithton at Montagu, black slates and greywacke breccias occur. Limestones may be present in this group near Smithton (Nye, Finucane and Blake, 1934). On the east coast of King Island at City of Melbourne Bay, slates, quartzites, breccias, tuffs, lavas and tillite occur (Waterhouse, 1916a). Carey (1946) suggested a Lower Palaeozoic or Precambrian age for the tillite. Scott (1951) published a more detailed section and described the volcanic rocks as dominantly spilitic. There is disagreement over the precise stratigraphy, especially the position of the tillite and the associated varved argillites. By analogy with the situation at Zeehan, the tillite has been considered as near the base of the Dundas Group and the lavas and tuffs correlated with those of the Dundas Group on grounds of lithological similarity.

THE DIAL RANGE AREA

Thomas and Henderson (1943) recorded sandstone, mudstone, conglomerate and breccia conglomerate at Natone, Blythe and on Penguin Creek. Twelvetrees (1905) reported Cambrian also at Stowport.

East of Penguin, Hughes (1953b) noted purple, black and white slates, now silicified to form cherts with beds 1 to 2 inches thick of volcanic breccia (or greywacke). These rest with an inferred unconformity on the Precambrian east of Lonah Point and are followed upwards and westwards by lavas and pyroclastics. These include spilites described by Scott (1952) from Groom's Slip. These are followed further west by greywacke and sub-greywacke conglomerates and breccia conglomerates near Penguin. Purple slates and white quartzites west of Penguin recorded by Hughes (1953b, p. 5) as Dundas Group are considered (Spry, pers. comm.) to be Precambrian.

In a road-cutting on the Preston Road just south of Gawler the section is as shown below:

Spilitic tuff		
Argillite, dark grey, thin-bedded, with beds of greywacke up to 2" thick, sponge spicules and carbonaceous markings.		110 ft.
Argillite, buff, thick-bedded		120 ft.
Feldspathic rock	more than	120 ft.

Cherts and chert breccias outcrop further along the road, and then, moving down dip, along Gunn's Plains Road, spilitic lavas, tuffs and breccias, and then a greywacke breccia occur. Basic lavas, sub-greywacke conglomerate, argillite, greywacke breccia and quartzite outcrop in cuttings along the east side of the Leven River below Gunn's Plains. Near Gunn's Plains the following section, which overlies these last rocks, was measured:

Owen Conglomerate (Ordovician)	
Unconformity	
Argillite	58 ft.
Greywacke	17 ft.
Argillite	88 ft.
Greywacke	37 ft.
Conglomerate	67 ft.
Argillite	56 ft.
Tuff	56 ft.
Argillite, with *Leiopyge* etc.	270 ft.
Tuff and lava	63 ft.
Argillite with *Clavagnostus*, etc.	300 ft.
gap of soil-covered rock	

The lowest argillite in this section contains fossils 55 feet from the top. The fossils include trilobites, (*Clavagnostus;* Öpik, pers. comm.), sponge spicules and inarticulate brachiopods. The overlying volcanic formation consists of keratophyric tuffs to the north and a vesicular keratophyric lava to the south. The argillite above the lava contains agnostid trilobites 181 feet above the base. These agnostids include *Leiopyge laevigata, L. laevigata armata* (Öpik, 1951c; letter, 1955), and suggest correlation with the Comet Slate and Tuff. The conglomerate is composed of siliceous boulders in a matrix of rock fragments, quartz and chlorite. This succession could be considered as consisting of parts of two cycles.

The succession exposed in an old timber road along the west side of the Leven Gorge is summarized below:

Quartz biotite keratophyre
Argillite
Micaceous salmon pink greywacke with *Pseudagnostus,* a dikelocephalid, and another trilobite with affinities to *Monocheilus* (Öpik, 1951c)
gap
Argillite
Greywacke
gap of hundreds of feet
Chert and argillite, thinly-bedded
Argillite (40-50 feet)
Argillite with greywacke beds up to 18" in thickness.

The fossiliferous greywacke was considered by Öpik (1951c) as basal Dresbachian, and as such is above the argillite with *Leiopyge* in the road section which Öpik considered (1955, pers. comm.) as Middle Cambrian. The road section is summarized as text-figure 2 (f).

Acid tuffs, greywackes, argillites, quartz keratophyre, and micaceous quartzites occur near Nietta (Carey, 1946, p. 25; and author). At Paloona, a few miles southwest of Devonport, cherts and argillites are overlain by a chloritic, albitic tuff and keratophyre.

SHEFFIELD AREA

Keratophyres, slates, and volcanic sediments occur near Lorinna (Reid, 1919a); Elliston (1953) recorded slates and volcanic rocks near Moina, and Twelvetrees (1913) reported grey and purple slates, schistose conglomerates and sheared quartz albite tuffs and quartz biotite keratophyre a little further north. Near Mount Claude just south of Sheffield, hornblende porphyries, tuffs, slates, schistose conglomerate, chlorite schist, talc schist, haematite schist and quartz sericite schist are overlain by Owen Conglomerate, in one place unconformably (Twelvetrees, 1913; Reid, 1919b; Hughes, 1948; and Elliston, 1953). East of Sheffield, porphyries, slates, schists and feldspar porphyrite have been noted (Twelvetrees, 1911; Reid, 1924; Nye, 1927a; and Hughes, 1950).

These rocks are correlated with the Dundas Group because of lithological similarity and their position below the Owen Conglomerate.

DELORAINE

The sequence of rocks below the Owen Conglomerate and above the schists correlated with the Davey Group in this area has recently been measured by Wells (1954) and is summarized below, and as text-figure 2(g):

Owen Conglomerate (Ordovician)	
unconformity	
Siltstone	2000 ft.
with keratophyre member (1300 ft.)	
and spilite member (1400 ft.)	
Slate	880 ft.
Slate and sub-greywacke	2000 ft.
unconformity	6280 ft.
Davey Group	

The lowest formation, the slate and sub-greywacke, consists of dark brown to orange brown slates, mottled pink and white coarse sub-greywackes and pink to orange siltstone and sandstone. These are succeeded by the slate formation which to the south apparently overlaps the lowest formation and rests unconformably on the Precambrian. The basal beds in the south are coarse greywacke conglomerates but most of the formation consists of black slates and calcareous sub-greywacke.

The siltstone, including the keratophyre member in the north and the spilite member in the south, is about 3400 feet thick, of which about 2000 feet is siltstone. The siltstone is thin-bedded, rather soft, pink to reddish-brown in colour, and there are inter-bedded greenish-brown and blue-grey slates. The spilite and breccia formation consists of sheared, chloritized and epidotized spilites and spilitic breccias. The keratophyre has phenocrysts of quartz and albite in a quartzo-feldspathic or chloritic groundmass.

About 20 miles southeast of Deloraine, on the slopes of O'Connor's Peak and beside the Lake River south of Cressy, Voisey (1949) recorded slates, phyllites and sheared tuffs, correlates of the Dundas Group on lithological grounds.

BEACONSFIELD

Taylor (1949, p. 31) noted the presence of clay slates, claystones, and sandstones at Anderson's Creek, and Scott (1954, p. 129) reported spilite from near Beaconsfield. These rocks are correlated with the Dundas Group on lithological grounds.

ADAMSFIELD

Rocks correlated with the Dundas Group on lithological and structural grounds occur in the valley of the Adam River below the Silver Falls (Nye, 1929, p. 10). Slates, cherts and fine-grained breccias are present. The slates include thin-bedded purple slates and white, grey-green, brown and red cherts are also present. The breccias are greywacke breccias with quartz and feldspar.

The author noted greenish micaceous siltstone and interbedded slaty siltstones and red siltstones west of Silver Falls.

SOUTH COAST

Dark-grey to green-grey slates, black cherts and breccias overlain, presumably unconformably, by the Owen Conglomerate, occur near Rocky Boat Harbour just east of New River Lagoon (Blake, 1938). These are correlated with the Dundas Group on lithological and structural grounds.

PALAEONTOLOGY AND CORRELATIONS

Sponge spicules, brachiopods, trilobites and other crustaceans, worm tracks, cystoids and dendroids have been recorded from the Dundas Group. Their known occurrence is summarized below:

Porifera	
Protospongia	Cycle 10, Huskisson River Section, Huskisson River (Öpik, 1951b).
Spicules	Preston Road, North Motton.
	Clavagnostus Bed, Gunn's Plains Road, Leven Gorge.
Brachiopoda	
Protorthis	Near top of cycle 9, Huskisson River section, Huskisson River (Öpik, 1951b).
Otusia (?)	Near top of cycle 9, Huskisson River section, Huskisson River (Öpik, (1951b).
Inarticulate brachiopods	*Clavagnostus* Bed, Gunn's Plains Road, Leven Gorge.
Annelida	
Tasmanadia twelvetreesi	Arthur River (Chapman, 1929).
Arthropoda	
Trilobita	
Ptychagnostus (?)	Judith Slate and Sub-greywacke, Dundas Group, Dundas (Öpik, 1951b).
Triplagnostus	Judith Slate and Sub-greywacke, Dundas Group, Dundas (Öpik, 1951b).
Peronopsis	Judith Slate and Sub-greywacke, Dundas Group, Dundas (Öpik, 1951c).
"perhaps *Homagnostus*"	Hodge Slate, 100 yards west of Bonnie Point, North-East Dundas Tram, Dundas (Öpik, 1951c).
Diplagnostus	"Keratophyre Tuff," Dundas Group, Summit Cutting, Comstock Tram, Zeehan (Öpik, 1951).
Phalacroma	Comet Slate and Tuff, Dundas Group, Dundas (Öpik, 1951c).
Clavagnostus	Argillite below tuff, Gunn's Plains Road, Leven Gorge (Öpik, letter, 2.8.1955).
Leiopyge laevigata	Argillite between tuffs, Dundas Group, Gunn's Plains Road, Leven Gorge (Öpik, letter, 19.6.1955).
Leiopyge laevigata armata	Argillite between tuffs, Dundas Group, Gunn's Plains Road, Leven Gorge (Öpik, letter, 19.6.1955).

Oidalagnostus	Comet Slate and tuff, Dundas Group, Dundas (Öpik, 1951c).
Pseudagnostus	Salmon Greywacke, road west of Leven Gorge (Öpik, 1951c).
	1000 ft. southeast of Bonnie Point, North-East Dundas Tram, in Hodge Slate (?) (Elliston, 1954; and Öpik, letter, 2.8.1955).
Glyptagnostus reticulatus	Cycle 10, Huskisson River section, Huskisson River (Öpik, 1951b).
Pagetia	Judith Slate and Sub-greywacke Dundas Group, Dundas (Öpik, 1951a).
Lorenzella	Judith Slate and Sub-greywacke, Dundas Group, Dundas (Öpik, 1951a).
Pachyaspis (= *Conaspis* of Öpik, 1951a)	Judith Slate and Sub-greywacke, Dundas Group, Dundas (Öpik, letter, 14.6. 1955).
Bathyuriscids	Hodge Slate, Dundas Group, 100 yards west of Bonnie Point, North-East Dundas Tram, Dundas (Öpik, 1951c;) and letter, 2.8.1955).
Solenoparia	Hodge Slate, Dundas Group, 100 yards west of Bonnie Point, North-East Dundas Tram, Dundas (Öpik, 1951a).
Blackwelderia cf. *biloba*	Comet Slate and Tuff, Dundas Group, Dundas (Öpik, 1951a).
Conocephalites (?)	Comet Slate and Tuff, Dundas Group, Dundas (Öpik, 1951a).
Anomocarella (?)	Comet Slate and Tuff, Dundas Group, Dundas (Öpik, 1951a).
Dikelocephalid	Salmon Greywacke, road west of Leven Gorge (Öpik, 1951c).
	1000 ft. southeast of Bonnie Point, North-East Dundas Tram, in Hodge Slate (?) (Elliston, 1954; and Öpik, letter, 2.8.1955).
aff. *Monocheilus*	Salmon Greywacke, road west of Leven Gorge (Öpik, 1951c).
Coosia	1000 ft. southeast of Bonnie Point, North-East Dundas Tram, in Hodge Slate (?) (Elliston, 1954; and Öpik, letter, 2.8.1955).

Aphelaspis (?) (= aff. *Wilbernia* (?)	1000 ft. southeast of Bonnie Point, North-East Dundas Tram, in Hodge Slate (?) (Elliston, 1954; and Öpik letter, 2.8.1955).
Phyllocarida	
Hurdia davidi	Dundas Group, railway cutting, Hatfield Plains (Chapman, 1926).
Echinodermata	
Cystoidea	Hodge Slate, Dundas Group, Dundas. "Keratophyre Tuff", Dundas Group, Summit Cutting, Comstock Tram, Zeehan (Öpik, 1951a).
Hemichordata	
Dendroidea	
Archaeocryptolaria skeatsi	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Mastigograptus	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Cactograptus flexispinosus	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Protohalecium hallianum	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Protistograptus	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Archaeolofoaea serialis	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Sphenoecium filicoides	Hodge Slate, Dundas Group, Dundas (Thomas and Henderson, 1945).
Archaeolofoaea	Near top of cycle 9, Huskisson River section, Huskisson River (Öpik, 1951b).
Sphenoecium	Near top of cycle 9, Huskisson River section, Huskisson River (Öpik, 1951b).
Dendroids	Near top of cycle 3, Huskisson River section, Huskisson River (Taylor, 1954a).

The lowest formation at Dundas contains *Ptychagnostus* (?), *Triplagnostus*, *Peronopsis*, *Pagetia* and *Lorenzella*, suggesting correlation with the *Ptychagnostus gibbus* Zone of the Middle Cambrian of the Camooweal area of Queensland (Öpik, 1954; and this symposium). The next assemblage is in the Hodge Slate which contains dendroids in the type area and *Solenoparia* and Bathyuriscids just west of Bonnie Point on the North-East Dundas Tram. This may be correlated with the upper part of the *Ptychagnostus atavus* Zone or the *P. punctuosus* Zone and is older than the *Amphoton* bed in Victoria (Öpik, 1955, letter). *Diplagnostus* occurs in slate in the "Keratophyre Tuff," Zeehan, which Öpik (1951a) correlated with the Hodge Slate. The Comet Slate and Sub-greywacke contains *Blackwelderia* cf. *biloba*, *Phalacroma*, *Oidalagnostus*, and *Conocephalites*, and Öpik (1951b; and letter, 1955) correlated this with the lower part of the range of *Leiopyge laevigata*. On the North-East Dundas Tram, in the type area of Waller (1905a), trilobites occur in a greenish mudstone about 1000 feet southeast of Bonnie Point. Öpik has identified *Pseudagnostus*, *Coosia*, *Aphelaspis* (?) and a Dikelocephalid, and he suggested (letter, 14.6.1955) a correlation with the lower Dresbachian (*Cedaria* Zone). This locality is shown on Elliston's map (1954) as Hodge Slate, but this would seem to be an error.

Fossils occur in the Huskisson River section on three horizons. Taylor (1954a) noted dendroids in his third formation and correlated them with those of the Hodge Slate. However, near the top of cycle 9 in the same section, Öpik (1951b) recorded the dendroids *Archaeolofoaea* and *Sphenoecium* with the brachiopods *Protorthis* and *Otusia* (?), and correlates this horizon with the Hodge fauna. Several possibilities arise from this situation:

(a) the lower fossils were misidentified;

(b) there is isoclinal folding;

(c) Taylor's correlation is correct and the local range of dendroids extends higher in the column than has been previously supposed;

(d) Öpik's correlation is correct and there is a major break in the succession at the end of cycle 9.

In the slates of cycle 10, Öpik (1951b) recorded *Glyptagnostus reticulatus* and *Protospongia*, and considered these to be basal Franconian.

Of the possibilities arising from the occurrence of the two beds of dendroids, the author does not consider the first two likely. Elliston found the lower dendroids and had had some previous experience in identifying dendroids in the Dundas area. Dips are consistently eastward in the Huskisson section and Taylor made no mention of westward or overturned eastward dips and it is difficult but not impossible to draw sections consistent with the succession as proposed by Öpik. Thus the second alternative is considered possible but unlikely. If the third possibility is correct, the range of the dendroids would be extended into the Upper Cambrian and this does not seem impossible. Öpik's correlation involves an unconformity or a fault between beds which he placed in the *Ptychagnostus punctuosus* Zone and beds which he placed as basal Franconian. Öpik (letter, 21.7.1955) said, "...the chert breccia and coarse conglomerate in between (i.e. between the dendroids and the *Glyptagnostus)* is, consequently, connected with a significant break." This possibility does not contravene any known fact and must be given at least equal weight with the third one. The author considers that there are insufficient facts known to chose between the third and fourth possibilities.

Four fossiliferous horizons are known in the Leven Gorge area. The lowest one, on the Preston Road, contains, as far as is known, only sponge spicules and carbonaceous markings, and cannot be dated. On the Gunn's Plains Road in the Leven Gorge, the lowest argillite in the measured section contains *Clavagnostus*, sponge spicules and inarticulate brachiopods. In the next argillite member, *Leiopyge laevigata* and *L. laevigata armata* are found, which suggests correlation with the *Leiopyge laevigata* Zone in Queensland and elsewhere (Öpik, letter, 14.6.1955). On the west side of the Leven Gorge, *Pseudagnostus*, a Dikelocephalid and a trilobite with affinities to *Monocheilus* occur in a salmon-coloured greywacke which Öpik (letter, 14.6.1955) correlated with the fauna east of Bonnie Point, Dundas, as being Lower Dresbachian.

Thus the Dundas Group covers at least the upper part of the Middle Cambrian from the *Ptychagnostus gibbus* Zone upwards through the basal Upper Cambrian to the *Glyptagnostus reticulatus* Zone near the base of the Franconian. Correlation of these zones with those on other continents is considered by Öpik (Cambrian Geology of Queensland, this symposium).

PALAEOCLIMATOLOGY

The climate under which the Dundas Group was deposited cannot readily be deduced from the information at present available. The Zeehan Tillite is associated with thin-bedded dark and light grey argillite which may be a formation of glacially varved silts and clays. Elliston (1954, p. 177) correlated the Zeehan Tillite with the Red Lead Conglomerate, which would place it in the upper Middle Cambrian. However, detailed mapping by Spry has not revealed the stratigraphic position of the Zeehan Tillite beyond establishing the fact that it rests unconformably on Pre-Dundas Group rocks, but its precise relationship to the Dundas Group is not yet known. On King Island a tillite with associated thin-bedded argillites underlies and is partly interbedded with, a sequence of spilitic flows which has been correlated with the Dundas Group on lithological grounds. Thus at King Island also there is some suggestion of glaciation at or near the base of the Dundas Group.

In his description of the geology of the Dundas Group, Elliston (1954) suggested that the Red Lead Conglomerate on upper South Comet Creek is a tillite because it consists of sparse large pebbles in a very fine purple silt matrix (p. 168). The Razorback Conglomerate is thought to have been the formation from which a striated pebble was obtained by Waller (see Elliston, 1954, p. 166). Elliston (1954, p. 171) thought that there was a possibility that the Fernflow Conglomerate, with its rare pebbles in a slate or greywacke matrix, might also be glacial. The author doubts that these conglomerates are glacial, but cannot prove this contention until the petrology and distribution of the formations are thoroughly worked out.

Carey and Scott (1952, p. 67) suggested the possibility that a silicified breccia at Smithton is the silicified equivalent of the Zeehan and King Island Tillites. Later (p. 70) they advocated a Cambrian age for the tillites which they considered to belong to the Dundas Group. However, until detailed stratigraphy is done at King Island, Zeehan and Smithton, the author prefers to regard the age of the tillites as an open question.

Just east of Penguin, Scott (1952, p. 123) reported a tillite and laminated slates, and correlated these with the King Island and Zeehan occurrences. However, these rocks at Penguin are not tillites as the rocks are too well-sorted and lack the rock flour matrix of true tillites. They are sub-greywacke breccias.

Purple slates, argillites and cherts are common in the Dundas Group, but no detailed work on them has been done so that it is not known whether the colouring is due to oxidation on exposure or not.

From the above it will be seen that no accurate information is yet available on the Middle and Upper Cambrian climate of Tasmania.

IGNEOUS ACTIVITY

Volcanic, hypabyssal and acid and ultrabasic plutonic activity occurred in Tasmania during or just after the deposition of the Dundas Group. The areal distribution of the Cambrian igneous rocks is shown on the map (fig. 3). Some aspects of the petrology of the volcanic rocks have been dealt with by Scott (1954).

Picrite basalt, olivine spilite, porphyritic pyroxene basalt, spilite, hornblende andesite or keratophyre, biotite keratophyre, quartz keratophyre and rhyolite have been recorded from the Dundas Group (see Scott, 1954; Bradley, 1954; Finucane, 1930; Taylor, 1954a). Pillow structure is common in the spilites (Scott, 1951; 1952; 1954) and Bradley (1954, comments on Mount Owen sheet) noted columnar structure in a keratophyre. The basic members of this spilitic suite have usually been regarded as volcanic in origin, but there is still controversy on the origin of the acid members. Finucane (1930) maintained that they were intrusive, basing his conclusions on the occurrence of dykes near Primrose Siding, Rosebery, and on the discordance of porphyry with associated rocks near Rosebery. This discordance may, however, be an unconformity, and there is ample evidence to show that many of the acid porphyries are extrusive (see Carey, 1946; Hall et al., 1953; Bradley, 1954). Basically, the evidence is that glass and pseudo-inclusions are common in the porphyries, angular fragments of porphyry occur in a porphyry matrix and fragments of glass and porphyry occur in the tuffs and breccias associated with the porphyries. Scott (1954) regarded the acid porphyries as originally basalts which had been silicified and albitized, supporting her contention with the argument that where the least altered basaltic rocks occur, there are no keratophyres, and that the acid porphyries seem to be restricted to the zone of structural weak-

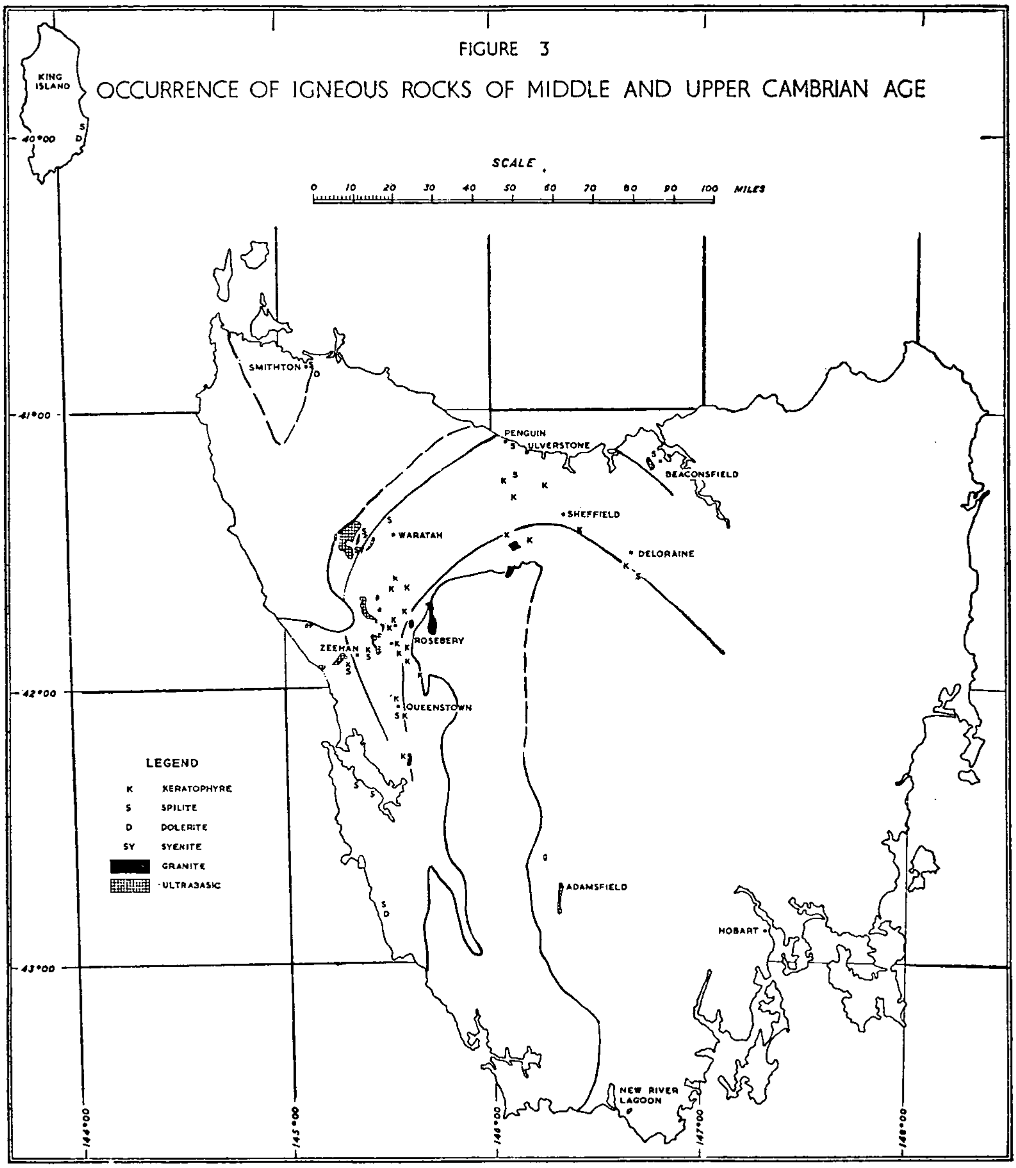

Fig. 3. Map of Tasmania showing the distribution of Middle and Upper Cambrian Volcanic Rocks.

ness (the Porphyroid Anticlinorium) where metasomatism has probably been at its greatest. She also adduced the association of a "spherulitic felsite" with the Montana Spilite and the occurrence of apparently intermediate stages between these two rocks at Zeehan and elsewhere to support the idea of silicification of original basalts. However, acid porphyries and tuffs are not restricted to the Porphyroid Anticlinorium, as they occur at Zeehan, the Leven Gorge, Paloona and Nietta, and in these areas are not associated with albitization of the sediment. Spherulitic rhyolite in a breccia occurs near Farrell Siding (Carey, 1946). Spherulites occur in a tuff from Smithton (Nye, Finucane and Blake, 1934), spherulitic basalt occurs on King Island, a fragment of spherulitic glass occurs in a greywacke at Magnet (author), and fragments of spherulites occur in a greywacke in the "Fuchsitic Breccia-Conglomerate" near Rosebery (Finucane, 1932). These observations indicate that at least some of the lavas were spherulitic by the time they consolidated. Spry (pers. comm.) has observed that angular fragments of fresh albite are common in the greywackes and tuffs, and that angular epidote is also present in some of the greywackes on Lynch Creek, Queenstown. He interprets this to mean that the albitization and epidotization took place before or very soon after the lavas were erupted and was deuteric. All of these lines of evidence suggest that Scott's hypothesis is based on invalid evidence. Yet another hypothesis (Bradley, 1954) postulates derivation of some of the feldspar porphyries and quartz feldspar porphyries from sediments by albitization and silicification. Quartz and albite porphyroblasts seem to be present in what were originally greywackes and greywacke conglomerates near Queenstown as suggested by Bradley (1954) and there is abundant evidence of secondary albitization along the West Coast Range. However, keratophyric and quartz keratophyric tuffs occur at Zeehan, Dundas, the Leven Gorge and Paloona away from areas of relatively intense alteration. Keratophyres occur with greywackes and sub-greywackes lacking porphyroblasts of albite in the Leven Gorge and at Paloona, and at Deloraine. These observations are not in favour of the application of this hypothesis throughout Tasmania. In view of the evidence quoted above, and earlier in the paper, it is here considered that most of the acid members of the spilitic suite in Tasmania represent originally acid volcanic rocks.

Volcanic breccias and crystal, lithic and somewhat vitric tuffs have been described from the Dundas Group (Bradley, 1954; Scott, 1954;

Twelvetrees and Ward, 1910; Finucane, 1932; Carey, 1946; Carey and Scott, 1952; Scott, 1951; Twelvetrees, 1909a; Wells, 1954). Many other authors have reported tuffs, but on examination of the descriptions or the rocks it is more likely that the majority of the tuffs recorded are sub-greywackes or greywackes. The tuffs vary in composition from spilitic to quartz keratophyric for the lithic tuffs, and from albite-augite tuffs to quartz-albite tuffs for the crystal tuffs.

One remarkable feature that emerged from this review was the position of the volcanic rocks in the cycles of sedimentation. In the Dundas section it is notable that they normally occur associated with the finer-grained rocks, the argillites, in the cycles. The same observation applies at Smithton, the Leven Gorge and Deloraine, and probably at King Island and Penguin. At Lake Dora there are several cases where this is true and one exception; at Zeehan there appear to be exceptions at this stage of our stratigraphic knowledge, which may be removed as knowledge advances; and at Lynch Creek it does not seem to apply. There is enough evidence to suggest that usually the volcanic activity occurred during deposition of the finer-grained sediments in the cycles. The significance of this is not yet known, and it needs to be tested in all sections.

Sills and dykes of Middle or Upper Cambrian age are comparatively rare. However, augite porphyrites, quartz feldspar porphyries, spilitic dykes, feldspar porphyry, dolerite, hornblende porphyrite and albitic dolerite have been recorded as intruding the Dundas Group (Blake, 1932; Nye, 1930; Twelvetrees and Ward, 1910; Finucane, 1932; Carey and Scott, 1952; Scott, 1954). A mass of igneous rocks considered by most authors (see Cottle, 1953) as a composite basic dyke occupying a fault at Magnet has been interpreted by Scott (1954) as probably volcanic, because of its concordance with the adjacent sediments, the presence of numerous amygdules, and of volcanic breccia. Another mass of igneous rock, called a complex dyke by Nye, Finucane and Blake (1934) has been interpreted by Carey and Scott (1952) as a suite of basic volcanic rocks. This mass at Smithton contains an abundance of vesicles and amygdules, pillows, volcanic bombs and breccia, so that a volcanic origin is indicated. However, there is no doubt that dykes of rocks belonging to the spilitic suite, and ranging from basic to acid in composition do cut the Dundas Group or part thereof, but have not been observed definitely to cut the Lower Ordovician rocks of the Junee Group.

Granites, supposed to be of Upper Cambrian age, have been reported from Mount Darwin and the Dove River area. Syenites from the Murchison Gorge, Mount Farrell and the Dial Range, are doubtfully also Upper Cambrian. The Darwin Granite which apparently is a tabular body occupying the core of an asymmetric anticline is said by Bradley (1954) to be a sill or several sills. The granite contains orthoclase, oligoclase, quartz, biotite, chlorite and hornblende, and possibly palimpsest pebbles (Bradley, 1954). The origin of the Darwin Granite is controversial, Bradley (1954) proposing that it was produced, at least in part, by granitization of the Dundas Group sediments and the Lower Ordovician Jukes Breccia, during the Tabberabberan Orogeny in the Middle Devonian. Hills (1913) noted the presence of pebbles of Darwin Granite in the overlying Jukes Breccia and postulated that it was a Cambrian intrusion. The problem requires detailed field and laboratory studies before the controversy can be settled.

The granites in the Dove River area also contain some chlorite pseudomorphing biotite and hornblende (Twelvetrees, 1913). These granites are associated with Dundas Group rocks but their relationship to the Ordovician is unknown. They are generally considered to be Cambrian but there is no real evidence on the point.

Syenite outcrops on the east bank of the Murchison River between Mount Farrell and Rosebery (Ward, 1908; Nye, 1930; Bradley, 1954). This has been considered as an intrusion on the one hand and as the result of granitization on the other. The age and origin of this body must remain controversial until such time as detailed work is done on it.

Basic and ultrabasic rocks, ranging in composition from quartz mica gabbros to dunites, but mainly pyroxenites, are common in Tasmania. Many of these have been extensively serpentinized. For a long time these were all considered to be co-magmatic with the Middle Devonian granite. In 1949, however, Hills and Carey suggested that some of them were pre-Lower Ordovician, and Carey (1953) considered that most of them were Cambrian, with the possibility that some were Devonian. Evidence of a Cambrian age for some of them is that they intrude Dundas Group rocks up to at least the Fernflow Conglomerate, that the Owen Conglomerate contains osmiridium, chromite and some gold, and that on the Sawback Range near Adamsfield, the serpentinite is overlain by the Junee Group, the basal beds of which are conglomerate, sandstone and shale, composed almost entirely of serpentinite fragments (Carey and Banks, 1954). The shale contains inarticulate brachiopods, gasteropods including *Scaevogyra,* and trilobites. This is overlain by Owen Conglomerate, Caroline Creek Sandstone and Gordon Limestone, the base of which contains brachiopods, cephalopods and trilobites of Middle Arenigian age (Brown, 1948; Teichert, 1947; Kobayashi, 1940). Thus the serpentinite at Adamsfield is not younger than Middle Arenigian, and is probably pre-Ordovician.

On the other hand, serpentinite is in contact with Eldon Group rocks at the Spero River and in the Wilson Huskisson, and Bald Hill belts. The Wilson River belt has argillite on its western side, and the argillite dips east beneath the serpentinite (Taylor, 1954a). On the eastern side the serpentinite is in contact with east-dipping beds of the Cambrian Huskisson River section, and, further north, the Junee and then the Eldon Groups. Reid (1921) noted that the beds of the Eldon Group were displaced up to 2½ miles horizontally on almost vertical planes, and Taylor (1954a) remarked that these faults do not displace the serpentinite. The author carefully examined the air-photos and Taylor's remark seems to be true. Thus the emplacement of the Wilson River serpentinite is post-Lower Devonian. Further north, this belt is intruded by large dykes and a batholith of granite which also intrudes the Eldon Group.

The ultrabasic rocks of Tasmania were intruded as slightly transgressive sills and occasional dykes into the Dundas Group and Precambrian rocks, and into faults or unconformities between the Junee or Eldon and Dundas Groups (Taylor, 1954b; 1954c; 1949; Elliston, 1954; Reid, 1921; Twelvetrees, 1909b). There are either two separate and unrelated intrusions of ultrabasic rock in Tasmania, one of Upper Cambrian, the other of Middle Devonian age, or, an intrusion during the Upper Cambrian as slightly transgressive sills and dykes of ultrabasic material, some of which was re-intruded during the Middle Devonian into faults or the unconformities between the Junee or Eldon and Dundas Groups. No evidence seems to be available at this time to allow any conclusion on this point.

The ultrabasic intrusions introduced chromite, osmiridium, gold and rare diamonds. The serpentinite bodies bear no clear relationship to the major tectonic framework of Tasmania.

During the Middle and Upper Cambrian, lavas and pyroclastic rocks of the spilitic suite, varying from picrite basalt to quartz keratophyre, were extruded, mainly during deposition of fine-grained sediments. The main zone of eruption was on or close to the Porphyroid

Anticlinorium, but vulcanism was by no means confined to this zone. Granite and syenite may have been intruded or developed, also mainly along this zone, in the Upper Cambrian. Pyroxenites, with minor amounts of other ultrabasic types, were intruded during the Upper Cambrian as transgressive sheets in the Dundas Group, or as dykes in the Precambrian, and carried osmiridium which is associated with the bronzitite or peridotite members of the suite. These were serpentinized before the deposition of the Junee Group, and may have been re-intruded in some places in the Middle Devonian.

METAMORPHISM

The Dundas Group has been metamorphosed to some extent whereever it occurs. The finer-grained sediments are commonly argillites or slates and the coarser ones have been compacted and are cemented by chlorite. Chert is common, and has usually been regarded as silicified argillite. In a restricted zone, schists are developed (see fig. 4).

Chert, which means locally any cryptocrystalline siliceous sediment, occurs mainly in an arcuate belt from Paloona and Ulverstone west to Waratah, at Smithton, in the Mainwaring-Wanderer Rivers area, and near New River Lagoon. Cherts in the northwestern arcuate belt would appear on general structural grounds to be relatively close to the base of the Dundas Group, and near Carey's (1953) Rocky Cape Geanticline. These cherts have usually been considered as silicified argillites, possibly following Nye (1928). Several people (e.g. Hughes, 1953b) have noted that they pass laterally into slates or argillites. This may imply silicification, but it is possible that some of the cherts were originally siliceous oozes.

Chlorite, quartz chlorite, quartz sericite and sericite schists occur along a belt from the Mainwaring River area to Rosebery and the Que River, and also in the Lorinna-Round Hill area. Chlorite and talc schists occur in the inland area of the Mainwaring-Wanderer district (Blake, 1936). On the southern shore of Macquarie Harbour, near Asbestos Point, sericite and quartz sericite schists outcrop (Taylor, 1949). Chlorite and sericite schists are found along the West Coast Range from Mount Darwin to Mount Murchison (Hills, 1913; 1927; Alexander, 1953; Bradley, 1954; Blake and Henderson, 1939). In the Rosebery area chlorite and quartz sericite schists have been recorded (Hall et al., 1953). A little further north in the Que River area, quartz sericite schists and chlorite schists were noted by Henderson (1938).

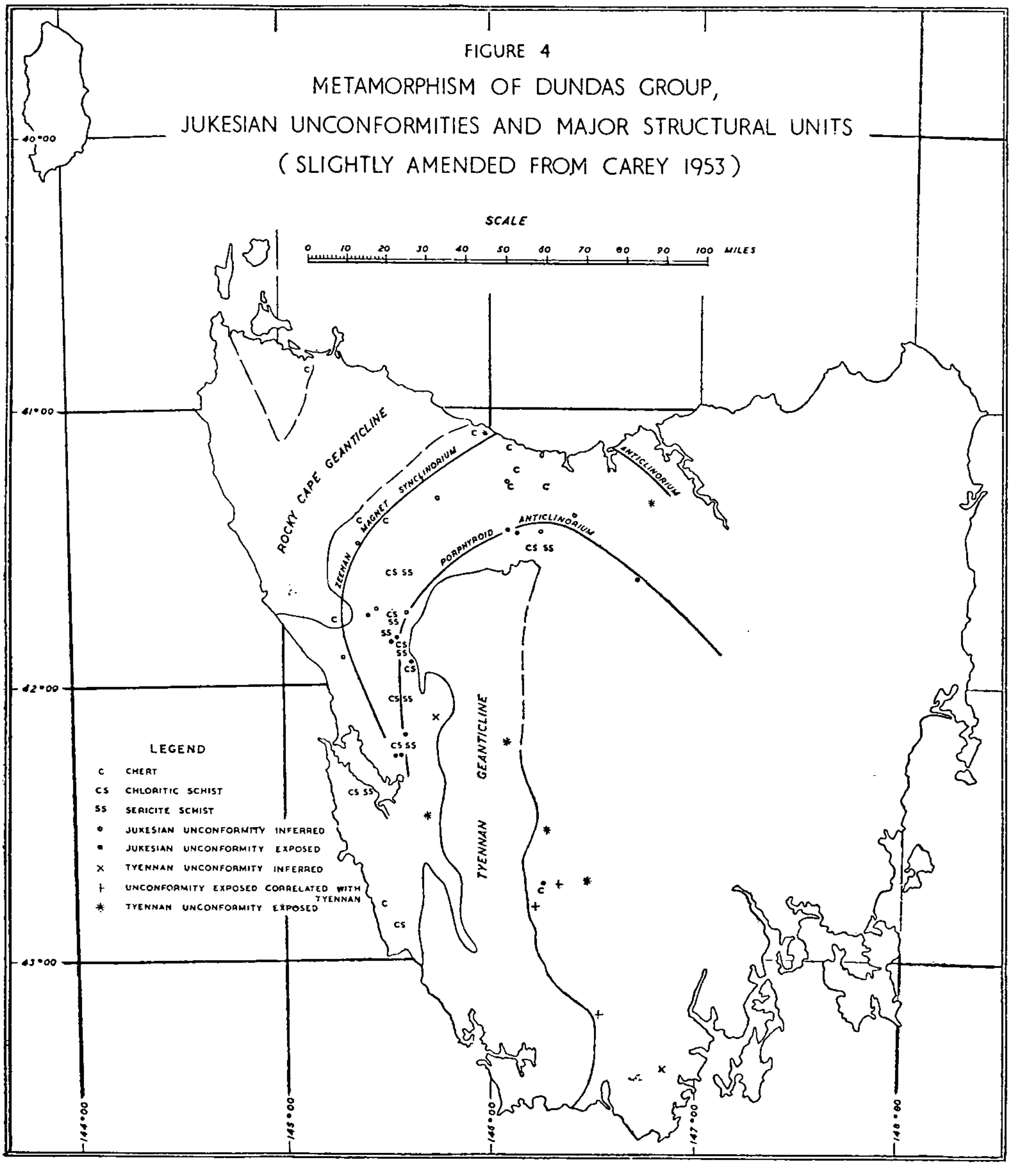

Fig. 4. Map of Tasmania showing the structure of Lower Palaeozoic rocks, and distribution of metamorphosed Dundas Group.

The only other occurrence of schisted Dundas Group rocks appears to be in the Round Hill area, where talc schists, haematite schists, chlorite schists and quartz chlorite schists have been noted by Hughes (1948), and earlier writers.

With the exception of this last occurrence, the schisted Dundas Group rocks fall into a narrow meridional belt from Low Rocky Point almost to Waratah. In this belt rocks of the Dundas Group have apparently been subjected to considerable shearing stress, and the action of mineral-bearing solutions at intermediate temperatures. Feldspar porphyroblasts occur in sediments in this belt at South Queenstown and near Tullah at least (Bradley, 1954), and the possible Cambrian granites are in or close to this belt. As the result of work along the West Coast Range, Bradley proposed a number of zones of alteration which in sequence are: silicification, haematitization, sericitization, chloritization and pyritization, feldspathization, epidotization, a potash zone with orthoclase and biotite, and finally, silicification. The early development of sericite and epidote is not in accord with the zones of metamorphism shown on Bradley's maps, in particular the Mount Darwin sheet, and with observations made by the author in the Lake Dora-Red Hills area, where it appears that chloritization and the development of quartz and feldspar porphyroblasts all precede the development of sericite. Chlorite is very widespread in Dundas Group sediments, and is probably developed during normal diagenetic processes affecting the greywackes and sub-greywackes. Epidote is also found in rocks which have not gone beyond the feldspar zone, and, to the author, appears usually deuteric. Metamorphism of Cambrian lavas in this belt and elsewhere in Tasmania, considered by Scott (1954) to be hydrothermal, is also considered to be deuteric by the author, as pointed out earlier, and the zonal arrangement of this alteration as proposed by Scott has also been considered earlier to be incorrect.

It is noticeable that economic mineralization seems to have accompanied the intense sericitization at Mount Lyell and Rosebery, and that some mineralization has occurred wherever chlorite schists occur. The schist belt was apparently a locus of metamorphism and mineralization. Carey (1953) suggested that the Porphyroid Anticlinorium was also such a locus. The schist belt does not, however, correspond to the Porphyroid Anticlinorium, as mapped by Carey (1953, fig. 3), nor does it lie along the structures so far mapped, as it cuts across the main anticlines obliquely. It corresponds to some extent with the belt of close

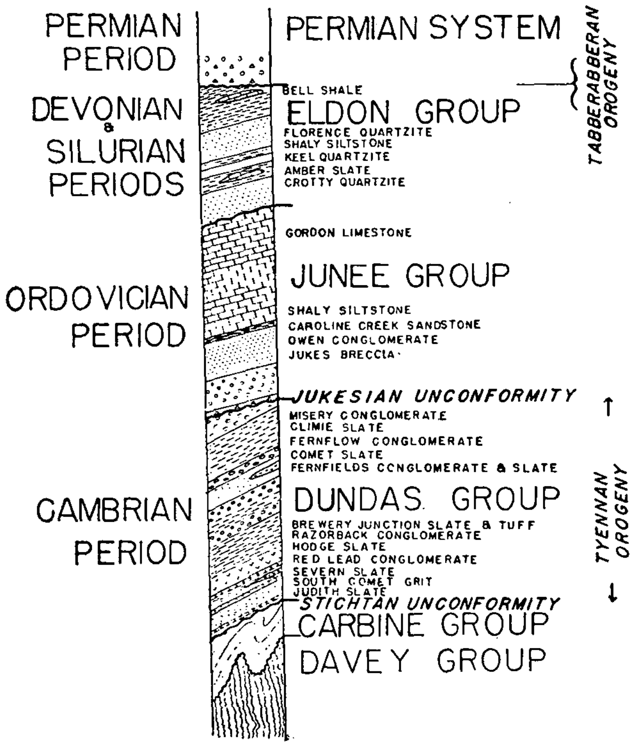

FIGURE 5

SECTION SHOWING
SUMMARY OF LOWER PALAEOZOIC HISTORY
OF TASMANIA.

Tyennan folding deduced in the next section, and it is interesting to speculate on the possibility of its correspondence with Carey's (1953, p. 1126) possible transcurrent fault in the basement rocks.

The metamorphism of the Dundas Group, especially along the schist belt, has generally been considered to have occurred in conjunction with the Tabberabberan Orogeny in the Lower and Middle Devonian, but there seems to be at least a possibility that metamorphism began in the schist belt during the Tyennan Orogeny in the Upper Cambrian.

STRUCTURE AND STRUCTURAL RELATIONSHIPS

The structure of the Dundas Group is the result of two orogenies, the Tyennan in the Cambrian, and the Tabberabberan in the Lower and Middle Devonian (see fig. 5).

At Sticht Range, Dundas, Lodder's Point near Ulverstone, and at Deloraine, the Dundas Group rests unconformably on older rocks, which at the Sticht Range show pre-Dundas folds. At the Sticht Range the basal bed of the Dundas Group contains boulders similar to the underlying rock, and in higher formations in the same area the same types of rock fragments occur as boulders. The Precambrian rocks of the Sticht Range are part of the Precambrian complex of the Tyennan Block (Carey, 1953). It seems then, that this block may have provided sediment during deposition of the Dundas Group, and it would then be a geanticline. Additional evidence on this point is the overlap of the basal formation at Deloraine by higher ones towards the Tyennan Anticlinorium. It is proposed therefore, to refer to it as the Tyennan Geanticline. The unconformity at the Sticht Range has been called the Stichtan Unconformity by Carey and Banks (1954). It represents two or more orogenic movements with intervening periods of deposition or erosion. The time interval covered by this unconformity cannot yet be estimated.

The idea of cycles of sedimentation in the Dundas Group was first proposed by Carey (1950), developed in terms of volcanic cycles by Elliston (1954), and further developed as due to orogenic movements by Carey and Banks (1954). At Dundas, there is evidence, as shown earlier, of at least eight cycles, and of at least eleven in the Huskisson River section. There are gradational contacts between several of the cycles at Dundas, but Elliston (1954) showed one of them to be sharp. Actual angular unconformities may occur at the Hercules and Rosebery Mines, and at Mount Farrell (see Hall et al., 1953). Bradley's inferred discordance in the Lynch Creek section at Queenstown (1954, p. 221) is not supported by later work by Solomon. The contact between the conglomerate and the underlying argillite in the author's section in the Leven Gorge is not regular, and may be an unconformity, but this is certainly not proven.

The structure of Tasmania proposed by Carey (1953, fig. 3) is dominantly the result of the Tabberabberan Orogeny. As the Tabberabberan structures have affected the Junee (Ordovician) and Eldon (Silurian and Lower Devonian) Groups, the effect of this orogeny on the Dundas Group can be estimated where it is overlain by the Junee or Eldon Groups, and, by levelling the dips of the Junee and Eldon Group sediments, the pre-Ordovician dip of the Dundas Group can be found.

The movement which terminated the Dundas sedimentation has been termed the Jukesian Movement (Carey and Banks, 1954, p. 265). Places where this movement is represented by an unconformity are shown in figure 4, and will all be seen to lie within the trough marginal to the Tyennan Geanticline. Where possible, the structure of the Dundas Group, when deposition began in the Lower Ordovician, has been estimated. West of Mount Sorell, there would have been an anticline overturned to the east, and at Mount Darwin, a complicated, overfolded structure. At Walford's Peak, the Dundas Group would have a low dip to the west, and in the Red Hills area, would be vertical and overfolded to the east. At Zeehan and along both limbs of the Huskisson Synclinal Basin, the residual dips would be low. At Gunn's Plains, dips of up to 30° to the northeast would have been present, and at Deloraine, there would have been an anticline with dips of 23° to the southwest and 40° to the northeast. A low dip to the east would have been present at Adamsfield. The results given above are as yet only fair approximations and far more information is necessary before Tyennan structures can adequately be deduced. There does, however, appear to have been a zone of close folding approximately along the present position of the West Coast Range with more open folding elsewhere. Bradley (1954, comment on Mount Owen sheet) deduced a faulted monocline with upthrow and northerly movement on the west side in this position which he considered was formed during the Upper Cambrian as an east-facing scarp. He also considered that the Lyell Monocline was part of this structure, and that this line was a line of intrusion and movement in the Upper Cambrian and again in the Devonian.

PALAEOGEOGRAPHY

Insufficient information is available on which to base a detailed palaeogeography. Many more sections need to be measured in detail and more fossils found to provide accurate correlations. The remarks which follow are thus only conjectural.

At some time prior to the *Ptychagnostus gibbus* Zone of the Middle Cambrian, the pre-Dundas rocks of Tasmania were folded and eroded, perhaps several times, before fold movements produced the Tyennan, and probably the Rocky Cape Anticlinoria with their intervening trough. The sea spread into the trough and sands, silts and gravels, probably produced by erosion of the Precambrian schists, gneisses and quartzites of these anticlinoria, were deposited rapidly in it. As shown earlier, it is probable that the anticlinoria acted as sources of sediment during deposition of the Dundas Group, and could be regarded as geanticlines. Deposition of the Dundas Group took place on the floor of this trough which sank rapidly as shown by the abundance of sub-greywackes and greywackes in the group. Widespread conditions of poor circulation are shown by the occurrence of black, pyritic slates on several horizons and in many places. Volcanic eruptions, many of them submarine, occurred in many parts of the trough, but there was probably a chain of volcanic islands along what is now the West Coast Range. Vulcanism usually occurred during deposition of the finer-grained sediments towards the end of the orogenic cycle. It is thought that uplift of the geanticlines, or of the volcanic islands which formed in the trough, occurred many times, and resulted in the cycles of sedimentation which occurred. Possibly mountain glaciers existed on the geanticline in the Middle Cambrian. Trilobites, brachiopods, dendroids, cystoids and worms lived in the sea filling the trough. At some time during the Upper Cambrian, basic and ultrabasic rocks were intruded through the Precambrian as dykes to spread out as somewhat transgressive sills into the Dundas Group, as at Adamsfield and Dundas. Also during the Upper Cambrian some granite was intruded into, or developed in, the Dundas Group at Mount Darwin. The Dundas Group and its associated extrusive and intrusive rocks were folded by the last, Jukesian, movement of the Tyennan Orogeny, which took place between the basal Franconian and the Middle Arenigian.

Conditions were probably similar in the Smithton and King Island areas, but insufficient information is available to make positive suggestions.

The Dundas Group is younger than the known Cambrian of South Australia, but contemporaneous with the Heathcotian of Victoria. It is possible that the movement which initiated deposition of the Dundas Group also initiated deposition of the Heathcotian and closed deposition in the Flinders Miogeosyncline. The association of a thick sequence of greywacke, sub-greywacke, chert, argillite and lavas and pyroclastics of the spilitic suite, with ultrabasic rocks, suggests that the trough in which the Dundas was deposited was part of a eugeosyncline.

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LOCALITY INDEX

	Latitude South	Longitude East
Adamsfield	42° 47′	146° 20′
Anthony Creek	41° 42′	145° 36′
Arthur River	41° 28′	145° 27′
Asbestos Point	42° 22′	145° 26′
Basin Lake	41° 59′	145° 32′
Beaconsfield	41° 11′	146° 45′
Blythe	41° 05′	146° 00′
Burnie	41° 03′	145° 55′
Cressy	41° 40′	147° 08′
Deloraine	41° 31′	146° 40′
Devonport	41° 11′	146° 22′
Dial Range	41° 11′	146° 01′
Double Cove	42° 20′	145° 20′
Dundas	41° 53′	145° 24′
Farrell Junction	41° 43′	145° 34′
Gawler	41° 12′	146° 10′
Gunn's Plains	41° 18′	146° 01′
Hatfield Plains	41° 40′	145° 34′
Huskisson River	41° 39′	145° 27′
King Island	40° 00′	144° 00′
Lake Dora	41° 58′	145° 39′
Langdon River	41° 59′	145° 31′
Leven Gorge	41° 15′	146° 05′
Linda Creek	42° 04′	145° 37′
Lodder's Point	41° 07′	146° 08′
Lonah Point (= Lodder's Point)		
Lorinna	41° 35′	146° 07′
Lynch Creek	42° 07′	145° 33′
Macquarie Harbour	42° 15′	145° 25′
Mainwaring River	42° 49′	145° 32′
Moina	41° 28′	146° 04′
Mount Claude	41° 30′	146° 12′
Mount Cleveland	41° 28′	145° 23′
Mount Darwin	42° 16′	145° 36′
Mount Farrell	41° 44′	145° 34′
Mount Lyell	42° 03′	145° 37′
Mount Murchison	41° 50′	145° 36′
Mount Ramsay	41° 36′	145° 27′
Mount Sedgwick	42° 00′	145° 35′
Mount Sorell	42° 15′	145° 32′
Natone	41° 10′	145° 55′
New River Lagoon	43° 27′	146° 35′
Nietta	41° 22′	146° 04′
Paloona	41° 16′	146° 15′

	Latitude South	*Longitude East*
Penguin	41° 07′	146° 04′
Pieman River	41° 40′	145° 02′
Que River	41° 36′	145° 31′
Queenstown	42° 05′	145° 33′
Red Hills	41° 52′	145° 35′
Renison Bell	41° 48′	145° 25′
Ring River	41° 48′	145° 27′
Rocky Boat Harbour	43° 42′	146° 40′
Rosebery	41° 47′	145° 31′
Sheffield	41° 23′	146° 21′
Smithton	40° 50′	145° 07′
Snake Spur	41° 13′	145° 35′
Spero River	42° 38′	145° 21′
Stanley River	41° 48′	145° 13′
Sticht Range	41° 52′	145° 38′
Stowport	41° 07′	145° 56′
The Pinnacles	41° 40′	145° 29′
Trial Harbour	41° 55′	145° 09′
Tullah	41° 43′	145° 35′
Tyndall Range	41° 57′	145° 34′
Walford's Peak	41° 56′	145° 36′
Wanderer River	42° 43′	145° 25′
Waratah	41° 26′	145° 31′
West Coast Range	41° 44′	145° 33′
	42° 18′	145° 38′
Williamsford	41° 50′	145° 29′
Wilson River	41° 45′	145° 22′
Zeehan	41° 53′	145° 17′

UPPER PROTEROZOIC AND SUB-CAMBRIAN ROCKS IN AUSTRALIA

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ABSTRACT

A brief review of the Australian Precambrian is given as background for more detailed discussion of Upper Proterozoic sedimentation which accomplished the final evolution of the Precambrian Shield.

The boundary between Precambrian and Cambrian can be studied on or near the margin of this Shield; the relationship between Precambrian and Palaeozoic in the area of the Tasman Geosyncline, in eastern Australia, is insufficiently known to contribute to this study.

The type section in which the Precambrian-Cambrian boundary can be fixed is provided by continuous sedimentation, through the Upper Proterozoic (Adelaidean System) and Lower Cambrian and extending into Middle Cambrian time, in the Adelaide Geosyncline in South Australia. In this succession, the lower boundary of the Cambrian System can be confidently restricted to one formation—the Pound Sandstone—but controversy exists as to whether the boundary should be placed at the top or bottom of the formation.

The Pound Sandstone contains *Collenia* and fossil jellyfish but no diagnostic Lower Cambrian forms, and is overlain by limestone bearing Archaeocyathinae. The writer restricts Lower Cambrian to the lowest limit of diagnostic fauna and places the boundary above the Pound Sandstone, which is therefore regarded as Sub-Cambrian.

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The difference in interpretation is not striking in the Adelaide Geosyncline but is very significant in central and northern Australia where strata correlated with the Pound Sandstone cover wide areas.

Apart from a probable continuous succession from Precambrian to Cambrian in the Amadeus Trough, where data are not conclusive, sequences of Upper Proterozoic and Cambrian sediments in central and northern Australia are incomplete. However, there is now sufficient information to correlate these sequences with portions of the Adelaidean System, and sediments containing jellyfish and *Collenia,* deposited in a late Precambrian transgressive sea, are regarded as equivalents of the Pound Sandstone of Sub-Cambrian age.

Lower Cambrian was principally a time of emergence in central and northern Australia, and, in most places, there is no record of this Epoch apart from plateau basalts which conformably underlie fossiliferous sediments deposited in the first epicontinental sea to cover wide areas of the Shield in Middle Cambrian time.

INTRODUCTION

Discussion of the Sub-Cambrian in Australia requires, as preface, a brief account of the geological history of the Precambrian as a whole so that the environments of deposition of late Precambrian rocks may be discerned. A short chapter on the Australian Precambrian and current nomenclature is, therefore, included in this paper to lead up to more detailed treatment of late Precambrian or Sub-Cambrian sedimentation.

The writer follows A. A. Öpik (this Symposium) and the Cambrian Subcommittee of the Geological Society of America (Howell *et alia,* 1944) in adjusting the Precambrian-Cambrian boundary to the lowest known limit of diagnostic Lower Cambrian fauna—the *Olenellus* fauna, including the *Bonnia* and *Obolella* zones as shown by the Subcommittee *(op. cit.).* Strata below this limit, which may contain a record of life but no diagnostic Lower Cambrian fauna, are placed in the Precambrian, and, for the purpose of this paper, uppermost Precambrian strata are referred to as Sub-Cambrian.

In addition to the literature cited in this paper, the writer has drawn on unpublished data collected by his colleagues in the Bureau of Mineral Resources, mainly in the Northern Territory and in western Queensland. Most unpublished data are acknowledged in the text and the writer is grateful for generous help, particularly by Messrs. Öpik, Walpole, Casey, Randal, and Carter.

Maps showing the main areas of outcrop of Precambrian rocks in Australia (plate 1) and the probable distribution of land and sea in Sub-Cambrian time (plate 2) and a correlation table for the Upper Precambrian rocks accompany the text. Some of these correlations rest on slender evidence but they appear logical and a useful basis for future work.

AUSTRALIAN PRECAMBRIAN

NOMENCLATURE

Two time divisions of the Precambrian have been formally recognized in Australia—Archaeozoic and Proterozoic. In most states, however, three broad divisions of the Precambrian record have been recognized, and, unfortunately, confusion has arisen in relating these to the standard time terms.

The Bureau of Mineral Resources and geological surveys of the eastern States, following David (1932), restrict Archaeozoic to the oldest of the three groups and designate the two younger groups Lower and Upper Proterozoic respectively. Western Australia and South Australia, however, restrict Proterozoic to the youngest group and use the terms Lower and Upper Archaeozoic where both the older groups are recognized.

Browne (in David and Browne, 1950) avoided this confusion by the use of Lower, Middle, and Upper Precambrian. The nomenclature followed in this paper is that in which the youngest group of Precambrian rocks is designated Upper Proterozoic.

EVOLUTION OF THE SHIELD (see plate 1)

Except for small areas in Tasmania, Precambrian rocks in Australia are all part of the great Australian Precambrian Shield which underlies the greater part of Western Australia, South Australia, Northern Territory, and portions of western New South Wales and northwestern and northern Queensland. The geological history of the Precambrian is largely the history of the evolution of this shield and has been discussed by many writers (Cotton, 1930; Andrews, 1938; Hills, 1946; David and Browne, 1950; Fairbridge, 1950; Noakes, 1953; Hossfeld, 1954).

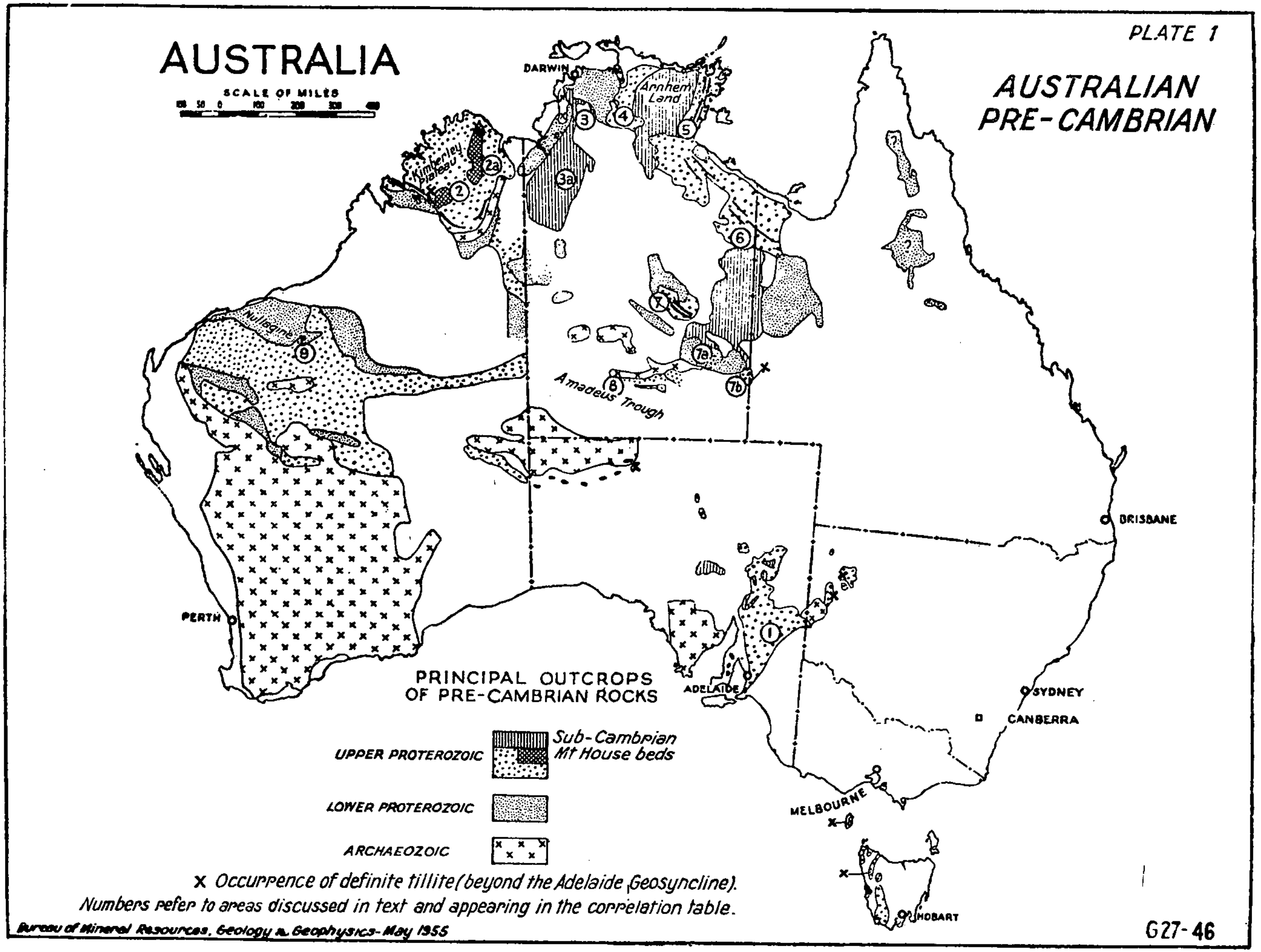
PLATE 1
AUSTRALIAN PRE-CAMBRIAN
AUSTRALIA
SCALE OF MILES
DARWIN
Arnhem Land
Kimberley Plateau
Nullagine
Amadeus Trough
PERTH
ADELAIDE
BRISBANE
SYDNEY
CANBERRA
MELBOURNE
HOBART
PRINCIPAL OUTCROPS OF PRE-CAMBRIAN ROCKS
UPPER PROTEROZOIC
Sub-Cambrian
Mt House beds
LOWER PROTEROZOIC
ARCHAEOZOIC
x Occurrence of definite tillite (beyond the Adelaide Geosyncline).
Numbers refer to areas discussed in text and appearing in the correlation table.
Bureau of Mineral Resources, Geology & Geophysics - May 1955
G27-46

Plate 1

The oldest group of Precambrian rocks covers large areas in the southern half of Western Australia and the western half of South Australia extending northward into the southern portion of the Northern Territory (central Australia).

Smaller, more isolated areas of Archaeozoic rocks are found in the Pilbara area and at the southern and southeastern margins of the Kimberley Plateau in Western Australia. In the Northern Territory they have recently been recognized south of Darwin and in both the northwestern and northeastern corners of Arnhem Land. In all these areas the rocks are deep-seated plutonics or highly metamorphosed meta-sediments or volcanic and, in general, are distinct from the less metamorphosed Lower Proterozoic strata.

About the beginning of Lower Proterozoic time, Archaeozoic rocks already provided a craton in southern Western Australia, extending into South Australia, and isolated cratons to the north, northeast, and east. Sedimentation around and between these cratons took place in the Proterozoic geosyncline (Noakes, 1953) largely in Lower Proterozoic time, although in some areas sedimentation and folding extended into the Upper Proterozoic. The welding of cratons into shield began with the folding of geosynclinal sediments about the end of Lower Proterozoic time and was gradually completed in the Upper Proterozoic. Apart from the filling of shallow troughs (indicated by fold belts on plate 1), which appears to be the final stage in the development of the Proterozoic geosyncline, Upper Proterozoic sedimentation was largely confined to platforms or shallow basins and was typically shallow and interrupted.

Furthermore, over most of the area of the present shield, Upper Proterozoic time saw a gradual change from orogenic to epeiric movements. The notable exception, apart from the Precambrian strata in Tasmania of which little is known, is the Adelaide Geosyncline of South Australia (mio-geosyncline of Sprigg, 1952) in which continuous sedimentation took place through Upper Proterozoic and Lower Cambrian time extending into the Middle Cambrian; this eventually linked the craton of western New South Wales to that of central and western South Australia (Sprigg, 1952).

In the area of the present shield there were three main environments of sedimentation in Upper Proterozoic time: mio-geosyncline in South Australia; sedimentation in shallow troughs along the sites of

Proterozoic geosynclines in northern Australia; and sedimentation in platforms or in basins. In the latter part of the Upper Proterozoic in central and northern Australia, the third environment was dominant and sedimentation verged on epicontinental in Sub-Cambrian time (plate 2).

UPPER PROTEROZOIC AND SUB-CAMBRIAN

GENERAL

The problem of relating Upper Proterozoic to Cambrian sedimentation in widely scattered areas of outcrop resolves itself into the problem of correlating those isolated and broken sequences in central and northern Australia with the type section in the Adelaide Geosyncline.

At this point, it is advisable to make some mention of the term "Nullagine." For many years Upper Proterozoic rocks in many places have been referred to as "Nullagine" or correlated with the Nullagine "System" (Clarke, Prider, and Teichert, 1944) inferring correlation with Upper Proterozoic rocks first described near Nullagine, Western Australia, by Gibb Maitland (1909). Unfortunately, the complete sequence of these rocks near Nullagine has yet to be established and until this is done, no reliable correlations are possible. At present, more is known of Upper Proterozoic sequences in the Kimberleys, in Arnhem Land, in the Jervois Range, and in central Australia, than is known of the sequence near Nullagine, and some logical correlations can be made with the Adelaidean System, but not with the rocks at Nullagine. Hence the use of the term "Nullagine" as a synonym for Upper Proterozoic has been largely discontinued.

The correlations shown on plate 1 indicate three broad divisions [1] of the Upper Proterozoic. In the lower part (the "Middle Proterozoic" of Hossfeld, 1954) sedimentation, apart from that of the Adelaide Geosyncline, was restricted and took place in shallow troughs or in neighboring platforms. Lavas are included in all these lower sequences and some folding and faulting and, in places, igneous intrusion followed.

The middle division saw more sporadic deposition of glacigene sediments followed by wider distribution of red-beds and dolomites.

[1] Formal nomenclature seems premature at this stage and should at least await completion of work in hand. Nomenclature proposed by Hossfeld (1954) needs revision but will make a valuable contribution.

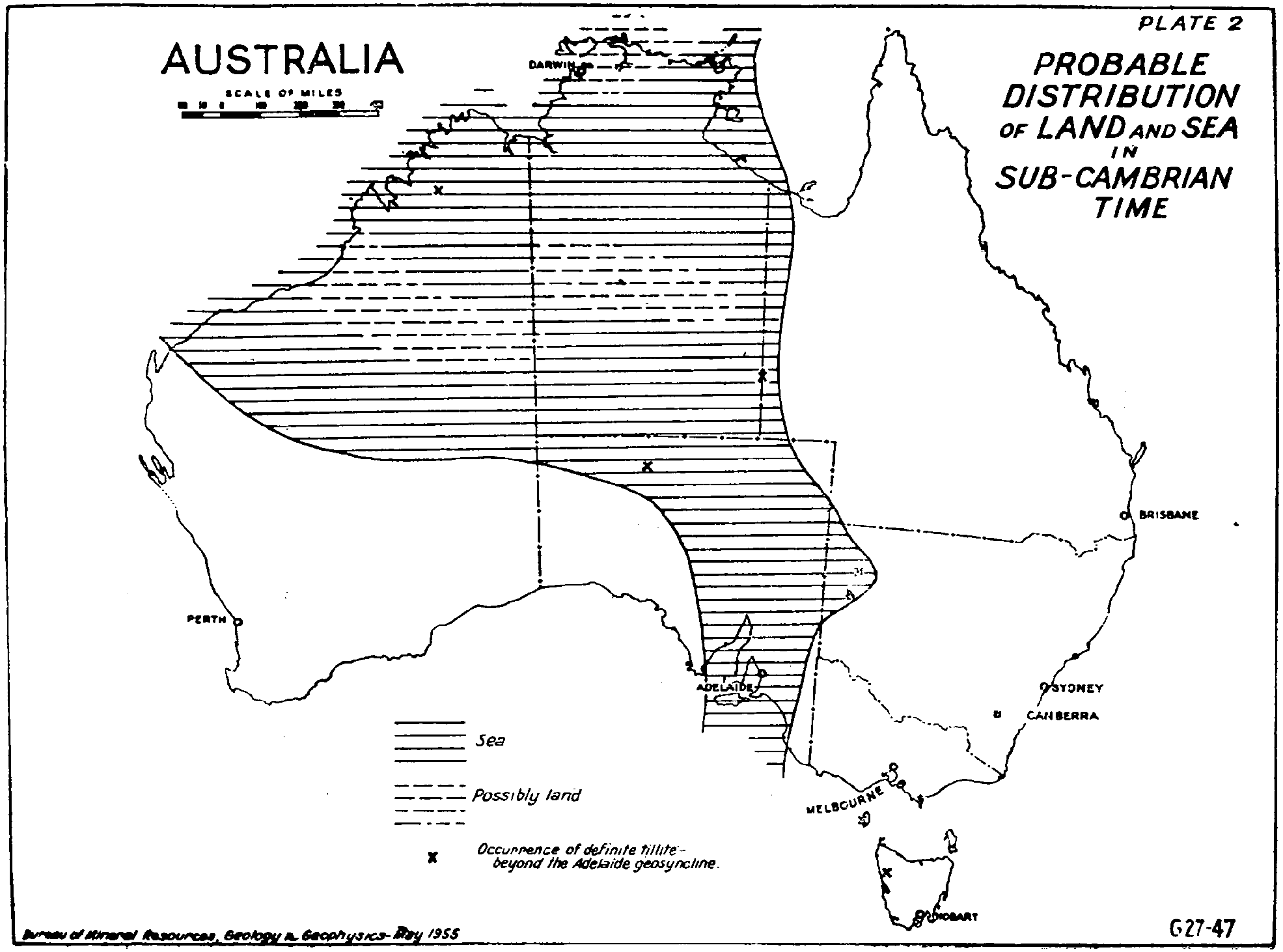
PLATE 2
AUSTRALIA
SCALE OF MILES
PROBABLE DISTRIBUTION OF LAND AND SEA IN SUB-CAMBRIAN TIME
DARWIN
BRISBANE
PERTH
ADELAIDE
SYDNEY
CANBERRA
MELBOURNE
HOBART
Sea
Possibly land
Occurrence of definite tillite beyond the Adelaide geosyncline.
Bureau of Mineral Resources, Geology & Geophysics - May 1955
G27-47

Plate 2

It is not clear whether sedimentation in northern Australia was completely interrupted at the end of this division or whether the uppermost Precambrian or Sub-Cambrian was initiated by a wider transgression of the seas in which the red-beds and dolomites were deposited. In any case, this transgression heralded the final stage of consolidation of the shield. In some areas at least, sedimentation was followed by faulting, uplift, and erosion, which does not affect overlying Middle Cambrian sediments.

CORRELATION OF UPPER PROTEROZOIC ROCKS

As this paper deals mainly with the Sub-Cambrian, brief mention only will be made of these areas in which the Sub-Cambrian is not known or is not represented. Two areas of Precambrian rocks in eastern Australia can be dismissed at this stage. The probably Lower Proterozoic rocks of northern Queensland are as yet little known and have no known relationship with the Cambrian. Precambrian rocks in the western half of Tasmania have been divided into two groups—the schists of the Davey Group followed probably unconformably by the quartzite, phyllite, and dolomite of the Carbine Group (Carey, 1953; Elliston, 1954). Both probably lie within the Upper Proterozoic, and the Carbine Group may range into the Cambrian, but there is at present no fossil evidence of this. The lowest fossiliferous Cambrian strata are found in the Middle Cambrian Dundas Group which unconformably overlies the Carbine Group. Tillites are known on King Island and at Zeehan but the age is disputed. They are correlated with the Upper Proterozoic Sturtian Tillite by David and Browne (1950) but are regarded as Middle Cambrian by Banks (this Symposium).

The Lower Palaeozoic strata of the Tasman Geosyncline include known Middle Cambrian in Victoria and inferred Cambrian rocks elsewhere (Öpik, this Symposium), but no underlying Precambrian strata are positively known between Tasmania and northern Queensland. Thus, the Tasman Geosyncline as a whole cannot aid our present enquiry.

Adelaide Geosyncline (Area 1)

Discussion of Upper Proterozoic successions properly begins at the type area—the Adelaide Geosyncline.

Many geologists, among whom one must mention Mawson, Howchin, Sprigg, Campana and Daily, have contributed to the sedimentary and tectonic record of this continuous Precambrian-Cambrian succession. The term "Adelaide Series" was first suggested by David (1922), and Howchin (1929) placed the base of the Cambrian at the top of the Brighton Limestone, i.e., the top of the present Marinoan Series. Mawson (1949) introduced "Adelaide System," used also by Browne (in David and Browne, 1950) and this was formally defined by Mawson and Sprigg (1950).[2]

With the growth of knowledge, Howchin's base of the Cambrian was shifted upwards to exclude completely unfossiliferous successions from the Cambrian and, by general agreement, the boundary was placed at the base of the (Wilpena) Pound Sandstone (see Daily, this Symposium). The Adelaidean System has been divided into four series (Mawson and Sprigg, 1950; Sprigg, 1952). Details of the Cambrian strata above the Adelaidean System are presented by Daily in this symposium.

Sub-divisions of the Adelaidean System from the top downwards are given below. The descriptions are taken from the Geological Map of South Australia, published by the South Australian Mines Department in 1953.

Marinoan Series: Reddish chocolate and grey slates, limestones, sandstones and quartzites frequently with macigno (sandstone-shale) associations and brecciolic limestones indicating submarine slopes. Restricted arkoses and the Elatina tillite of Flinders Ranges. Problematic Cryptozoa. Maximum recorded thickness 11,300 feet.

Sturtian Series: Massive tillites, glacigenes and laminated slates. Macigno (sandstone-shale) associations and limestone brecciolas including red "heiroglyphic" limestones near top; iron formations in Olary province. Maximum recorded thickness 24,450 feet.

Torrensian Series: Massive well-sorted (basal) sandstones attaining 6000 feet in thickness, with or without massive conglomerates in westerly geosynclinal and shelf zones. Grey shales with interbedded thin limestones and brecciolic sedimentary magnesites and quartzites. Maximum recorded thickness 17,000 feet.

Willouran Series: Occurs at the base of the Adelaidean System only along the western margin of the geosyncline. Numerous quartzites interbedded with fine argillaceous shales. Maximum recorded thickness 3000 feet.

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[2] In conformity with rules suggested by the Australian code of Stratigraphical Nomenclature since 1950, the System is termed "Adelaidean" in this paper.

The Willouran Series is found only along the western margin of the geosyncline, but the Torrensian Series is more extensive. According to Sprigg (1952), faulting became quite severe, particularly in the northeast portion of the geosyncline, during this Epoch, and movement seems associated with acid porphyry intrusions and with basic flow extrusions.

Block mountains to east and west of the geosyncline were glaciated in the Sturtian Epoch and provided large quantities of glacigene sediments which temporarily filled some parts of the geosyncline. In discussing later Sturtian time, Sprigg (1952) remarks that "the 'macigno' and brecciola sediments of this cycle were at first dominantly grey coloured reflecting the earlier cold phase but later the change to red-bed sediments became marked, the line of demarcation being earlier in the north (low latitudes) than in the south. This change to red colouration marks the onset of the Marinoan phase (Mawson and Sprigg 1950) and continues into and throughout the Cambrian. The onset of Cambrian times is taken at the base of the Pound Quartzite when stability was again retained."

The Cambrian succession in the Adelaide Geosyncline is fully described by Daily in this Symposium, but the lower boundary of the Cambrian deserves discussion. The lowest part of the Cambrian succession is the Pound Sandstone, which ranges in thickness from a few hundred feet to 7000 feet and is overlain by limestone and dolomite formations up to 1200 ft. thick which have different formal names in different localities (see Daily, this Symposium).

The first acknowledged Lower Cambrian fossils—Archaeocyathinae—appear above the base of these limestone formations. The only fossils recorded from the Pound Sandstone—jellyfish and algae—were found by Sprigg (1947) near the top of the formation at Ediacara.

The adjusted Cambrian boundary, placed at the bottom of the Pound Sandstone, is logical in that the Sandstone marks the beginning of a major transgression and within it is found undoubted evidence of life other than algae. On the other hand, this boundary is well below the first Archaeocyathinae horizon in the limestone overlying the Pound Sandstone and, therefore, below the Cambrian as strictly defined by diagnostic fauna in Europe and America (Howell *et alia*, 1944). It is argued, therefore, that until the limits of the Lower Cambrian are redefined, the adjusted boundary of the Lower Cambrian in the Adelaide Geosyncline would more logically be placed at the bottom of the limestone formation overlying the Pound Sandstone. The writer advances this view because strata carrying jellyfish and algae to be correlated with the Pound Sandstone have been mapped over wide areas in northern Australia where they are regarded as uppermost Precambrian or Sub-Cambrian. These beds include dolomites and shales and provide more favorable conditions for the preservation of life than does the Pound Sandstone, yet search has yielded only *Collenia* and fossil jellyfish. In these circumstances, a Lower Cambrian boundary not based on diagnostic forms becomes too vague for the purposes of correlation and thus defeats the main purpose of universal time divisions.

For the purposes of this paper then, the base of the Cambrian in the accompanying correlation table is placed at the top of the Pound Sandstone in the sequence of the Adelaide Geosyncline, and main outcrops of the Pound Sandstone are shown as Sub-Cambrian on plate 1.

CENTRAL AND NORTHERN AUSTRALIA

Criteria for Correlation

In attempting to relate the isolated and incomplete successions of Upper Proterozoic rocks in central and northern Australia to the type section in the Adelaide Geosyncline, there appear to be a number of features in the type area by which correlation might be made.

Since the lowest fossiliferous Cambrian strata in the northern successions, apart from the Amadeus Trough, are Middle Cambrian, resting disconformably or unconformably on older rocks, the base of fossiliferous Cambrian is no sure guide to the boundary between Precambrian and Palaeozoic.

However, the fossil jellyfish of the Pound Sandstone seem significant and, apart from fossils, the marked climatic changes recorded by glaciation in the Sturtian Epoch and by red-beds in the Marinoan Epoch are likely to have been widespread over the Australian continent, and should allow correlation within broad limits. Such correlation could not be regarded as precise because Mawson (1949) records the Elatina glacial horizon in the Marinoan Series, so that tillites found in northern

CORRELATION OF AUSTRALIAN UPPER PROTEROZOIC

	1 ADELAIDE GEOSYNCLINE	2 KIMBERLEY PLATEAU	3 VICTORIA RIVER	3a DALY RIVER	4 WESTERN ARNHEM LAND	5 EASTERN ARNHEM LAND	6 GULF & BARKLY TABLELAND	7 DAVENPORT RAS. & JERVOIS RA. a TOBERMORY b	8 MACDONNELL RANGES	9 NULLAGINE DISTRICT, W.A.
UPPER CAMBRIAN / MIDDLE CAMBRIAN / LOWER CAMBRIAN	Cambrian sediments Ⓐ	Carlton Group; Antrim Plateau Volcanics	Elder S/s; Negri Gp; Antrim Plateau Volcanics	Daly River Group Volcanics	Daly River Group; Dolerite Sills ?	Dolerite Sills ?	Sediments of Undilla Basin; Lavas ?	Sandover beds	Cambrian sediments not mapped in detail Ⓐ	Lavas ?
UPPER PROTEROZOIC (ADELAIDE SYSTEM)	☆ Ⓒ Wilpena Pound S/s up to 7,000 ft; Marinoan Series 11,300 ft; Sturtian Series 24,450 ft; Torrensian Series 17,000 ft; Willouran Series 10,000 ft	(2a) ☆ ? Mount House Beds 2,800 ft+; Walsh Tillite; ?; Warton Beds 4,000 ft+; Mornington Volcanics; King Leopold Formation 1,800 ft+	☆ Ⓒ Victoria River Group 2,000 ft+ ?	☆ Ⓒ Tolmer Group 2,200 ft	Ⓒ Wilton beds; Katherine R Group with acid and basic volcanics 3000-4000 ft	Ⓒ Wilton Beds; Portion of the System represented by thick sandstone overlain by red beds and shales; ?	Camooweal Dolomite 1,000 ft+; McMinn Beds ?; Robinson Beds ?; Constance Formation; Wollogorang Volcanics; McArthur River Beds and Nicholson Beds	Camooweal Dolomite 1,000 ft+ (a) (b); Mopunga Group (a)(b) 3,300 ft+ (Arkose); Red shale Tillite (b); Davenport Series	?; Pertaknurra "Series" 3,300 ft.?	? (Correlation uncertain) Dolomite ? Sandstone Shales; Sandstone with lavas and porphyry; Basal conglomerate; ?
LOWER PROTEROZOIC	?	Halls Ck Metamorphics; Lamboo Complex	Halls Ck Metamorphics; Lamboo Complex	Brocks Creek Group	Brocks Creek Group	?	Inliers	7 7a 7b	White Range Quartzite	Mosquito Ck. "Series"
ARCHAEOZOIC	Archaeozoic Complexes	Lamboo Complex in part	Lamboo Complex in part	Granite	Inliers	Granite	?	?	Arunta Complex	?

Ⓐ Archaeocyathinae ☆ Fossil jellyfish Ⓒ Collenia

Bureau of Mineral Resources, Geology & Geophysics G27-48

Table 1

Australia, although presumed to represent major glaciation in the Sturtian Epoch, could be the equivalents of minor glaciation recorded in the Marinoan. Furthermore, Sprigg's remark, quoted above, that the red-beds in the Adelaidean System appear earlier in the north than in the south is a warning that similar lithology could appear earlier than Marinoan in northern Australia. Finally, igneous rocks in the Adelaidean System, including flows and porphyries, are restricted to the Torrensian Series; and although correlations based on the stratigraphic position of igneous rocks are admittedly very inconclusive, the occurrence of flows, and in some places granites, restricted to the lower portions of northern successions, is at least striking.

Successions in central and northern Australia are discussed in the order which best develops the correlation.

Kimberley Plateau (Areas 2, 2a)

The rocks of the Kimberley Plateau have long been regarded as Upper Proterozoic in age, but only in the last few years have some details of the sequence been established by Guppy *et alia* (in press), by Traves (in press) in liaison with the Land Research and Regional Survey Section of the Commonwealth Scientific and Industrial Research Organization, and by geologists of the Broken Hill Pty. Company.

The rocks of the Kimberley Plateau are discussed by Traves in this symposium; the following succession, in descending order, is reiterated here. These units are known to vary widely in thickness and no reliable thicknesses have yet been established:

Mt. House Beds: 2000′ +	Interbedded sandstone, siltstone, shale and quartzite with bands of limestone and dolomite.
Walsh Tillite: ?	Unsorted sediments, from silt to boulders with matrix of green or red siltstone. Quartzite erratics probably from Warton Beds. Faceted and striated boulders.
	Unconformity
Warton Beds: 4000′ ?	Bedded conglomerate, white to light brown quartzite, red micaceous sandstone and shale.

Mornington Volcanics: ?	Fine-grained andesite, amygdaloidal in places, and medium-grained dolerite. Interbeds of shale and quartzite, dykes of basalt, quartzite veins.
	U n c o n f o r m i t y
King Leopold Formation: 1800′ +	Quartzite, basal conglomerate in places with probable shale interbeds.

The lower part of the succession from the King Leopold Formation up to and including Warton Beds is severely folded, in places, in a westerly trending belt along the southern margin of the plateau. The sedimentary iron ore deposits of Yampi Sound lie in this fold belt,[3] probably high in the Warton Beds. The succession can be traced northward from the fold belt on to the Kimberley Plateau, where folding becomes gentle or is absent.

In the upper part of the succession the Walsh Tillite is at present known at few localities and is conformably overlain by Mount House Beds. Guppy *et allia* (in press) do not mention ferruginous strata at the type locality of these Beds, but Traves (in press) records some chocolate shales and ferruginous sandstones in sections examined in the presumed easterly continuation of these beds near, and to the south of Wyndham (Area 2a). In one of these sections about 40 miles east of Wyndham, A. A. Öpik (unpublished) found fossil jellyfish in greenish shale. Similar fossils and *Collenia* bioherms, which will be mentioned later, have been found in the Victoria River Group farther east and are regarded as Sub-Cambrian.

Relationships of the Upper Proterozoic with fossiliferous Cambrian strata immediately east of Wyndham are partly obscured by faulting, but the position is made clear farther east. Lower Cambrian basalts rest on an eroded surface of Upper Proterozoic and Sub-Cambrian rocks and conformably above these basalts rest fossiliferous Middle Cambrian strata.

The lower part of the succession in the Kimberley Plateau below the tillite is correlated with the lower part of the Adelaidean System, although to what extent the Willouran and Torrensian Series are

[3] Personal communication from geologists Broken Hill Pty. Co.

represented is not known. Guppy *et alia* (in press) suggested the probable correlation between the Walsh Tillite and glaciation in the Adelaidean System, and whether it be regarded as representing part of Sturtian or Marinoan time, the conformable Mt. House Beds are mainly Marinoan. Ferruginous beds are known both high in the Warton Beds and in the upper part of the section above the Walsh Tillite. The Sub-Cambrian strata which are high in the section of the Mt. House Beds near Wyndham are presumably conformable, and either the Mt. House Beds as a whole, or a late stage of them, are widely transgressive; this transgression will be followed to the north and east where relationships with the Cambrian are better discerned.

Daly River, Victoria River Areas (Areas 3 and 3a on plate 1)

A sequence of gently dipping sandstone, dolomite, and limestone in the Daly River area (Area 3) has been a source for controversy for some years. The succession rests unconformably on folded Lower Proterozoic rocks and the uppermost sediments include Middle Cambrian *Girvanella* limestone. Hossfeld (1937) proposed the name Buldiva "Series" to embrace the whole sequence, which he believed to be continuous and of Lower Cambrian age. Voisey (1939b) referred to the Buldiva Quartzite overlain conformably by the Daly River Limestone and regarded the Buldiva Quartzite as Lower Cambrian, possibly extending down into Upper Proterozoic. Noakes (1949) reported evidence of regional unconformity and erosion between the Buldiva Quartzite and the overlying Cambrian beds, and placed the Buldiva Quartzite in the Upper Proterozoic, beneath the Daly River Group, which was regarded at that time as upper Lower Cambrian. Hossfeld (1954) reiterated his belief that there was no break in sedimentation in the succession and resurrected the Buldiva "Series" of Lower Cambrian age.

However, detailed mapping of the Katherine-Darwin area by B. P. Walpole and colleagues is now almost complete and has confirmed the break between the Buldiva Quartzite and the Daly River Group. The Daly River Group is Middle Cambrian and the Lower Cambrian is missing on present knowledge (see A. A. Öpik, this Symposium).

The sequence has now been mapped in detail and the nomenclature revised. B. P. Walpole and colleagues record the sequence below the Middle Cambrian sediments as follows:

Group	Formation	Member	Description
Tolmer Group	Hinde Dolomite		Pink and grey dolomite; *Collenia* reefs. Thickness about 120 ft. (with top beds missing)
	Buldiva Sandstone	Stray Ck. sandstone member	Clean flaggy quartz sandstone with siltstone bed at the top with fossil jellyfish. Thickness about 1000 ft.
		Depot Ck. sandstone member	Friable ripple-marked quartz sandstone. Silicified in places. Thickness about 1000 ft.

No fossils other than *Collenia* and fossil jellyfish have been found in this sequence. Moreover, the Tolmer Group has now been traced southward into at least the upper part of the Victoria River Group of Traves (in press) (Area 3a), with which it has previously been correlated. The Victoria River Group contains *Collenia* reefs, and at Mt. John, Wade (1924) discovered fossils which were eventually established as fossil jellyfish by Sprigg in 1949. Again, search over many years has produced no other fossils in these rocks.

The Victoria River Group consists mainly of quartz sandstone, limestone, and dolomite with gentle dips, except where beds are affected by faulting or monoclinal flexures. The sandstones, like those of the Tolmer Group, typically show ripple marks, mud pellets, and cross bedding, and are strongly jointed. The Group has not been subdivided and, according to Traves (in press), is at least 2000 ft. thick.

The Antrim Plateau Volcanics, referred to the Lower Cambrian, are found resting on an eroded surface of the Victoria River Group, and conformably above them lie fossiliferous Middle Cambrian sediments. Lavas in the Daly River area were thought by Noakes (1949) to be the equivalents of the Antrim Plateau Volcanics, but nearly all of the lavas in the Daly River area are now known to be post-Cambrian. Lower Cambrian volcanics underlie the Daly River Group farther west near Arnhem Land.

West and Southwestern Arnhem Land (Area 4)

Towards the western and southwestern edge of the Arnhem Land Plateau, a gently dipping sequence consisting of sandstone and volcanics rests with marked unconformity on folded Lower Proterozoic rocks. Noakes (1949) recognized the succession as Upper Proterozoic and correlated it with the Buldiva Quartzite, now the Tolmer Group. Walpole (unpub.) has now shown that the sequence in western Arnhem Land is stratigraphically below the Tolmer Group.

The sequence at the western edge of the Arnhem Land Plateau, the Katherine River Group, is regarded by Walpole as the lower part of the Upper Proterozoic succession in this area. It consists of 3000 to 4000 ft. of coarse clastic sediments with interbedded acid and basic lavas and pyroclastic material. Sandstones range from quartz greywacke to quartz sandstone, are strongly jointed, and in many places show typical shallow-water structures.

Resting unconformably on the Katherine River Group is a subhorizontal sequence of dolomite, limestone, and sandstone, with some shale, with a total thickness of 1500-2000 ft. This sequence is known as the Wilton Beds (Öpik, unpub.). *Collenia* reefs of the same type as those examined in the Tolmer and Victoria River Groups are found in the dolomites but no other fossils have yet been found in the sequence. Sills of dolerite intrude the Wilton Beds and are probably referable to the Lower Cambrian; volcanics overlie the Beds in the Waterhouse area, in southwestern Arnhem Land. Above these volcanics are found Middle Cambrian sediments of the Daly River Group.

The Katherine River Group is regarded as low in the Upper Proterozoic; it can be correlated broadly with the Kimberley section below the Walsh Tillite. No red-beds have been found in the western part of Arnhem Land and the Wilton Beds may represent only the upper portion of the Mt. House Beds. The Wilton Beds are regarded as Sub-Cambrian and correlated with the Tolmer Group.

Detailed mapping in the Katherine-Darwin region by Walpole has thrown much light on sedimentation in the Upper Proterozoic. In early Upper Proterozoic time, the fold mountains of the Lower Proterozoic rocks were shedding eastward onto the Arnhem Land platform, and, farther south, westward onto the Kimberley platform. The Sturtian and Marinoan series are represented in part in the Kimberley Plateau but are missing in western Arnhem Land, although the Marinoan is probably represented in eastern Arnhem Land.

Eastern Arnhem Land (Area 5, plate 1)

The stratigraphy of eastern Arnhem Land is insufficiently known to aid our present enquiry. Archaeozoic and presumably Upper Proterozoic rocks have been found in places, and geologists from the Broken Hill Pty. Co. have in recent years examined, in reconnaissances, a discontinuous succession of gently folded rocks which lie below the Wilton Beds and are almost certainly Upper Proterozoic.[4]

This succession cannot yet be correlated with the better known Upper Proterozoic sections farther west, but it is very likely that a more complete section will be found in eastern Arnhem Land than in the western portion of the plateau. The Marinoan, missing in western Arnhem Land, may well be represented in eastern Arnhem Land by the chocolate shales recorded by Wade (1924) along the northwestern coast of Arnhem Land, and by chocolate and purple shales and mudstone reported from the eastern coastal zone.

Gulf of Carpentaria and Barkly Tableland (Area 6, plate 1)

An arcuate belt of Upper Proterozoic sediments, some of which are folded, borders the southwestern shores of the Gulf of Carpentaria. The area of sub-Cambrian rocks to the immediate south comprises part of the Barkly Tableland (see plate 1).

The stratigraphy of the folded belt around the Gulf is still little known but reconnaissance data indicate that most of these rocks are Upper Proterozoic. Early workers, including Woolnough (1912) and Jensen (1914), regarded many of the rocks as Cambrian in age, but later Jensen (1940) expressed doubts. The present writer traversed some of the area in 1947 and D. M. Traves made further reconnaissance in 1948. Uranium prospects have resulted in some more recent work but none of these reconnaissances have been published. The writer has no doubt that most of the rocks are Upper Proterozoic and agrees with Hossfeld (1954) in that much of the sequence belongs to the lower part of the Upper Proterozoic (Davenport "Series" of Hossfeld). The upper part of the Adelaidean is also represented.

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[4] Personal communication - Company geologists.

Towards the southeastern end of the belt, the folded sandstone, limestone and shale of the McArthur River Beds are intruded by granite in the Nicholson Valley (Nicholson Beds). Near the Northern Territory border, north of the Nicholson River, acid and intermediate flows with interbeds of tuff and sandstone form part of the sequence, and south of the Nicholson River the Constance Formation, which rests unconformably on Lower Proterozoic rocks, appears to be a shelf or platform facies of strata high in the Nicholson Beds (Carter, unpub.). The Formation includes a marker bed of very ferruginous sandstone. Immediately east of the McArthur River, the McArthur River Beds are unconformably overlain by sub-horizontal sandstone of the Robinson Beds, and farther to the northwest between the McArthur and Roper Rivers, there are a number of flat or gently folded formations forming a discontinuous sequence which rests with marked unconformity on folded strata. In this discontinuous upper sequence lie the McMinn Beds of Woolnough (1912) which are notably ferruginous sandstone and shale for which Woolnough suggested a correlation with "Cambrian" red-beds of South Australia. Along the southwestern rim of the belt the writer traversed flaggy sandstone and dolomite intruded by a dolerite sill and overlain by presumed Lower Cambrian lavas at Nutwood Downs. The sandstones appear to be the youngest beds of the succession and are correlated with the Wilton Beds.

On the Barkly Tableland, the Camooweal Dolomite, which consists mainly of dolomite with chert nodules and with interbeds of sandstone, overlies the Constance Formation and possibly some younger rocks and is regarded as Sub-Cambrian and the equivalent of the Wilton Beds. The Camooweal Dolomite was earlier regarded as definitely Cambrian until A. A. Öpik (unpub.) showed that it lay beneath the fossiliferous Middle Cambrian of the Barkly Tableland and was, in fact, the source of sediments for the Middle Cambrian Age Creek Formation in the Undilla Basin. The formation was largely deposited in an evaporite environment; no fossils other than algae have been found in the Dolomite, which is at least 1000 ft. thick.

As shown in plate 1, a considerable part of the Adelaidean System is probably represented in the Gulf and Barkly Tableland areas, with volcanics and granitic intrusion again restricted to the lower part. Notably ferruginous beds apparently occur in lower and upper portions of the succession as in the Kimberley Plateau.

The Camooweal Dolomite, the youngest part of the sequence below the fossiliferous Middle Cambrian, could extend into the Lower Cambrian, but for reasons given in the next section, it is regarded as Sub-Cambrian; the sequence of events in this area would, therefore, follow the pattern established to the northwest—except for volcanics, the Lower Cambrian is missing.

Davenport Ranges, Jervois Ranges, Tobermory

(Areas 7, 7a, 7b, plate 1)

These areas trend along another of the Proterozoic geosynclines—the Warramunga geosyncline (Noakes, 1953) but little detailed mapping has been done. The most recent workers in the area include P. S. Hossfeld and C. J. Sullivan in the Davenport Ranges and Öpik, Noakes, and Casey in the Jervois Ranges and Tobermory areas. A considerable part of Upper Proterozoic time seems to be represented but not in any one locality. Part of the earlier Upper Proterozoic is represented in the Davenport Ranges and portions of the upper part and some Cambrian and Ordovician in the Jervois-Tobermory areas.

Hossfeld (1954) has summarized his unpublished work in the Davenport Ranges (Area 7). The Hatches Creek Group consists mainly of quartzite, sandstone, shale, tuff, and lavas. Dolerite, amphibolite, and granite intrude the folded Group. Hossfeld places the Group in his Davenport "Series" equivalent to the earlier Upper Proterozoic of this paper.

Recent reconnaissance work has been carried out in the Jervois Ranges (Area 7a) by Joklik in 1952 (Joklik, in press) and by Öpik (unpub.) and Bell in 1952. Noakes and Casey measured reconnaissance sections through the Upper Proterozoic sequence in 1953 and in the same year Noakes found a tillite associated with the same sequence in the Tobermory area (Area 7b). Casey determined its stratigraphic position within the Tobermory section in 1954 and added some detail of the stratigraphy of the area.

The combined section from the two areas is given below. The thickness of individual formations varies from place to place and the approximate thicknesses quoted are those measured in the Jervois Ranges.

Mopunga Group (after Tindale, 1931)	Ferruginous quartz greywacke (some micaceous) with sedimentary iron ore—about 1300 ft.
	Fawn to brown limestone probably with dolomite—about 40 ft. Brown greywacke and quartz greywacke with some shale—about 1000 ft.
	Brown quartz greywacke with some shale and dolomite, with *Collenia*—about 650 ft.
	slight disconformity?
	Arkose (Oorabra) grit and limestone—about 300 ft.
	slight unconformity.
	Red and brown shale and quartz greywacke—about 200 ft. Tillite

The beds are block faulted and their dips are mainly due to faulting and tilting of the fault blocks rather than to folding. Some of these dips may also be depositional. Dips average about 12° in the east and west Jervois Ranges, except where affected by faults. In the Jervois Ranges the beds rest with marked unconformity on severely folded metamorphics of probable Lower Proterozoic age. *Collenia* has been found in a bed of dolomite in the lowermost part of the section in the East Jervois Range; no other fossils have been found in the Mopunga Group.

The existence of the tillite and the marked red colouration of the fine sandstone and shale beds suggest Marinoan Age. The Camooweal Dolomite extends southward from the Barkly Tableland into the Tobermory/Jervois Range area but the exact relationship between the Dolomite and the Mopunga Groups is not known. The Dolomite is either slightly younger than the Mopunga Group or grades into the top of the Mopunga sequence. Present data favour the second alternative; hence the Camooweal Dolomite is regarded as Upper Precambrian rather than Lower Cambrian.

The fossiliferous Middle Cambrian cherts and limestones either unconformably overlie the Mopunga Group (north of the Jinka Plain) or are faulted against it. This fault contact is commonly between Cambrian limestones and a dolomite which may be one of the interbedded dolomites in the Mopunga Group, or it may be equivalent to the

Camooweal Dolomite. Dolomites of more than one age occur in the area, and if the dolomite is not associated with other rock types in outcrop, its position in the stratigraphic column becomes a problem.

MacDonnell Ranges (Area 8, plate 1)

A sequence of Cambrian and Precambrian rocks is preserved in a westward trending trough—the Amadeus Trough—in central Australia. The town of Alice Springs lies near the northern boundary of the structure. It has been referred to as a geosyncline but appears to be a broad, linear down-warp in which slightly folded sediments range from Upper Proterozoic to Ordovician.

The sequence has been discussed by Mawson and Madigan (1930), Madigan (1932a, 1932b), Voisey (1939b) and Hossfeld (1954), and Öpik and Bell (unpub.) have made further reconnaissances. However, the stratigraphy is too little known to allow sub-divisions of the sequence to be made.

There seems to be a straight sequence from Upper Proterozoic rocks into the Cambrian, and Madigan's work indicates some 7000 ft. of sediments between the lowest sediments that may be Lower Cambrian and the Archaeozoic basement on which the sequence rests. These Upper Proterozoic rocks below the presumed Lower Cambrian were divided in ascending order into the Pertaknurra and Pertatataka "Series" with a presumed break between. Voisey (1939b) and Hossfeld (1954) show that there is no evidence of this break and regard these two series as part of the same conformable sequence. However, it seems likely that detailed mapping will reduce the thickness of 7000 ft. accredited to the Upper Proterozoic portion of the sequence, as there is evidence of repetition by strike faulting (Voisey, 1939a). It is not even certain that there was, in fact, continuous deposition from Proterozoic into Cambrian time although present data do suggest this.

The sequence starts with a thick quartzite, the Heavytree Quartzite, in places, over a thin bed of shale, and consists mainly of alternations of dolomite or limestone and shale, much of which is red or chocolate in colour. *Collenia* is abundant in the section and the topmost beds are purple slates and red sandstones. Above these beds, Madigan records dark red sandstones and quartzite with bivalve or clay gall impressions and places the lower limit of the Cambrian below these beds. Farther up the section, he found *Girvanella.* Archaeocyathinae were found not in the type section but elsewhere in the MacDonnell Ranges; the position of the Archaeocyathinae horizon has not yet been determined in the type section.

Correlations have been made with the Adelaidean System, but detailed mapping is required before any except broad correlations are possible No tillite has been found, but the basal Heavytree Quartzite has been suggested as the equivalent of the Sturtian tillite. Perhaps a more logical correlation would be with the Oorabra Arkose in the Mopunga Group. In any case, it certainly appears that the Upper Proterozoic sediments of the Amadeus Trough are equivalent to all or part of the Marinoan and that sedimentation in the trough only began in Upper Adelaidean time. The Sub-Cambrian is probably represented, but detailed sections have yet to be established.

Nullagine Area (Area 9)

The occurrence of Upper Proterozoic rocks at Nullagine in the Pilbara district has been referred to earlier in this paper. These rocks were first described by Gibb Maitland (1949), who named part of the sequence around Nullagine as the Nullagine Formation, but the sequence has never been mapped in detail nor has the stratigraphical succession been established.

At Nullagine, the sequence starts with a basal conglomerate overlain by sandstone and grits with interbedded lavas and tuffs. Maitland and Montgomery (1924) mention that lavas occur close to the base of the sequence. Other sections show interbedded acid, intermediate, and basic lavas and Casey reports gently folded sandstone intruded by porphyry. Dolomite, limestone and shale are dominant in other sections and in places are covered by lavas which apparently rest on the erosional surface of the underlying sediments.

The basal conglomerate has caused much speculation as to whether it is in part tillite or glacial outwash; David and Browne (1950) provide a summary of the data available. Certainly some outcrops, particularly one outlier at Rooney's Patch, resemble a tillite, but it is very possible that the observers are confusing two entirely separate formations. Casey (unpub.) has observed widely scattered occurrences of tillite in the general Pilbara area which are remnants of the Permian glacigene sediments, and Rooney's Patch could well be one of these. The matter is important because if the basal conglomerate is periglacial, the Nullagine sequence must be regarded as Upper Adelaidean, but if not, it would be more logical to correlate basal sequences containing lavas and porphyries with the Lower Adelaidean.

Dolomite, sandstone, and shale successions appear very widespread and, particularly where the uneven surface is covered by basic lavas, resemble sections in the Victoria River area (Area 3a) or in southern Arnhem Land, (Area 4), where Sub-Cambrian strata are covered by Lower Cambrian volcanics. No fossiliferous Cambrian rocks have been recognized in the Pilbara area. The writer is of the opinion that both Lower and Upper Adelaidean are represented in this district, but only field work can provide definite information on this point.

CONCLUSIONS

Although Upper Proterozoic successions in northern Australia show many breaks and are isolated one from another, there appear to be sufficient data available to correlate many of them with the Adelaidean System. Despite the present problem of the Sub-Cambrian, the writer considers that the term "Adelaidean System" should now be formally extended to Upper Proterozoic successions in northern Australia. A formal adoption of the Sturtian and Marinoan Series may eventually be possible in some areas, but the immediate need for sub-division in northern Australia can conveniently be met by following Browne (editor of David, 1950) in the use of Upper and Lower Adelaidean. The break between Upper and Lower Adelaidean in northern Australia shows, in many places, as a marked orogeny which is apparently represented in the Adelaide geosyncline by movements towards the end of Torrensian time.

At present the Adelaide geosyncline provides the only Australian sequence in which the lower boundary of the Cambrian can be fixed. This boundary can be tied down with confidence to one formation—the Pound Sandstone—but within these narrow limits there arises the familiar controversy.

Those who would restrict Lower Cambrian to the lowest formation in which are found faunas recognized as diagnostic in type sections in American and Europe, place the boundary at the top of the Pound

Sandstone, and those who follow a more elastic definition of Lower Cambrian, place the boundary at the bottom of the Sandstone. The differences between these two interpretations are not so striking in the Adelaide geosyncline as they are in northern Australia because in northern Australia, rocks carrying fossils similar to those found in the Pound Sandstone cover very wide areas, whereas strata carrying diagnostic Lower Cambrian fossils are very restricted. Hence, the placing of these older rocks in the Cambrian markedly affects the timing of major events in northern Australia.

The beds concerned in northern Australia, mainly sandstone, dolomite and shale, despite search, have yielded only *Collenia* and jellyfish and no fossils clearly of Palaeozoic age; they are, therefore, regarded as Sub-Cambrian.

These rocks were deposited in a widely transgressive sea which completed the evolution of the Precambrian shield. Lower Cambrian in northern Australia was a time of emergence with restricted sedimentation, culminating in gradual submergence and outpouring of plateau basalts which were, in turn, followed by the first great transgression of the Shield in Middle Cambrian time.

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CAMBRIAN PALAEOGEOGRAPHY OF AUSTRALIA

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ABSTRACT

The Cambrian palaeogeography of Australia, the history of land and sea, tectonic events, lithology, bathymetric conditions, climate, hydrography, and provincial relationships of Australian Cambrian faunas, are discussed. Distribution of land and sea is illustrated on seven maps representing eight different stages in the development. The Lower Cambrian palaeogeography as presented here is speculative because of scarcity of evidence. The Middle Cambrian history is presented on five maps (six stages) illustrating significant phases related to agnostid zones. Upper Cambrian is represented on one map together with the Ordovician, because the sequences involved are not yet stratigraphically and geographically interpreted, and single events and their dates are not discernible. In Lower Cambrian time an intracontinental sea across the continent is postulated. In the first half of the Middle Cambrian an intercontinental meridional sea existed, separated from an eastern sea by a meridional divide which acted as a faunal barrier. About the time of *Ptychagnostus gibbus* South Australia was folded and a general regression prevailed in northern Australia west of the Meridional Divide; east of the Divide the sea persisted. In central Australia sedimentation continued, perhaps in temporarily closed basins. Towards the end of the Middle Cambrian and in the Upper Cambrian the meridional trend of sea and land became obsolete and was replaced by a longitudinal trend, which also prevailed in the Ordovician until the folding of the MacDonnell Ranges. The lithology suggests shallow water, and the existence of a siliceous lithological province in epicontinental northern Australia is evident. Temperatures were cool, and evidence for seasonal ice is present. Glacial deposits of possible Middle Cambrian age are recorded in Tasmania. Volcanic activity (plateau basalts) is recorded in the Lower

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Cambrian in the north. Submarine volcanic activity was intense in Tasmania and Victoria in the Middle and Upper Cambrian; intrusive activity and metamorphism occurred during the early Middle Cambrian orogeny in South Australia. Some folding occurred in Tasmania at the end of the Cambrian.

The palaeozoogeographic aspect of the Australian Cambrian faunas varies according to the region and the time. The faunas west of the Meridional Divide were Pacific and Oriental, while east of the Divide a Pacific character was evident at the beginning, but was later replaced by Acado-Baltic faunas, which culminated in the possibly cool-water *Centropleura*-fauna of the Selwyn Range. In the same Range, the Upper Cambrian starts with a Pacific *Cedaria*-fauna subsequently replaced by Acado-Baltic assemblages. Endemic forms are common at all stages of the palaeogeographical history of the Cambrian in Australia.

The faunal history of the Australian Cambrian demonstrates that provincial isolation of faunas was non-existent, except for the "*Limen Caledonicum*" in the Atlantic sector of the Northern Hemisphere.

Geotectonically, in Cambrian time the existence of the Western Australian Shield became apparent. Marine deposition started in eastern Australia early in the Middle Cambrian, as is evident in Tasmania. The Meridional Divide may be a cordillera similar to the Caledonian Barrier. Other barriers may have existed, but their detection depends on palaeozoogeography. The barriers may be the result of mechanics of the Precambrian crust that are not yet fully recognized.

PREVIOUS INTERPRETATIONS COMPARED WITH PRESENT CONCEPTS

The Cambrian palaeogeography of Australia has been discussed by Whitehouse (1936), Kobayashi (1942), Kölbel (1945), and Browne (1950; 1953). Although each author has a different approach, they have all encountered the same limitation: the subdivision of the Australian Cambrian, and the geographical distribution of the subdivisions, were insufficiently known; consequently, the Cambrian of Australia had to be treated as a single unit (System) and the course of Cambrian events could not be presented in detail.

Whitehouse's map shows the Cambrian seas restricted to a minimum of known geographical occurrences. Accordingly, a meridional sea is shown to extend from South Australia into the Northern Territory, where it swings towards the Timor Sea. A separate Victorian and Tasmanian Gulf is postulated and the Tasman Geosyncline is shown along the east coast, although Cambrian rocks are not indicated here.

Kobayashi follows Whitehouse in the interpretation of the geographical limits of the Cambrian deposits of Australia.

Kölbel's conjecture is geotectonic; the western half of Australia is the stable shield—with the embayment of the MacDonnell Ranges in the centre—and the whole eastern half of the continent is sea. This is in accordance with the doctrine of the growth of the continent by tectonic accretion in the east. Kölbel's interpretation is very different in principle from the others: it shows sea over the whole of Queensland and New South Wales, whereas Whitehouse and Browne regard it as land.

Browne's interpretation is essentially the same as that of Whitehouse, except that the Tasman Geosyncline is connected with the Victorian Gulf, Tasmania, and South Australia, and the greater part of the Western Australian Shield is also submerged. The palaeogeography of the Ordovician in Browne (1950; 1953) practically coincides with that suggested in the present paper for Upper Cambrian and Ordovician.

The maps here presented show a near-meridional sea. It has already been indicated by Whitehouse, but with the distinction that it is here dated as Lower Cambrian and early Middle Cambrian. A coincidence with Kölbel's concept is also evident in that Queensland and New South Wales are shown as sea and not land during Cambrian time. The present maps, however, are not an adaption from Kölbel, but an independent deduction, based on some geological and palaeontological evidence.

The paramount feature of Cambrian palaeogeography in the present interpretation is the early Middle Cambrian Meridional Divide between the sea in the east and the intracontinental sea in the west. The presence of a divide or barrier is necessitated by the faunal differences between northwestern Queensland and the Northern Territory; moreover, its shores are actually observable in both regions. The backbone of the Divide in Cambrian time was a consolidated belt of basement rocks. Its position east of the shield and its separation from the shield in Cambrian time are not quite compatible with the accretion doctrine of Kölbel's interpretation; they are, however, in accordance with Browne's (1953) theory of meridional geanticlines in the Palaeozoic history of eastern Australia.

The palaeogeography of Australia, as presented here, is based on evidence presented in the papers for the Australian part of this symposium. However, the problem of Cambrian rocks in New South Wales has not been treated in a separate paper in the Symposium and is therefore discussed below.

PALAEOGEOGRAPHICAL AND GEOTECTONIC TERMINOLOGY

Some Australian Cambrian palaeogeographical and geotectonic units referred to in the text are explained below; their position is shown on map 2. Some of the units have already been recognized by Cotton (1930), Andrews (1938), Hills (1946), Browne (1950), Noakes (1953), and Fairbridge (1953), and are common knowledge to Australian geologists. In the following explanations, however, the terminology has been modified to conform with changing palaeogeographical aspects during Cambrian time.

PALAEOGEOGRAPHICAL UNITS

B. *Barkly Tableland.* Barkly Tableland is the geographical name for the grass plain on the Camooweal Dolomite and adjacent Cambrian rocks. It can be regarded as the site of a stable block of Precambrian consolidation (Stuartiana, Sturtian Nucleus). It is sometimes referred to as the "Barkly Basin," but no basin structure is evident, for the Cambrian rocks form a blanket and the Camooweal Dolomite is an extended sheet. In early Middle Cambrian time it was a submerged platform.

BS. *Brisbane Schists.* The Brisbane Metamorphics (commonly known as "Brisbane schists") form a thick sequence of lower Palaeozoic rocks in the coastal region in the vicinity of the Queensland/New South Wales border; the presence of Cambrian is inferred from their position below rocks believed to be Ordovician. Geosynclinal conditions are evident (Denmead, 1928; Browne, 1950; Bryan and Jones, 1954).

C. *Carpentaria* (block, basin, nucleus, platform). Cambrian rocks are missing in the Carpentaria region, which was a platform of a low elevation in Cambrian time. Along its southwestern edge Cambrian rocks have the appearance of near-shore deposits. Its southeastern limit in Cambrian time is inferred and approximate, because no Cambrian has been recorded along this limit as yet.

CA. *Central Australia.* The MacDonnell Ranges of central Australia were in Cambrian time subsiding as a basin or basins and shield conditions were non-existent. For further explanation see "Cambrian Geology of the Northern Territory" (this Symposium) and "Flexible Belt" (below).

CG. *Cambridge Gulf.* The borderland of Western Australia and Northern Territory at the Cambridge Gulf is a region of recurrent Palaeozoic basins.

DL. *Duchess Land* (or Island). Duchess Land formed a large island in Queensland north of the Tropic of Capricorn in Middle Cambrian time. Its eastern extension is unknown. Southeastern Tasmania formed a similar land; between Duchess Land and Tasmania, other islands may have existed at one or another time during Cambrian time in Australia.

DR. *Daly River area.* The Daly River area, in which the country along the Victoria River is here included, was an extension of the platform of the Barkly Tableland (B) since Middle Cambrian time.

F. *Flexible Belt.* The structural meaning of the Flexible Belt is explained below (Geotectonic terms).

K. *"Kimberleys."* East and West Kimberley Divisions of Western Australia (Kimberley Block, Nucleus). In late Precambrian time the Kimberleys were a deep-seated platform, and in Cambrian time elevated land.

MD. *Meridional Divide.* The Meridional Divide acted as a palaeozoogeographical barrier in early Middle Cambrian time in Australia, As a barrier it is comparable with the *Limen Caledonicum* of the North Atlantic but was of smaller extent and lesser tectonic significance. (see also: P, QP, W.)

O. *Ord River.* The Ord River area contains early Middle Cambrian basins and the Elder Sandstone; the Elder Sandstone is interpreted as an extension of the Cambrian sediments of the Cambridge Gulf (CG) area.

P. *Capricorn Segment.* The Capricorn Segment is that part of the Meridional Divide (MD) seated on the "Flexible Belt" (F). It subsided at the end of the Middle Cambrian and was converted to a seaway between west and east in Upper Cambrian and Ordovician time.

Q. *Northwestern Queensland.* The Cambrian region of northwestern Queensland includes the Undilla Basin. The land or island east of the region is the "Duchess Land" (DL).

QP. *Queensland Platform.* The "Queensland Platform" of authors is concealed under Mesozoic sediments of the Great Artesian Basin. Its significance in Cambrian time is not clear; but the possibility of its being part of the Meridional Divide (MD) is inferred. Its eastern extent (as land) was limited, because a faunal interchange between northwestern Queensland (Q) and Victoria and Tasmania is evident.

SA. *South Australia.* The present South Australian mountain chains were derived from an early Palaeozoic orogeny of a late Proterozoic to early Cambrian geosyncline.

T. *Tennant Creek Island.* The Tennant Creek Island existed in the Northern Territory during *Redlichia-* and *Dinesus/Xystridura-*time; it represented, perhaps, the central part of the Stuartion Nucleus of the present Australian Shield. The outline shown on map 2 is approximate. Smaller islands existed to the east, at Alexandria, for example.

W. *Willyama Land* (or Block). The southern segment of the Meridional Divide (MD) comprises the Willyama Block. Its western edge coincides with the Shatter Belt (Hills, 1946).

W.A. *Western Australia.* Western Australia constitutes the main part of the present shield south of the "Flexible Belt" (F). In Cambrian time it was most probably already shield, and land.

GEOTECTONIC TERMS

The definitions of the geotectonic terms as given below refer to the meanings of the terms as used in the present paper. The general usage may be different and varies depending on the views of different authors. Some of the common accessories of geotectonics, as for example, *craton* and *orogen*, are omitted because the known part of the Cambrian history of Australia can be presented without them.

The term *land* means simply an area elevated above sea level and implies no structural discrimination.

A *shield* is a land consisting of consolidated basement rocks eroded to the deeper levels of the crust, with an inferred persistent tendency to uplift. The term is preferably applied to those segments of the Earth's crust that were consolidated in Precambrian time, because only for such old segments can the elapsed geological time justify the application of the characteristic "persistent uplift tendency." However, shields and parts of shields may be transformed into platforms temporarily or indefinitely.

A *platform* is a consolidated segment of the crust covered by sediments with a great unconformity at their base. The unconformity testifies that at an early stage the platform was land, and that the basement, if Precambrian, was shield.

A *block* is a consolidated segment of the crust of a certain mechanical rigidity in relation to its more flexible or mobile surroundings at any time in geological history.

A *nucleus* is a shield or platform that acts as a centre of continental accretion. It is a nucleus in relation to the surrounding subsequent accretes, but may form together with the accretes a shield, a platform, a craton, etc.

The *Flexible Belt* is an historical structure within the present Australian Shield. It is situated between the Kimberley Block (K) and the Western Australian Block (WA), and trends east over the MacDonnell Ranges to cross at "P" the Cambrian Meridional Divide. It consists essentially of "post-nuclear" accretes of Precambrian age and includes in its centre the Arunta Block, the rocks of which are believed to be of Archaeozoic age. The belt was flexible in late Proterozoic, Cambrian, and Ordovician times, and was even folded after the Ordovician. According to Hills (1946) this Flexible Belt exercised its "parental control" even in the Mesozoic. Hills designates this internuclear belt as the "Central Geosyncline," a term that refers to the Precambrian history of the belt. The description "Flexible Belt," as applied here, refers to the late Precambrian, Cambrian, and Ordovician, when the Precambrian geosynclinal rocks had been folded, metamorphosed, accreted, deeply eroded, and subsequently inundated.

THE PROBLEM OF CAMBRIAN IN NEW SOUTH WALES

No Cambrian fossils have been found as yet in the folded rocks of New South Wales and eastern Queensland. However, the presence of marine Cambrian deposits in considerable thickness in the Tasman Geosyncline of Australia is probable on circumstantial evidence.

The "Brisbane schists," which cross the border of Queensland and New South Wales, (Denmead, 1928; Bryan and Jones, 1945) have a total of thickness of about ten miles, and are in part older than Ordovician. The lowest visible unit of the "Brisbane schists," the "Greenstone Series," is generally believed to be Cambrian from its position in the sequence and by lithological similarity to the Cambrian sequence of Victoria. Bryan and Jones (1954) consider the Brisbane Metamorphics as a whole to be older than Devonian and to be divided into two parts by an intervening orogeny. The authors reserve any particular age correlation for the rocks of this "small part of the great Tasman Geosyncline."

I. A. Brown (1933) has described as Cambrian (?) a sequence of metamorphosed sediments from the South Coast of New South Wales. These sediments later became known as the Wagonga Series (W. R. Browne, 1950). The series is older than Upper Ordovician and lithologically is "remarkably similar to those of certain types of Cambrian rocks in Victoria"; "there are also resemblances to portions of the Brisbane schist series of Queensland," and "also to the pre-Silurian rocks of Cobar, Canbelego and possibly the Forbes-Parkes districts" of New South Wales (Brown, 1933). Brown concludes that the source of the Wagonga sediments is in the east.

The most western of the named occurrences is Cobar. The sequence at Cobar is obscured structurally, but the presence of Cambrian rocks seems probable. Öpik (Iten and Carter, 1951) identified in the Packham Formation of the Cobar area the cystid *Heliocrinites* known from Europe and Burma; it indicates a Middle to Upper Ordovician age. Below this probable Ordovician two other sedimentary groups of rocks occur: the Cobar Group of slate, arenite, and tuffaceous rocks; and the Canbelego Group (at the base) of arenite, slate, schist, phyllite, and chert.

Iten (1952) has interpreted the stratigraphy of the Cobar sequence differently: he takes for granted the Benambran (Upper Ordovician) age of the unconformity between the Canbelego Group (basement) and the Cobar Group and neglects the palaeontological evidence for the Ordovician age of the Packham Formation, which is stratigraphically well above the unconformity. According to Iten, the Packham Formation is somewhere in the Middle Silurian, and only the Canbelego Group is "pre-Silurian." The present writer considers that the unconformity in question is not "Benambran," but considerably older, that the Cobar Group above the unconformity may contain Cambrian, and that the Canbelego Group may even be the Precambrian basement. It may be also mentioned that the fossiliferous Upper Silurian and Devonian rocks of Cobar are very similar to the corresponding sequences of Victoria in the south. Consequently, a belt of lower Palaeozoic rocks, including Cambrian, extends from Victoria into New South Wales and the confinement of the Cambrian to a "Victorian Gulf" is improbable or, at least, disputable.

According to Öpik (1954a; 1955), in southern New South Wales, in the Canberra region and in the Australian Alps, the lowest fossiliferous deposits are dated as Lower Ordovician (with *Phyllograptus, Pterograptus, Isograptus,* and *Trigonograptus).* Below this fauna a continuous great thickness of arenite and slate is present, probably separated from the Ordovician by a break. All these rocks have been traditionally dated as Ordovician, or Upper Ordovician, from the occurrence of scattered infolds of Ordovician black shale. In reality, the greater part of this sequence is pre-Ordovician, and can be inferred as Cambrian.

The nearest occurrence of fossiliferous Cambrian rocks is at Dolodrook in eastern Victoria, which has been interpreted by previous authors as the eastern limit of the "Victorian Gulf." The Cambrian at Dolodrook occurs in the core of an anticline; it is marine and may contain a break *(vide* Browne, 1950), but no indication of an eastern shoreline is present.

According to Harris and Thomas (1954) the occurrence of the Cambrian at Dolodrook is structurally complicated and includes basic volcanic rocks (diabase), tuff, and porphyry. Fossils occur in the limestone and are dated as Upper Cambrian with *Aphelaspis* (at one locality) and upper Middle Cambrian at Dolodrook River itself. The list contains *Pseudagnostus, Bynumia, Eugonocare,* and *Crepicephalus etheridgei* (Chapman), which certainly indicate an Upper Cambrian age. In favour of a Middle Cambrian age is the occurrence of *Triplagnostus australiensis* (Chapman) and *Hypagnostus* spp. The present writer interprets, however, *Agnostus australiensis* Chapman (1911, Pl. LVIII, fig. 9) as an *Acmarhachis* Resser. The occurrence of *Eugonocare* and

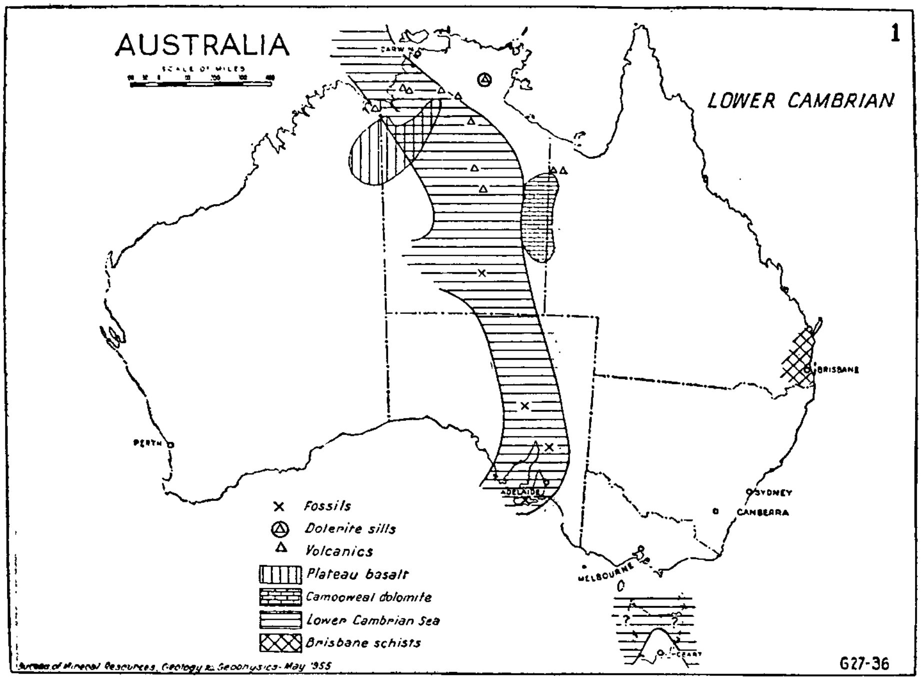
Acmarhachis may indicate a correlation with the fauna of the main part of the O'Hara Shale of northwest Queensland (Selwyn Range), which follows the *Cedaria*-fauna.

No evidence has yet been produced that in New South Wales the Ordovician rests on a Precambrian basement, and the absence of Cambrian rocks cannot be demonstrated. The same applies for eastern Queensland, where, of course, the Mesozoic sediments of the Great Artesian Basin and younger Palaeozoic rocks conceal the deeper levels of the crust. Rather than believe that the Ordovician rests on the Precambrian basement, the author prefers to regard the whole of eastern Australia as an area of marine sedimentation since the Cambrian time, which conjecture is also in conformity with the accretion doctrine; the "Greater Tasman Geosyncline" is still the youngest accrete to the continent.

It cannot be demonstrated, however, that submergence was general at any time in the lower Palaeozoic, including Cambrian; the meridional geanticlines of Browne (1950; 1953) must be taken into consideration. In the Duchess area of Queensland, an island, or a "land," is evident in the Cambrian, and similar "lands" may have existed within the "Greater Tasman Geosyncline"; however, eastern Australia must be regarded generally as an area of marine deposition in the Cambrian Period, beginning with the Middle Cambrian, which assumption, moreover, facilitates the understanding of faunal similarities between northwestern Queensland, Victoria, and Tasmania, and simplifies the presentation of the palaeogeography as well. In Tasmania the sedimentation started in the time of *Ptychagnostus gibbus*, which suggests widespread terrestrial conditions in Lower Cambrian time in eastern Australia.

LOWER CAMBRIAN (MAP 1)

The palaeogeography of Australia in Lower Cambrian time, as presented on map 1, is conjectural. Fossil evidence is known only in South Australia (see Daily, Cambrian Geology of South Australia, this Symposium) and central Australia, as discussed in the paper "Cambrian Geology of the Northern Territory." Beds with *Bathynotus* (Northern Territory, Sandover River), *Archaeocyathus* (Ranken limestone, Northern Territory), and *Lancastria* (Beetle Creek, Queensland) are regarded as Middle Cambrian in spite of the presence of the named



forms which in the Appalachian region occur already in Lower Cambrian. The *Bathynotus* is not dated by other fossils. If it represents a residual of a Lower Cambrian sequence no change in the map 1 is necessary, because the locality is covered by the Lower Cambrian sea. The South Australian/central Australian intracontinental sea is evident; the possibility of its extension to the west-northwest, along the "Flexible Belt," is indicated; and a connexion with the Timor Sea is suggested.

A continuity of deposition from late Precambrian into Lower Cambrian is evident in South Australia but the geology of central Australia needs further study. Eastern Australia is shown as land for lack of evidence to the contrary. In northwestern Queensland and in Tasmania Lower Cambrian deposits are absent. However, in Tasmania the history is not quite clear. The Middle Cambrian rests there unconformably on an older sequence (Carbine Group), which may be Lower Cambrian; on the other hand Lower Cambrian may have been present above the unconformity, and eroded before the Middle Cambrian *Gibbus*-time.

A special feature is the Camooweal Dolomite, which is shown as a deposit earlier than Lower Cambrian. It can be interpreted, however, as a Lower Cambrian sediment, precipitated in a great internal bay which was separated from the sea to the west by bars with narrow passages across the bars, perhaps in the south.

Most probably about Lower Cambrian time the Kimberley Platform was uplifted, and in Western Australia the shield became apparent after the erosion of its late Proterozoic sedimentary cover. Carpentaria, including Arnhem Land, already above sea level in the Lower Cambrian, retained its moderately folded cover of late Proterozoic sediments, which were intruded by diabase sills. Evidently there was no shield at that time, and the platform had just attained a rigidity which was not apparent at the end of the Proterozoic. The stabilization in the Lower Cambrian of northern Australia was accompanied by effusion of plateau basalt.

At the end of the Lower Cambrian the sea temporarily receded from northern Australia. It persisted only in South Australia and may have reached the Tropic of Capricorn.

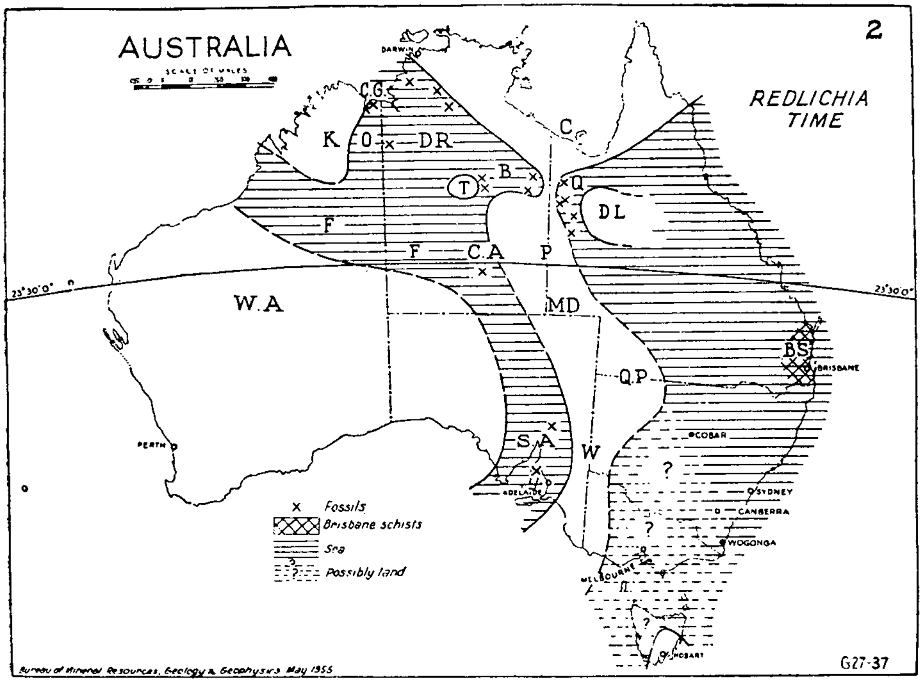
MIDDLE CAMBRIAN

The Middle Cambrian rests in epicontinental northern Australia on Precambrian rocks. In central Australia, as in South Australia, continuity of sedimentation from Lower to Middle Cambrian is probable. Thus, the Middle Cambrian rocks mark a widespread inundation of the continent.

REDLICHIA-TIME (MAP 2)

The term "*Redlichia*-time" in the present paper refers to the northern Australian faunas of the Negri Group, of the Gum Ridge Formation (Northern Territory), and the *Redlichia*-fauna of northwestern Queensland, and to the fauna of the Wirrealpa Limestone of South Australia. These faunas are all of a lower Middle Cambrian age. The South Australian fauna from Kangaroo Island, which also contains *Redlichia*, is Lower Cambrian.

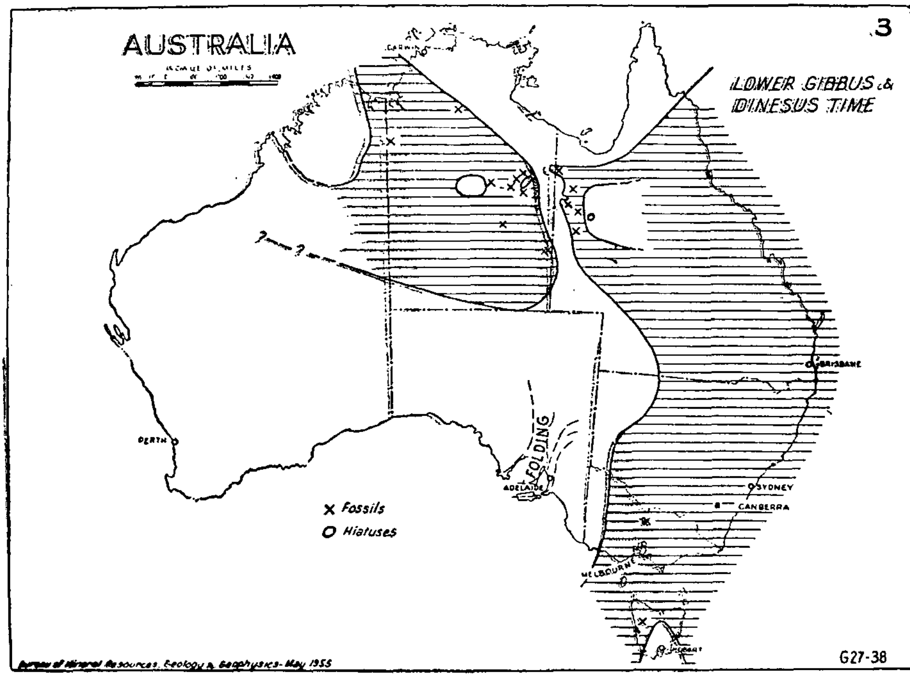
The initial Middle Cambrian inundation is nearly simultaneous in the Northern Territory and Queensland, as is seen from the *Redlichia*



fauna of the basal beds, followed above by *Xystridura*-oryctocephalid assemblages in both regions. The first ingression of the sea probably took place on the Ord River. The *Redlichia*-faunas of Queensland and the Northern Territory are specifically different, and were therefore separated by the Meridional Divide. In northwestern Queensland, the Undilla Basin, between the Meridional Divide and Duchess Land, was initiated in the *Redlichia*-time.

How far south the sea reached in eastern Australia is not known. In Tasmania, in the Judith "Slate and Tuff" (Elliston, 1954), a fossil band with a fauna of the *Ptychagnostus gibbus* Zone is conformably underlain by an unfossiliferous sequence which may represent the *Redlichia*-time. However, such an interpretation is questionable, as indicated on map 2, because the sedimentation in Tasmania seems to have resulted from the South Australian orogeny, in which the Middle Cambrian *Redlichia* beds (Wirrealpa Limestone) are involved. Therefore, the other possibility, that the present Queensland Platform was a land extending south into Victoria and Tasmania, is preferable.

The Northern Territory (Barkly Tableland/Daly River Area) was a shallow sea with islands and platform (shelf), and the Kimberley area was platform and land, with a thick cover of late Precambrian sediments. In Western Australia shield conditions prevailed. The Flexible Belt may have been inundated, but the region is unexplored and no evidence is available as yet. The South Australian Geosyncline was nearly filled up with sediments, but was still submerged and connected by a seaway with northern Australia.



XYSTRIDURA/DINESUS (LOWER *GIBBUS*)-TIME AND SOUTH AUSTRALIAN OROGENY (MAP 3)

It can be assumed that in South Australia marine sedimentation ceased in *Gibbus*-time because fossils younger than *Redliciha*-fauna are unknown.

In the Northern Territory the rocks of *Xystridura/Dinesus*-time are conformable with the underlying *Redlichia* beds wherever the two sequences occur together. However, in the Northern Territory the sea is transgressive to the east and southeast, inundating the previously exposed Precambrian basement. A similar transgression occurred in northwestern Queensland, in the Border Waterhole area, but its extent was small. As a consequence of the transgression, the Meridional Divide became quite narrow, but persisted as a practically unsurmountable palaeozoogeographical barrier. Its elevation was low, and it may have been crossed by temporary shallow seaways—at its northern end (Border Waterhole) and on the Tropic of Capricorn (Flexible Belt), for example—though no intermingling of western and eastern faunas can be detected.

The distance of 60 miles between the isolated faunas in northern Australia must be compared with the 1500 miles between northwestern Queensland and Tasmania. The fauna of the Judith formation and, even more, the Victorian fauna with *Dinesus ida* and *Kootenia* can be correlated with ease with the corresponding Beetle Creek and lower *Gibbus* faunas of northwestern Queensland. A communication between the two distant regions along the eastern coast of the Meridional Divide is, therefore, obvious. Eastern Australia was sea, perhaps with several islands, of which Duchess Land is an example.

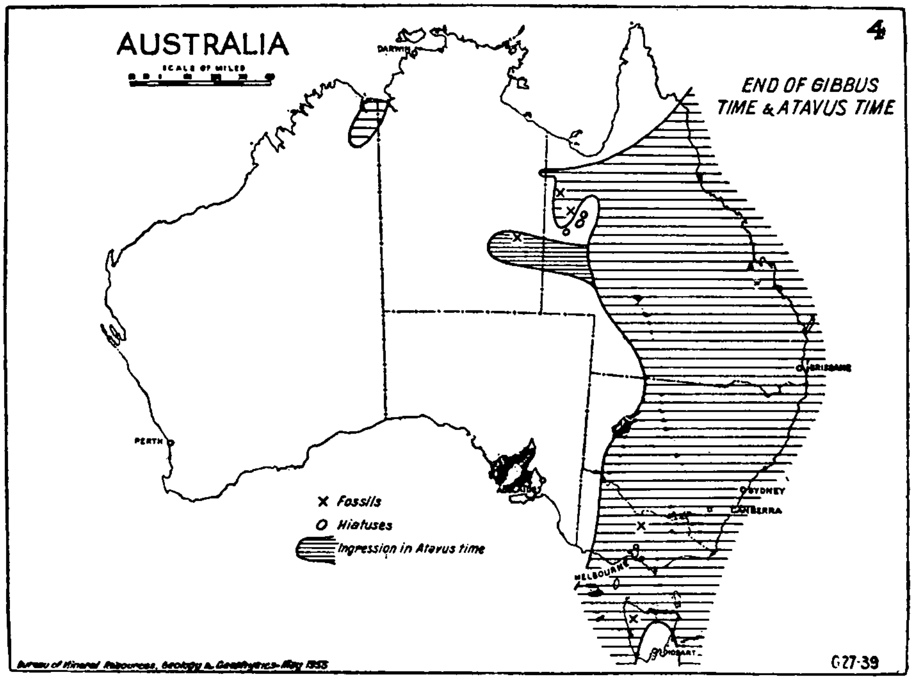
In Tasmania and Victoria, and possibly Cobar, the deposition of a thick sequence of clastic and volcanic rocks was initiated, signifying an important tectonic phase, the South Australian orogeny. In Tasmania, the Cambrian sequence, beginning with the *Ptychagnostus gibbus* Zone, contains about 9000 feet of Middle Cambrian and about 2500 feet of Upper Cambrian sediments. At the same *(Gibbus)* time the sedimentation in the Adelaidean geosyncline ended. The suggestion is that the regression was accompanied in the Adelaidean geosyncline by folding and uplift and by a regional subsidence and transgression in Tasmania, and, perhaps, generally in eastern Australia.

In this connexion, the Kanmantoo sequence of South Australia (Sprigg and Campana, 1953) may be of similar origin, and of Middle Cambrian age. It was laid down, seemingly, in an intramontane depression. According to Sprigg and Campana, the sedimentation of the Kanmantoo sequence may have continued into the Ordovician, which is not improbable, of course. However, the Kanmantoo belt is folded and metamorphosed by the same orogenic event as that which deformed the rest of the Adelaidean. The flysch character of the Kanmantoo rocks may indicate a synorogenic origin. The assumption that the post-Ordovician orogeny of central Australia implies a similar age for the South Australian orogeny is not substantiated. They are very different in style: igneous activity is completely absent in central Australia, but is prominent in South Australia. The age of the orogeny in the Adelaidean geosyncline is otherwise not evident because of lack of any fossiliferous cover from which reasonably narrow time limits can be inferred. According to Campana (1955), the stratigraphic evidence as preserved in South Australia gives the age of the folding as pre-Permian.

According to Browne (1950), the age of the folding in South Australia is Tyennan, which is described as an orogenic event between the Middle and Upper Cambrian in Tasmania. According to Carey and Banks (1954), the Tyennan Orogeny refers to an unconformity between basal Ordovician and Precambrian, in an area where Cambrian rocks are missing altogether. The main Tyennan event must be dated as Upper Cambrian to lowermost Ordovician and is essentially of Tasmanian significance.

The complete history of the South Australian orogeny is unknown. It is assumed here that it started about the *Gibbus*-time early in the Middle Cambrian, but the duration of the folding is unknown. According to Daily (this Symposium) in the Lake Frome region above the Wirrealpa Limestone (lower Middle Cambrian with *Redlichia)* redbeds formations (the Lake Frome Group) totalling 8500 feet occur which are involved in the orogeny. The Middle Cambrian age of these redbeds is inferred from their position above the *Redlichia* fauna of Wirrealpa. The great thickness of the Lake Frome Group may not be interpreted as an indication of long duration of deposition, because comparable redbeds, 3000 feet thick, separate the Lower Cambrian and lower Middle Cambrian deposits of the same region and represent only the "passage beds" between the two series. The great thickness of the Lake Frome redbeds indicates tectonic uplift and the initiation of the orogeny within South Australia. Evidently the redbeds are synorogenic and became involved in the folding subsequently themselves. The marine palaeogeography of northern Australia indicates regression and uplift ranging from the *Gibbus*-time to the end of *Punctuosus*-time and this time range may be interpreted as the interval of the South Australian orogenic events comprising the deposition of the Lake Frome redbeds as well.

The folding of the Adelaidean geosyncline is much older than the Tyennan epoch. The South Australian orogeny was a major event of plication, intrusion, and metamorphism, in consequence of which the region became an accrete to the Western Australian Shield, which acted in the present case as a nucleus. Moreover, the folding of the Adelaidean geosyncline united the southern portion of the Meridional Divide with the shield in the west, and created the necessary "hinterland" for the next folding in the MacDonnell Ranges. The unification however, did not transform the South Australian chains into a shield; a consistent residual instability persisted until the Tertiary (Campana, 1955).



THE END OF *GIBBUS*-TIME, AND THE *ATAVUS*-TIME (MAP 4)

As a consequence of the orogenic events in South Australia the lower Middle Cambrian Meridional Divide disappeared about the end of *Gibbus* (middle Middle Cambrian)-time as a morphological feature.

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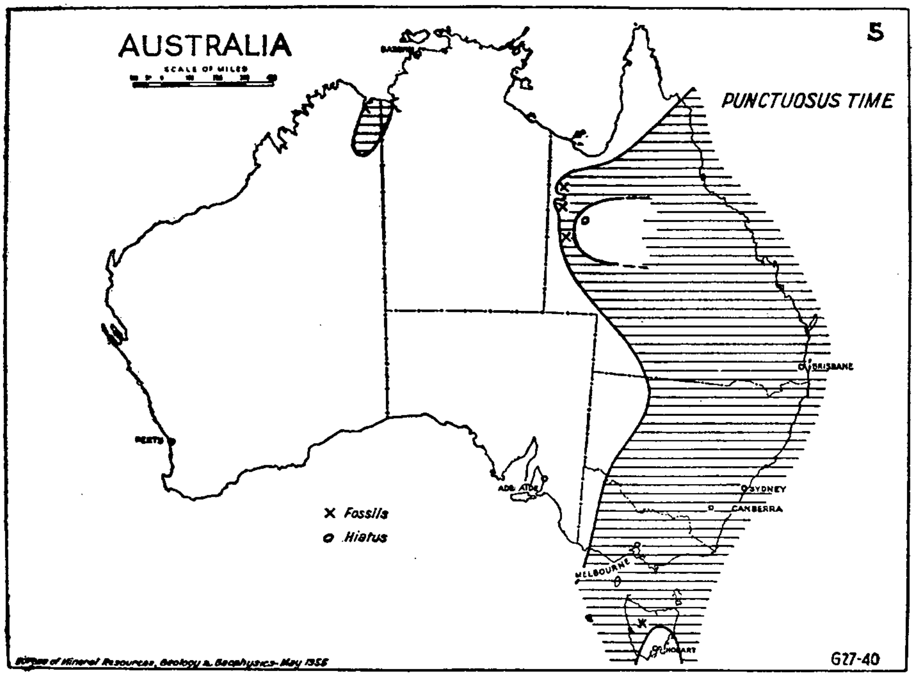
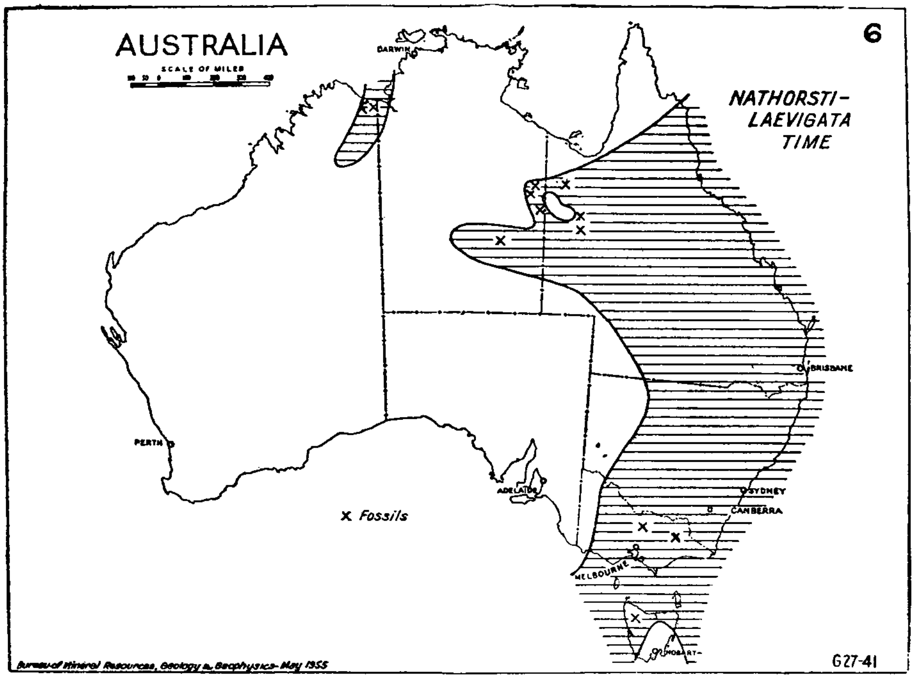
The disappearance was caused not only by a general uplift of the Northern Territory and a regression west of the Divide, but by a change in the structural setting: the meridional trends of sea and land, which had dominated the palaeogeography, disappeared, and the Flexible Belt along the Tropic of Capricorn was about to be submerged. Sea is evident in eastern Australia and land prevails in the west. Subsequently, in the time of *Ptychagnostus atavus* an inlet extended from northwestern Queensland into central Australia for a time.



PTYCHAGNOSTUS PUNCTUOSUS-TIME (MAP 5)

In *Punctuosus*-time the sea reached a minimum as seen from map 5. It is, however, possible that in central Australia sedimentation was continuous in depressions not connected with the sea. This may explain the absence of middle Middle Cambrian fossils in the seemingly uninterrupted sequence of the MacDonnell Ranges.

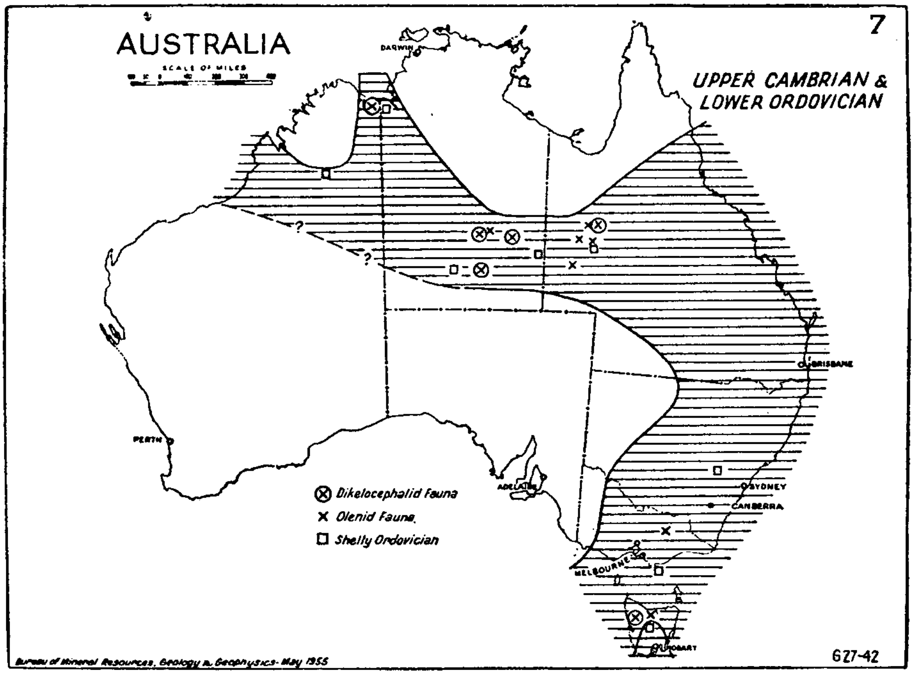


THE END OF MIDDLE CAMBRIAN (MAP 6)

At the end of the Middle Cambrian, in the time of *Ptychagnostus nathorsti* and *Leiopyge laevigata*, a transgression proceeded along the Tropic of Capricorn and toward the Cambridge Gulf area, indicating a subsidence along the Flexible Belt. A sandstone with *Asthenopsis* and *Crepicephalina*, of the *Leiopyge* age, occurs at Huckitta and is described in the "Cambrian Geology of the Huckitta-Marqua area" (this Symposium). Eastern Australia is sea, and similar faunas are present in northwestern Queensland, Victoria, and Tasmania *(Amphoton, Nepea, Leiopyge laevigata)*. In northwestern Queensland the Duchess Island was submerged, but another, smaller, island arose west of Mt. Isa.

UPPER CAMBRIAN AND ORDOVICIAN (MAP 7)

In Upper Cambrian time the Flexible Belt was completely submerged and was surrounded by three lands: the Kimberley Platform,



Carpentaria, and the united Western Australian Shield and South Australian land.

The Upper Cambrian fauna, which arrived from the northwest, is "Pacific" and its dikelocephalids reached central Australia. In the east, however, the traditional Acado-Baltic fauna persists, and evidence of a complete intermingling of the two provincial populations is slight. However, dikelocephalids are found as far east as the Queensland/ Northern Territory border—so that isolation by the complete restoration of Capricorn Segment of the Meridional Divide is doubtful, except for a chain of disconnected bars possibly on the critical 138th meridian acting as obstacles to currents.

The Ordovician sea coincides with the limits of the Upper Cambrian inundation. The Ordovician shelly fauna has everywhere a similar provincial character in Australia.

Map 7 is a diagram of the known Upper Cambrian and shelly Ordovician occurrences taken together, because a discrimination of stages and their distribution is not yet possible. In central Australia, transgressions and regressions probably occurred within the area shown as sea on the map.

LITHOLOGY OF CAMBRIAN SEDIMENTS AND BATHYMETRIC CONDITIONS

No comprehensive study on the lithology of Australian Cambrian sediments has been made, and therefore only a brief note can be given on the subject. In the following discussion geosynclines and basins are characterized as regions of intensive sedimentation, as distinct from epicontinental regions, where the sedimentation produced thin but geographically extensive formations. This sub-division is applied in the paper "Cambrian Geology of the Northern Territory" (this Symposium).

REGIONS OF INTENSIVE SEDIMENTATION

The regions of intensive sedimentation are South Australia and central Australia, and the Victorian and Tasmanian geosyncline. In South Australia and in central Australia shale, arenite, limestone, and dolomite were deposited and the lithology there can be regarded as normal. The arenite formations vary between quartzose and greywacke types. In central Australia, in Upper Cambrian, quartzose sandstone with glauconite prevails.

In the southeast, however, in Tasmania and in Victoria, limestone and dolomite are absent, and this deficiency continues in the Ordovician in Victoria. Volcanic material is prominent in the Cambrian sequence. The volcanics are basic and submarine: hence lime was not extracted from them by weathering and limestone could not be produced. In Tasmania, Elliston (1954) describes 13 formations constituting the Cambrian Dundas Group, of which the two uppermost formations are Upper Cambrian. Seven of these formations are volcanic, or contain volcanic material (tuff); volcanic rocks constitute more than half of the total Cambrian sequence of 11,500 feet at Dundas. The rest of the Dundas Group is predominantly lutitic—an indication of a fair distance of the Dundas region from the source land of the erosional detritus. Some of the tuffs may be greywackes; but even then arenites are in a minority, in contrast to the prominence of conglomerates in several horizons. According to Scott (1954), "most of these tuffs are not true pyroclastics, but sedimentary rocks composed of a great deal of transported igneous material." In this case these rocks are arenites produced by redistribution of local volcanic material. The described conditions may indicate the presence of volcanic islands in the Cambrian sea in southeastern Australia.

According to Carey and Banks (1954), within the Cambrian Dundas sequence six orogenic pulses are reflected by recurrent rudites. This may indicate a prolonged unrest initiated by the South Australian orogeny, or an unrest in Tasmania itself, which is already reflected in the volcanic activity. The interpretations are, however, speculative, because the Cambrian of Tasmania is only a border fragment of a larger region and very little is known about the Cambrian tectonic history in Victoria and New South Wales.

The bathymetric conditions are not quite clear everywhere. In central Australia the water was shallow, as suggested in the article on Cambrian Geology of the Northern Territory. In South Australia Sprigg (1952) suggests a continental terrace, maximum deposition, and shallow water along the western margin of the geosyncline and a deep along the eastern margin, remote from the source of the detritus.

In Victoria the conditions are interpreted by Hills and Thomas (1954): "contributions of terrigenous detritus to the marine trough were negligible"; black mud deposits are common, and may have been formed on the bottom of submarine closed basins; "such basins could have been formed by the irregular piling up of submarine volcanic products"; "Volcanic rocks provide an adequate source both for the manganese and for the silica to form bedded cherts, and the association of limestone (only at Dolodrook, A. A. Ö.) and well-preserved shelly fossils with the tuffs preclude the assumption of deep water sedimentation"; and, finally, "although many of the features of the Cambrian facies are such as have been taken to indicate bathyal or even abyssal deposition in other geosynclines, there is nothing to indicate deep water sedimentation in Victoria." This interpretation is also applicable to the Cambrian deposits of Tasmania.

In Tasmania, according to Elliston (1954), a Middle Cambrian conglomerate (Red Lead Conglomerate and Tuff) may be of glacial origin and correspond to the Zeehan Glacials, generally believed to be of late Precambrian age. At the locality mentioned by Elliston (at the Montana Western Mine), the Zeehan Glacials are true varves and true till, which mean land conditions and fresh water. The Red Lead Conglomerate itself, however, contains no direct evidence of glacial or periglacial conditions, but the possibility of a fluvioglacial deposit, conformably interbedded in a marine sequence, may be considered. To conclude, the Zeehan Glacials rest in a sequence of volcanic rocks and sediments, which are lithologically comparable with a part of the fossiliferous Cambrian sequence; however, this correlation based on similarity of lithology is opposed by the similarity of the Zeehan Glacials to the South Australian Sturtian (late Precambrian) glacials; consequently, a final decision must be reserved. Mawson (1949) lists the Zeehan Glacials as late Precambrian in age.

The bathymetric conditions of deposition of the Cambrian in Victoria and Tasmania are of importance for the geosynclinal classification of the region. In Victoria, as cited above, the sea was shallow and the supply of terrigenous material to the marine trough was negligible, indicating a rather small and slow subsidence.

In Tasmania the Dundas sequence of 11,500 feet may be taken as the measure of subsidence during the Middle Cambrian and lower Upper Cambrian in northwestern Tasmania. This is less than half the thickness of the Lower and lower Middle Cambrian deposits of the Adelaidean geosyncline, which however contains no volcanic rocks.

The subsidence in Tasmania cannot be considered, consequently, as great or rapid. Moreover, the estimation of the subsidence in Tasmania also depends on the significance of the thickness of the sediments and of the volcanics taken separately. For simplicity, only the Middle Cambrian sequence of the Dundas group (9000 feet) is discussed (Elliston, 1954). Half of it consists of indigenous volcanic rocks. They changed their position in the crust and the volume of material piling up on the surface was compensated concurrently by subsidence of the crust layer between the surface and the magma chambers. No real subsidence in the sense of a general deepening was the result.

The remaining part of the sequence (4500 feet) comprises sediments the accommodation of which naturally indicates a real subsidence of the same magnitude. Part of these sediments (greywackes) may be re-distributed volcanic material and therefore may imply even a smaller subsidence than the above limit. The estimated figure of 4000 feet is about half the depth of the water of the present oceans distributed over the whole of the Globe and cannot be taken as evidence of a geosynclinal or eugeosynclinal "rapid and deep subsidence." The moderate thickness of the Cambrian sediments in Tasmania supplements the fact that the basement beneath the Cambrian is exposed in several places and not deeply buried under the superstructure.

REGIONS OF EXTENSIVE SEDIMENTATION

In the regions of extensive sedimentation in the epicontinental northern part of Australia, three distinct types of lithological province are present. The first is the completely arenitic Cambridge Gulf area, including the Elder Sandstone of the Ord River area. The sandstones were deposited in a shallow but subsiding basin receiving sediments from the Kimberley Platform. The conditions of sedimentation in the Cambridge Gulf area can be interpreted as a basin within the shelf.

The second type is limestone with some dolomite. The marine Cambrian of the Daly River area is mostly limestone with some organic matter; glauconite occurs along the northeastern fringe of the limestone area in the vicinity of outcrops of acid basement rocks. The Daly River limestone was deposited on a shallow shelf. Limestone is also prominent in the Ord River Region, as interbeds in recurrent shale. Shallow-water conditions for this sequence have been already inferred by Matheson and Teichert (1948). A shale at Mt. Panton contains abundant gypsum and, according to Traves (this Symposium), gypsum is also present in the Nelson Shale. The presence of gypsum may indicate temporary non-marine conditions, which may explain the absence of fossils in the shale formations of the Negri Group. The lower limestone of this group contains also chert nodules, similar to the occurrences in the Barkly Tableland and northwestern Queensland.

The Cambrian of northwestern Queensland is also calcareous, but formations of siliceous shale and visible amounts of chert bands and nodules are present in shale and limestone formations. The cherts and the shales are essentially spiculites, "felts" of sponge spicules. Lutitic and organic silica is also disseminated abundantly in the limestones. The sediments were laid down on a shelf, and even in the Undilla Basin the depth of water was at no time greater than the total thickness of the sediments. Part of the calcareous material of the Undilla Basin is derived from the Camooweal Dolomite; another part may be thalassogenic, originating from a large sea east of the northwestern Queensland Cambrian shelf. The Undilla Basin itself belongs to, and is a depression near the edge of, the epicontinental region. Similarly, the Daly River limestones and the calcareous marine interbeds of the Negri sequence may indicate proximity to an ocean with its supply of calcareous matter.

All the sediments of the Cambrian of northwestern Queensland are prominently siliceous, even the limestones, in which the insoluble siliceous component is "diluted" by thalassogenic carbonate. From this point of view, a distinctive (the third) siliceous lithological province is apparent in northwestern Queensland and is even more prominent in the Northern Territory, west of the Cambrian Meridional Divide.

The third, siliceous, lithological type is prevalent in the Barkly Tableland and on the Sandover River and covers the region of the transgression in the *Gibbus/Dinesus*-time (map 3). The Cambrian sediments here are siliceous shale and chert, with minor developments of limestone and fine-grained clean sandstone. The soft siliceous shale and chert consist essentially of sponge spicules. Tests of all fossils, formerly calcareous, are leached out or silicified, and all the oolitic limestones are also silicified. The non-oolitic portions of the Ranken limestone, which is the only known larger Cambrian limestone body in the Barkly Tableland, are partly silicified also. In the Northern Territory fossil localities are known, where all the fossils are chalcedony and the space between is visibly crystalline quartz. Of course, climatic silicification has accentuated the siliceous character of the rocks on the surface, but fresh rocks present a similar picture, as seen in the section of the Old Well on Alexandria, where hard cherts and soft siliceous shale are interbedded with soft, friable siltstone, the fossils in which are silica.

The predominance of silica on the surface in the Northern Territory has sometimes been interpreted as the result of lateritization in Tertiary times. The softer upper layers of the laterites are believed to have been removed by erosion, leaving behind the basal, siliceous and harder, portion (billy). Lateritization is actually present, but is confined to areas of outcropping argillaceous sediments, and the ubiquity of siliceous sediments has merely facilitated the formation of the silica cement of the "billy" in the laterite profile. The siliceous sedimentary material has obviously influenced the composition of the northern Australian laterites, and may be one of the reasons why they are distinct from those of southeastern Asia.

The existence of the Cambrian siliceous province can be explained, when its geographic occurrence and marine origin alone are considered, and the time of deposition is regarded as generally irrelevant. Siliceous sedimentation was present in the Barkly Tableland before and after the Cambrian. Thus, the Precambrian Camooweal Dolomite abounds in nodules, layers, and lenses of chert, arranged in the bedding planes. The chert is inorganic coagulated silica, displaying often convolute slump-roll structure. The post-Cambrian marine Mesozoic transgression again introduced into the region siliceous shales, which are preserved as scattered erosional residuals and are spread far beyond the limits of the former Cambrian sea.

It now seems that the siliceous sedimentation is the property of the subhorizontal epicontinental region of northern Australia. In times of really large thalassocratic transgressions and remoteness of land authigenic silica was accumulated in the sea, on the fringes of which calcareous matter was supplied from the oceans. The water was shallow, sedimentation was slow, and the thickness of the siliceous "concentrates" is only a small fraction of sediments deposited in the same time in "normal" conditions elsewhere.

PALAEOCLIMATOLOGY

Terrestrial deposits and land vegetation are unknown in the Cambrian and palaeoclimatological speculations must rely on the circumstantial and scanty evidence preserved in marine sediments and on hydrographic conditions deduced from them.

The presence of limestone in South Australia, northwestern Queensland, and the Northern Territory may indicate generally temperate and seasonally warm water in the Cambrian seas of the western half of the Australian continent. According to Sprigg (1952) the archaeocyathids "appear to have been adapted to shallow, warm-water environment," and consequently in South Australia "sub-tropical seas" existed, "traversed by south-directed food-laden currents." This interpretation is not supported by the available evidence.

The probability of seasonal changes is seen in the occurrence of ice-crystal casts in Upper Cambrian sandstone in central Australia. Ice-crystal casts, even in marine sediments, are truly climatological evidence, because the ice can be formed only on low, emerged, and moist sand bars, possibly in tidal conditions. Ice crystals in sea water indicate a temperature of about —3°C., which is impossible in Australia to-day. Similar conditions may also have existed at various times in the Proterozoic. The writer has observed ice-crystal casts in the sediments of the Upper (or Middle?) Precambrian Warramunga Group at the Skipper Extended Mine at Tennant Creek, and Wade (1924, pl. VII, VIII, and XI) illustrates similar forms as Lower Cambrian fossils (undetermined) from Mt. John, Osmond Range, Western Australia, in beds containing *Protoniobia wadea* Sprigg and interpreted as "Eocambrian" or probably Lower Cambrian in age. The late Precambrian Sturtian and Elatina glaciations in S.A. and in the Kimberleys are common knowledge.

Pseudomorphs of salt crystals from undoubted lower Middle Cambrian sediments of the Negri Group have also been observed by Wade, and saline deposits in the Daly River Group are mentioned above. The gypsum in the shale of the Negri Group is interpreted as a sign of evaporitic sedimentation in basins cut off from the sea in lower Middle Cambrian time in Western Australia and western Northern Territory. Similar conditions are suggested by Browne (1950) for South Australia. According to Daily (this Symposium), in the northern portion of the Adelaidean geosyncline, in the Lake Frome region, Cambrian redbeds of great thickness are present.

The late Precambrian or early Lower Cambrian Camooweal Dolomite is also suspected to be of evaporitic origin, deposited in a nearly closed large lagoon or inlet. Thus, signs of some aridity of the climate in Cambrian and late Precambrian times are evident.

It may be concluded that in Cambrian time 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. It is still not possible to say that such conditions have persisted consistently from the Sturtian glaciation into Cambrian time or even from the time of deposition of the Warramunga Group; nor can it be maintained that alternation of cold, temperate, and subtropical conditions prevailed.

In southeastern Australia only two observations have palaeoclimatological significance. One is the almost complete absence of limestones, which may be related to the low temperature of the water even in summer; the other is the Zeehan Glacials in Tasmania, which are probably of Middle Cambrian age. If future investigation disproves this age and places the Glaciation in the Sturtian Epoch, the deficiency in limestone remains. It may indicate the existence of a cool or cold current directed to the north, with a volume of water too great to be warmed in the summer.

The inferred cool Cambrian climate and low temperature of the sea water may be a reason for the presence of the *Centropleura*-fauna in the present tropical northwestern Queensland, and in Tasmania where it is represented by agnostids. The *Centropleura*-fauna in the Northern Hemisphere was at home even in the present Arctic, on Bennet Island (Holm and Westergaard, 1930), at latitude 77° north.

Before Cambrian was discovered in northwestern Queensland, a warmer climate on the poles was postulated for Cambrian time, following the discovery of archaeocyathids in Antarctica.

The Cambrian rocks of Antarctica as described by Skeats (1916) are dolomite and silicified oolite, and differ little from the lithology of the Cambrian in South Australia and the Northern Australia. Taylor (1914) described archaeocyathids from these rocks, and Chapman (1916) a calcareous alga *(Epiphyton)*. The fossils may indicate South Australian connexions with Antarctica in the Lower Cambrian. Taylor (1914) interprets the palaeoclimatology of the Cambrian as follows: "one may hazard the speculation that in Cambrian the period of luxuriant life at the Poles was correlated with conditions of great heat at the Equator..." This seems to be doubtful in Lower Cambrian, and the subsequent observations in the Arctic and in tropical Australia confirm the opposite for the palaeoclimatology of the Middle Cambrian in general. However, the occurrence of Cambrian limestone at the South Pole remains palaeoclimatologically unexplained. The actual position of the poles in Cambrian time is unknown (compare last page).

PROVINCIAL RELATIONSHIP OF THE AUSTRALIAN CAMBRIAN FAUNAS

NOTES ON PROVINCE CONCEPTS

Charles Doolittle Walcott (1891) established zoogeographical provinces in the Cambrian of North America as actually existing structural and geographical regions. They remain a necessary basis in the study of Cambrian faunas, though the number of the provinces has been amplified by subsequent authors.

The concept of a palaeozoogeographical province, as applied by students of the Cambrian, is complicated. As commonly accepted, a province means a geographical region with a distinct fauna. Commingling of Cambrian faunas has been admitted as possible although isolation was regarded as the rule. For example, the almost impenetrable isolation of the Atlantic Coast (or Atlantic, or Acado-Baltic) Province from the Appalachian Province of the Cambrian and Lower Ordovician of Europe and America by the *Limen Caledonicum* is common knowledge.

Intermingling of faunas may occur in two ways:

1. As a commingling of contemporaneous faunas over a shorter or longer range of time, and

2. As a sequence of faunas of various provinces replacing one another in time within one and the same geographical region, or even within a local section.

The two cases are not the only alternations, because diverse combinations of both are possible. The discovery of intermingling of faunas in a region is, of course, only possible when two other faunas are already known elsewhere which have little in common and are believed to be "pure." However, the names of the faunal provinces are more-or-less priority names; they refer to the "accident of first discovery," which itself is no guarantee that the fauna in question is "pure" and not a blend. The Middle Cambrian agnostids of northwestern Queensland are Acado-Baltic, but the diversity of Australian agnostid fauna may suggest that the Baltic region itself got only a selection of the Acado-Baltic agnostids.

In the present paper, the term "Acado-Baltic Province" is used in the sense proposed by the Richters. It consists of two regions, the American Atlantic Coast region (Acadian) and the Baltic (Scandinavian-British). The fauna contained in these regions is here referred to as the "Acado-Baltic fauna."

The term "Pacific" covers the regions: the Appalachian Chain, the Rocky Mountain or Western Border Province, and all the regions subsequently recognized within the "Interior Continental or Central Province" of America; the Oriental or West Pacific including the Cathayan regions; and the Himalayan Province or region. They constitute the Pacific realm of faunas, or of regions, and the faunas described from it are Pacific. However, within this realm of regions occur faunas which, by the accident of first discovery in northwestern Europe, are regarded as Acado-Baltic.

The Siberian Province contains several regions, the faunas of which, because of the late date of their discovery, are considered as blends, or alternations of blends, or even "pure" assemblages, of already named province faunas. Local representatives are inevitably included, which are endemic genuinely or by the accident that they were first discovered in Siberia.

The distribution of the Australian Cambrian faunas follows a similar pattern, as is seen from the following discussion.

LOWER CAMBRIAN

The archaeocyathids indicate the prevalence of a Pacific faunal realm in Australia in Lower Cambrian time. This Lower Cambrian realm also included Antarctica, some regions in Siberia, the Mediterranean, and Morocco, but not the Acado-Baltic region, where, according to the present state of knowledge, archaeocyathids are missing. The newly discovered and the previously known fauna of South Australia indicate the existence of one more palaeozoogeographical subdivision of the Lower Cambrian sea.

LOWER HALF OF MIDDLE CAMBRIAN

During the Middle Cambrian two separate marine regions persisted in Australia, one in the west, the other in the east. The western region was of short duration, except for the inlet at Cambridge Gulf, which continued to exist in Upper Cambrian and Ordovician time. The sea in the east also persisted, but the general configuration of the regions changed fundamentally.

The Middle Cambrian *Redlichia*-fauna of the two Australian regions is co-provincial and Oriental; Pacific elements are represented by *Chancelloria* and *Pagetia*. *Peronopsis* in the western Australian region may be Acado-Baltic (perhaps by accident of first discovery). *Redlichia chinensis* in the eastern region indicates a communication with south-eastern Asia; its occurrence can be interpreted as a migration from one geographical region into another, or from a third, unknown, region, or as an evidence of an Asian-Queensland habitat of the species *R. chinensis*. The trilobite *Xystridura* is for the time being endemic; but it occurs in Australia in two geographically isolated regions, and therefore a third unknown habitat of *Xystridura* must have existed.

In the *Xystridura/Dinesus* (or lower *Gibbus*)-time, the isolation of the Australian two regions was maintained. In the western region the oryctocephalids indicate free communication with the Pacific realm, especially with the Rocky Mountain region, and the agnostids suggest Acado-Baltic and Siberian relationship. Although, at this early stage of the Middle Cambrian, the prominence of agnostids is only beginning, their distribution already is evidence of marine communications.

In the eastern region, the relationship at first is similarly Pacific, except for the presence of *Peronopsis*. However, the *Ptychagnostus gibbus* assemblage follows immediately, introducing the Acado-Baltic fauna into the region. Soon after the *Xystridura/Dinesus*-time the western marine region ceased to exist.

UPPER HALF OF MIDDLE CAMBRIAN

The fauna of the Cambridge Gulf area is Pacific, even Oriental. In the east, on the Pacific side of the Australian Continent, the Acado-Baltic fauna is dominant, and culminates in *Laevigata*-time as the *Centropleura*-fauna of the Selwyn Range. The great number of Acado-Baltic species of trilobites and their stratigraphic arrangement, which is identical with the arrangement in Sweden, renders any hypothesis of a confined and directed migration problematical. Unconfined spreading in all directions, and disconnected but otherwise non-isolated habitats over the Globe, as in the case of graptolites, seem to be the probable explanation. The planktonic transport of agnostid larvae was very rapid, compared with the rates of evolution. Isolation of the Acado-Baltic and Pacific Provinces did not exist, except for the *Limen Caledonicum* in the Atlantic region.

Associated with the Acado-Baltic fauna in eastern Australia are many forms of the Pacific realm; most of them have been described from eastern Asia. Thus, *Blackwelderia* cf. *bioloba* is abundant in Tasmania, though the species is based on a single immature specimen from China.

Mapania is so common in Queensland that it is probably "Cathayan" only by the accident of first discovery. *Holteria*, in turn, in association with *Centropleura*, indicates American and Australian marine communication. The fauna of the Middle Cambrian Currant Bush Limestone of northwestern Queensland is not yet satisfactorily listed, and may produce more evidence for a general unity of the seas of the Globe in Middle Cambrian time.

UPPER CAMBRIAN

A single marine Upper Cambrian region existed in Australia, extending from Cambridge Gulf to the centre, and into the eastern sea. The northwestern faunas in this region are Pacific (or Oriental) as in the Middle Cambrian; in the east the Acado-Baltic fauna persists. A directed migration of the Pacific fauna from the Timor Sea toward central Australia seems apparent, and a commingling is indicated in the Eastern MacDonnell Ranges. At the beginning of Upper Cambrian time, the Appalachian *Cedaria*-fauna intervenes abruptly in the otherwise Acado-Baltic sequence of faunas. It is seemingly a Pacific (not Oriental) intervention, and this time on the correct, Pacific, side of Cambrian Australia.

CAMBRIAN GEOTECTONICS

THE AUSTRALIAN CONTINENT IN CAMBRIAN TIME

In Cambrian time Australia did not exist as a unified continent in its present geographical form, although from a tectonic point of view a small and partly submerged "continent" was present. It was a group of islands, some of which attained subcontinental dimensions. They were temporarily joined together in late Middle Cambrian and soon after were divided into islands again.

The present Western Australian Shield and the southern segment of the Meridional Divide (the Willyama Block) were two islands of some stability in the south; another chain of islands existed in the north (as seen, e.g., on map 2). The Kimberley Island was a block and a platform; Carpentaria was a block. Possibly one extended to the northwest and the other to the north, but this is a matter of conjecture. The Duchess Island was consolidated land, and the island at Tennant Creek was, perhaps, the elevated part of what has subsequently been called Stuartiana, or the Stuartian, or the Sturtian, Nucleus.

The space between the two chains of islands, the Flexible Belt, and the interspaces between the islands were submerged. The Meridional Divide had its northern segment confluent with Carpentaria, and its southern segment was the Willyama Block and also comprised the "Queensland Platform" and the basement rocks of western Victoria. The Capricorn Segment of the Divide, however, was the epeirogenetically unstable intersection of the Divide and the Flexible Belt which continued to the east along the Tropic of Capricorn. This, of course, does not eliminate the possibility of the extension of a branch of the Flexible Belt into South Australia, as Hills (1946) suggested for the corresponding "Central Geosyncline."

The mechanism of the Precambrian consolidation of this part of Australia has been studied by Hills (1946). It can be concluded that no unilateral accretion is evident, and that the primordial nuclei were the foci of consolidation, and defined the trends of the folds of the interspaces, which, after the consolidation, retained a certain and lasting degree of mobility. This "interspace mechanism" is clearly reflected in the palaeogeography of Australia in Cambrian time. It was active till the end of the Ordovician, in the MacDonnell Ranges, as demonstrated above. It may be assumed that the mechanism acted until all the interspaces were consolidated.

There is no reason to postulate that the space of the Earth's Crust "allotted" to this mechanism was limitless in all directions and therefore universal. On the contrary, the palaeogeographical setting in Cambrian

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time suggests that another mechanism of formation of blocks and accretes was active, with the result that long meridional structures arose in the eastern half of Australia. This is seen in the present structure of the Palaeozoic part of eastern Australia. The Meridional Divide is, perhaps, an early manifestation of this meridional mechanism. The grain of the rocks of the Divide is near-meridional and their age is middle Proterozoic or perhaps even older. The Divide in Cambrian time was seemingly a morphological residual of an orogenic belt, converted into a tectonic land, a welt, and finally, in Cambrian time, into a low-lying "torso," which could be interpreted as an orthodox accrete to the shield's eastern border as a younger addition to the shield. This younger age is, however, a deduction to satisfy the accretionistic doctrine, and is not evident otherwise. A different interpretation can be contemplated.

No shield existed at the time of the tectonic formation of the Meridional Divide, but land masses as sources of sediments were present. The time-lag between the folding of the internuclear spaces and the folding that produced the Divide was small; it can be assumed that the trend of the Meridional Divide is not necessarily younger than all the internuclear trends, and that the tectonic events were, in parts at least, concurrent. In such a case it can be concluded that the different trends are not the result of a fundamental and general change of the mechanical environment in time, but the expression of the coexistence of two different mechanical environments. Of course, the "meridional mechanical environment" survived longer than the "interspace mechanism" because it was fortified by the meridional edge of the subsequent shield. It is not necessary to postulate that the orogenic belt of the Meridional Divide was immediately accreted to the edge of the shield, because there was no shield in its present state before the Cambrian.

The Divide can be interpreted as a welt, originally separate and gradually incorporated in the shield, in the course of a general consolidation. Most probably, this welt was, after its formation, separated by a mobile belt from the nuclear space in the west and had the character of a foreset geanticline or cordillera. Similar geanticlines followed in the Palaeozoic, as demonstrated by Browne (1953), in eastern Australia (the Benambran, Bowning, and Kaniamblan geanticlines); and perhaps more of them are not yet discovered, being of smaller dimensions and partly simultaneous in origin. None of the geanticlines was immediately accreted to pre-existing structures, being formed each as a cordillera on its own. It may be even a matter of argument whether the geanticlines are accretes of the shield in the west or of Tasmantis in the east.

Returning to the Cambrian palaeogeography of Australia, the described substitution of the meridional trends of the transgressions by the Upper Cambrian latitudinal control can be viewed once more: the meridional transgressions are a part of the "meridional mechanism" which prevailed in the eastern half of Australia, whereas the MacDonnell Ranges represent the final act of the "interspace mechanism" and of the consolidation of the shield.

The South Australian geosyncline by its trend is a product of the "meridional mechanism," and is a major phase in the consolidation of the space between the "torso" of the Meridional Divide and the Shield. It is therefore in all possible senses a marginal case of the meridional mechanism, or even the result of interplay of the two mechanisms. It is truly an accrete to the shield, because the latter term is applicable in Cambrian time. Judging from the sections in Campana (1955), tectonic forces directed towards the northwest were present, that is, towards the shield, supporting the idea of an orthodox accrete in the case of the South Australian chains.

CAMBRIAN GEOSYNCLINES OF AUSTRALIA

Some notes may be added concerning the geosynclinal structures of the Cambrian of Australia. The Brisbane Metamorphics, the Wagonga Series, and the Cobar sequence, together with southern New South Wales, are omitted from consideration, because fossils have not been found in them and the Cambrian part of the sequences cannot be clearly defined.

Five structures, the sequences of which are fossiliferous are discussed:

1. The Adelaidean or Flinders geosyncline in South Australia, 2. The MacDonnell Ranges (Amadeus geosyncline) in central Australia, 3. The Tasmanian-Victorian geosyncline, 4. The Undilla Basin, and 5. the basin at Cambridge Gulf. The historical significance of

these structures and some aspects of their classification may be of interest; Kay's (1951) suggested classification of geosynclines, which deals mainly with Cambrian, might be applied here. However, the Australian structures under discussion are not well enough known to satisfy completely the definitions of Kay's classification.

The initial age and the duration of the Australian Cambrian geosynclines vary. The earliest are the Adelaidean geosyncline and the Amadeus depression of the MacDonnell Ranges, which contain late Proterozoic rocks at their base; the Cambridge Gulf basin was possibly initiated at about the same time. The largest of them, the Adelaidean geosyncline, was folded first (in the Middle Cambrian); it is the most strongly deformed and has pronounced metamorphism. The next largest, the MacDonnell Ranges, survived considerably longer; the folding was of lesser degree and no metamorphism occurred. The smallest structure, the Cambridge Gulf basin, together with the Ord River sequence, contains only about 3000 feet of Cambrian and Ordovician rocks. Sedimentation ended here about the same time as in the MacDonnell Ranges. However an early deformation of the Cambridge Gulf basin is not evident, because the subsequent mild Carboniferous orogeny is sufficient to explain most of the observed structures. Decreasing size of the geosynclines and basins means in this case longer duration of sedimentation and subsidence, and lesser final deformation.

The Adelaidean geosyncline has been termed miogeosynclinal (Sprigg, 1952), because no volcanics have been recorded in it. However, only the northern segment of the geosyncline is seen. Its southern, submerged, extension is unknown. Obviously, the term "miogeosyncline" is not applicable to the unknown part, but "geosyncline" is.

In the MacDonnell Ranges volcanic rocks are completely absent; consequently, if there is an Amadeus geosyncline recognized by linearity, it is a "miogeosyncline." The linearity may refer to the whole of the subsidence, or may indicate a linear arrangement of several basins (a string of basins). The magnitude of the subsidence is not orthogeosynclinal, because the basal unconformity is well preserved and not diffused by regional metamorphism. At the present time, it is an intracratonic structure, and has been since the Ordovician. The intracratonic characteristic was, perhaps, in development in Cambrian time, but is not quite clear because of a generally meridional trend of the

Cambrian seas, not coincident with the linearity of the trough and subsequent Ordovician trend. The intracratonic character of the central Australian depression in the late Proterozoic time, however, is in doubt, because the existence of a unified craton (the subsequent shield) at that time is not evident. A classification of the Amadeus geosyncline, therefore, should take the consecutive stages of development into account, and is not simple. The MacDonnell Ranges differ in many other ways from the Adelaidean orthogeosyncline, as already stated in the paper "Cambrian Geology of the Northern Territory." This may explain the author's preference for less committal terms like "basin," "string of basins," or "depression," in connexion with the lower Palaeozoic development of central Australia, where the application of such a term as "geosyncline" may be only a colloquialism.

The Cambridge Gulf basin is an indentation of the platform border, with sediments derived from the platform. Its extent into the Timor Sea is unknown; by the similarity of its sediments to those of the MacDonnell Ranges and its present "intracratonic position," it may belong to the same class as the latter, or may have been another basin of the same "string."

The Undilla Basin was initiated at the beginning of the Middle Cambrian and was filled up before its end. Its structural position is shelf, with shores to west and north and epicontinental sea to south and east. The sediments of the Undilla Basin are terrigenous (the Age Creek Formation) and thalassogenic (remaining formations). It was deposited as an autogeosyncline with concurrent subsidence and sedimentation; its magnitude, however, is not geosynclinal.

The Tasmanian-Victorian Cambrian geosyncline cannot be accommodated conveniently in the classification of M. Kay. Because of the amount of volcanic rocks it might be termed a eugeosyncline; in Tasmania, however, part of the tuffs may be greywackes. The present linearity of trends is not in itself evidence of an original, pre-orogenic geosynclinal linearity of the trough; the thickness of the sediments is only moderate, and a "relatively rapid subsidence" is doubtful as indicated above (lithology and bathymetric conditions). The absence of limestone may be explained climatologically. The basement of the Dundas sequence is exposed, and therefore the deep burial characteristic of orthogeosynclines is excluded.

It cannot be demonstrated that the volcanic activity was confined to the geosyncline, nor that it was a geosyncline "in a belt of active volcanism." No evidence has been produced that the volcanic rocks are distributed "in strips called eugeosynclinal" within an orthogeosyncline, or that the Tasmanian-Victorian geosyncline was "a linear and arcuate subsiding area along the continental border with thick volcanic sequences restricted to the outer parts." The concept of "eugeosyncline" is definitional; the meaning is "high-grade geosyncline," and the application of the term presumes an amount of knowledge not yet available for Victoria and Tasmania.

The subsequent depositional history of Tasmania and Victoria is illuminating. In Tasmania, only 5000 feet of Ordovician, Silurian, and Devonian rocks overlie the Cambrian; among them quartzose formations are predominant and no volcanic rocks are present. In Victoria the Cambrian is followed by 10,000 to 15,000 feet of Ordovician greywackes representing a thickness of geosynclinal magnitude, but also without volcanic rocks. It can be concluded that in Tasmania and Victoria a submarine volcanic region existed in Middle Cambrian and lower Upper Cambrian time, perhaps with, perhaps without, geosynclinal trenches. At the beginning of the Ordovician the volcanicity was extinguished, and in Victoria a non-volcanic geosyncline came into being.

According to M. R. Banks (this Symposium), folding and intrusions occurred in the Dundas region in Tasmania at the end of the Upper Cambrian. The present writer considers that the sedimentation was also interrupted locally at the end of the Middle Cambrian. The general aspect of the Cambrian sediments in Tasmania suggests a recurrent tectonic unrest during the sedimentation. This tectonic activity is covered by the term "Tyennan Orogeny" or "Tyennan orogenic epoch" (period) but no mountain structure that may be designated a continental accrete was built during this Epoch. The final consolidation was the result of a Middle Devonian diastrophism.

The marine and depositional history of the Victorian-Tasmanian geosyncline started early in the Middle Cambrian, post-dating the beginning of all the other structures discussed above. Although this Middle Cambrian age is evident only in Tasmania, it is the only date available as yet for the whole of the Greater Tasman Geosyncline, and must be regarded as a significant date in its history.

GEOTECTONIC SIGNIFICANCE OF THE CAMBRIAN MERIDIONAL DIVIDE

The Meridional Divide acted as a faunal barrier during the existence of meridional intracontinental seas. Tectonically it is interpreted as a Precambrian cordillera and geomorphologically as a "torso" in Cambrian time. In its northern part it was of low elevation, being a barrier dividing epicontinental seas. In the south the elevation above its base must have been greater, in view of the trough west of it. More such barriers could have existed but remain unknown because their crests were below the surface of the sea and no zoogeographical isolation resulted.

A similar barrier was the much greater Caledonian Barrier or *Limen Caledonicum* in the Atlantic part of the Northern Hemisphere, which caused the traditional belief in the isolation of Pacific and Acado-Baltic Cambrian faunas. The Caledonian Barrier has the appearance of a very extended and narrow cordillera built up in Precambrian time; unlike the Australian Meridional Divide it functioned as a foreland of orogenies. However, the southern segment of the Australian Meridional Divide coincides with the "Shatter Belt" of South Australia and New South Wales (Hills, 1946) and lies in a region of greater tectonic activity compared with the northern part of the Divide. It has actually been involved in subsequent tectogenesis, although a foreland character is not evident.

Alpine geologists work with the concept of cordilleras arising at an early stage in an orogeny and separating the resulting geosynclinal trenches of a greater geosyncline. This sort of cordillera seems to be different from the lower Palaeozoic barriers under discussion, which seems to have been linear crests or backbones of consolidation, preserving their morphological prominence unchanged over long periods of time. They appear to be "lower Palaeozoic" because the appearance of marine faunas at the beginning of the Palaeozoic time makes palaeozoogeography and discovery of faunal barriers possible. The barriers themselves, however, are the result of Precambrian tectogenesis and, perhaps, of mechanics of the crust not yet fully recognized.

SUCCESSION OF TECTONIC EVENTS

1. At the end of the Proterozoic time widespread regression is apparent in Western Australia and in the Northern Territory. In the Daly River area mild orogenic movements which may have reached into the beginning of Lower Cambrian time produced an unconformity seen at the base of the Middle Cambrian rocks. Plateau basalts were effused after that movement.

The beginning of the Palaeozoic was the time of shield consolidation accompanied by "fault-folding" (Hills 1946) of late Proterozoic rocks in western and northern Australia.

2. Tectonic unrest is evident in Lower Cambrian time in the South Australian geosyncline on Kangaroo Island (see Daily, "Cambrian Geology of South Australia," this Symposium).

3. Early in the Middle Cambrian, subsidence and transgression affected northern Australia.

4. In the Middle Cambrian (beginning with the *Gibbus*-time), folding is apparent in South Australia with a concurrent uplift and regression in the Northern Territory and subsidence and inundation in Tasmania, Victoria, and, perhaps, New South Wales (Tasman Geosyncline).

5. Tectonic movements in Tasmania are apparent in Middle Cambrian, at the end of the Middle Cambrian, and at the end of the Upper Cambrian.

6. In Upper Cambrian time a transgression spreads from the Timor Sea into central Australia and Queensland.

7. Sea persists in central Australia until the folding of the MacDonnell Ranges in the Ordovician.

Cambrian movements in the MacDonnell Ranges are apparent but their history and significance are not yet clear.

POSITION OF THE POLES IN CAMBRIAN TIME

Creer, Irving, and Runcorn (1954) suggest that the Cambrian North Pole was in the vicinity of the Marshall Islands in the Pacific, and the South Pole at St. Helena in the South Atlantic.

For such a position of the axis, the distribution of climates is deduced below. It is speculative—because British samples only have been considered and continental drift is disregarded. The coincidence of magnetic, rotational, and climatic poles in Cambrian time can be assumed, but is not evident.

The position of the Cambrian magnetic poles in the middle of the present oceans may mean that Cambrian deposits north and south of the ± 45 degrees Cambrian latitudes are submerged and not observable.

The known regions of Cambrian rocks occur between the Cambrian latitudes of ± 45 degrees. Most of the known Cambrian occurs between the Cambrian latitudes of ± 30 degrees. The Salt Range, Wisconsin, Vermont, northeastern Greenland, and the present South Pole were equatorial (± 5 degrees) in Cambrian time. Archaeocyathids, the *Centropleura*-fauna, and the Cambrian faunal provinces are not confined to particular latitudinal belts, nor are faunas of the three Epochs of the Cambrian Period.

The latitudes (distances from the equator) of several regions (South Australia, Korea, the Anti-Atlas, Palestine, and Argentina) were similar in Cambrian time to those of the present day, the difference being 5 degrees or less. Tasmania was 12 to 15 degrees nearer to the equator, and hence the difficulty of accepting the Cambrian age of the Zeehan Glacials is increased.

The presence of archaeocyathid limestone in Antarctica can be explained. The actual distribution of the *Centropleura*-fauna was latitudinal, and not simultaneously arctic and tropical.

However, the cool conditions deduced for the Australian Cambrian are not invalidated. Perhaps the general climate of the Globe was cooler than now: marine life flourished between the "forties," beyond which arctic and subarctic hydrology prevailed.

E. J. Öpik (1953) suggests "an average global temperature of + 20°C for the Cambrian, by 5° higher than now," and attributes the palaeoclimatic variations to variations of solar luminosity.

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