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Upper Permian and Lower Triassic Sedimentation in Part of the Bowen Basin, Queensland

by

A.R. Jensen

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SUMMARY

This report describes the Upper Permian and lowermost Lower Triassic succession exposed at a number of localities around the Bowen Basin, and suggests a correlation between areas. A possible interpretation of the depositional history is presented.

The oldest Upper Permian sediments are marine, and these are overlain by Upper Permian and Lower Triassic continental accumulations. The Upper Permian succession is shown to be of the order of 9000 feet thick in the eastern parts of the basin, and considerably thinner towards the western margin.

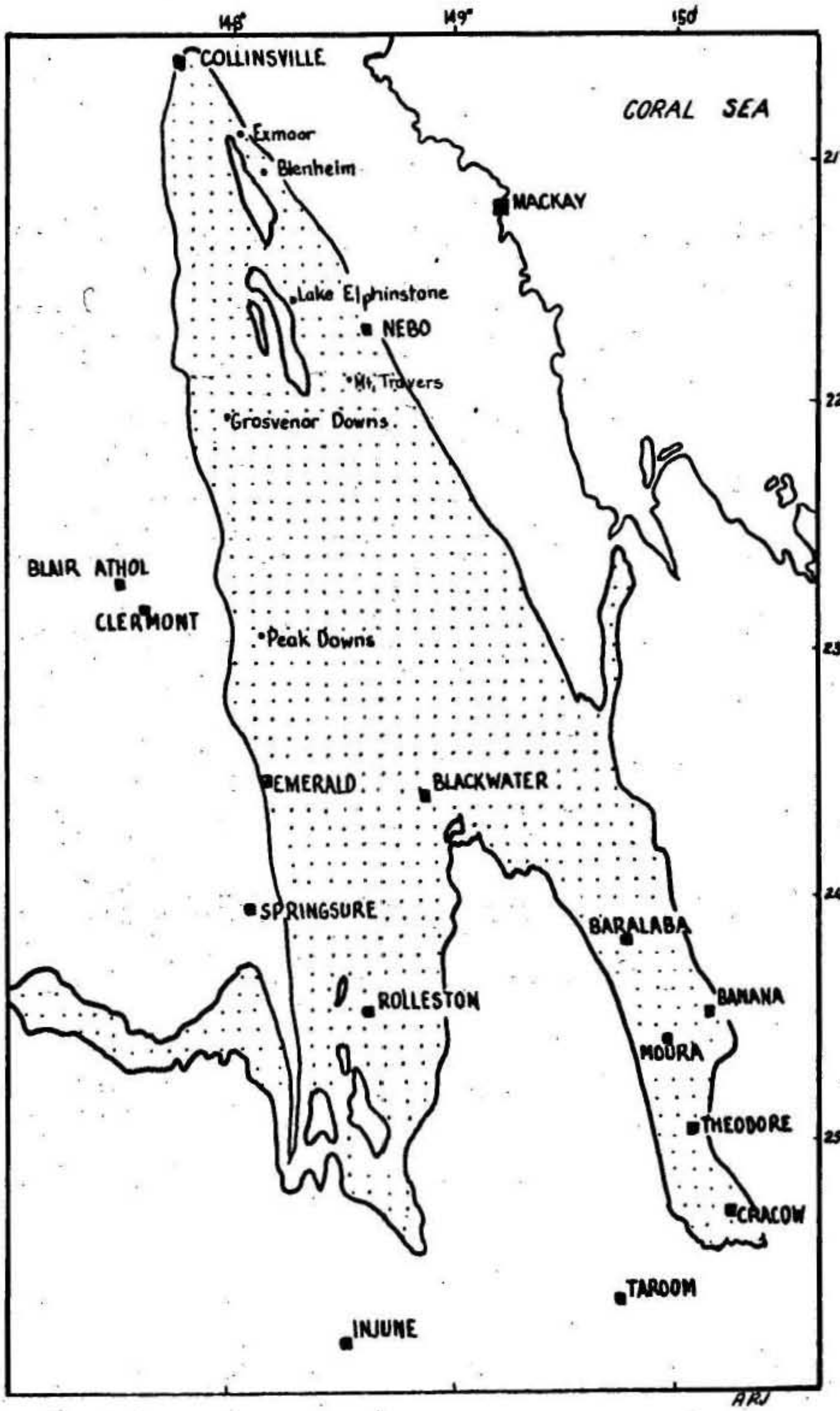
The sequence in the south-eastern part of the basin is shown to represent relatively continuous deposition associated with a deeply subsiding trough, at first in a marine, and later in a continental environment. Most of the sequence in this area is shown to have a volcanic provenance, and primary pyroclastic material is recognized in the Mount Steel and Kia Ora Formations. Large cross-strata exposed in sandstone of the coal measures at Moura are briefly described and interpreted as being the result of deltaic sedimentation and differential compaction. No new stratigraphic terminology is introduced for this area, but it is confirmed that the term Kia Ora Formation includes the Baralaba Coal Measures. The Acacia Formation is equated with at least part of the Flat Top Formation of the Theodore area, and the Mount Steel Formation with the Wiseman Formation.

The succession in the northern part of the basin is shown to reflect a similar sequence of events although the marine sediments were deposited on a more stable shelf and the sea possibly withdrew at an earlier time than in the south-east part of the basin. The basal marine section, although consisting mainly of fine grained sediments, contains large angular blocks of volcanic and metamorphic rocks which suggest distribution of some material by ice-rafting. The overlying unit, the Hail Creek Beds, is newly defined in this report, and the old terms Elphinstone and Fort Cooper Coal Measures are strictly defined for the first time. The division of the 'Upper Bowen' Coal Measures into an

Figure 1

OUTCROP OF UPPER PERMIAN AND REWAN FORMATION

BOWEN BASIN



upper Rewan Formation and a lower Blackwater Group is confirmed.

The western parts of the basin, where the sequence is thinnest, are shown to have acted as a stable block from which the shallow upper Permian sea probably retreated towards the south-east. Sediment accumulated on this side of the basin was derived initially from mixed provenance and finally a volcanic provenance as continental conditions were established over the whole basin towards the close of the Permian. In the south-western outcrop areas subsidence slowed markedly at this time and it is suggested that parts of the sequence deposited elsewhere in the basin are not represented in this area.

A brief description of the Triassic Rewan Formation is presented, particular attention being paid to the problem of the boundary between this unit and the underlying coal measures, and it is concluded that the most satisfactory boundary is at the top of the youngest coal seam. The lower part of the unit on the western side of the basin, the Sagittarius Sandstone Member, is described, and a northerly direction of sediment transportation postulated. It is concluded that the Rewan Formation is dominantly a continental deposit.

The basin-wide lithological uniformity of the Rewan Formation, Rangal Coal Measures, and Burngrove Formation permits relatively clear cut lithostratigraphic correlation of the upper part of the succession studied. Units lower in the sequence cannot be correlated over long distances with any certainty, but it is suggested that the Hail Creek Beds in the north are equivalent to the Gyranda and Mount Steel Formations in the south-east, and to the Fairhill Formation in the Blackwater area. The Blenheim Formation is correlated with the Acacia, Orange Creek and Oxtrack Formations of the south-eastern part of the basin, and with the German Creek Coal Measures, and Hurdle Creek beds near Blackwater.

A possible history of deposition during the Upper Permian and Lower Triassic is presented. This synthesis describes the basin in terms of a relatively unstable eastern part which subsided deeply, probably adjacent to a rising eastern hinterland, and a western, relatively more stable area, on which was deposited mineralogically mature sediment derived mainly from the west but later from the north and south. It is suggested that the Upper Permian sea retreated towards the south-east and that marine conditions may have lasted longer in the southern part of the basin than in the north.

INTRODUCTION

For over a century now the existence of the Bowen Basin has been recorded in a multitude of geological reports and maps. The promise of vast coal resources has always acted as an incentive to geological investigation, but paradoxically it was the recent search for petroleum in Queensland which has been responsible for advances in our knowledge of the regional setting of the coal measures of the basin.

A programme of regional geological mapping by the Bureau of Mineral Resources and the Geological Survey of Queensland was commenced in 1960. The regional framework having once been established, the way was open for more detailed studies of certain rock units. The aim of the present survey was to investigate the Upper Bowen Coal Measures, with a view to elucidating the stratigraphy, and in the course of this work to study the origins and overall economic significance of the sequence.

Geological Setting

Outcrop of the Bowen Basin occupies an area of about 25,000 square miles in eastern Queensland (Fig. 1), and the basin extends southwards, subsurface, beneath the Surat Basin. From the Lower Permian or earlier, the basin was the site of geosynclinal sedimentation in a number of troughs and on unstable shelves (Malone, 1964). During the Lower Permian, marine sediments were deposited over certain restricted areas of the basin, but a major marine transgression in the Upper Permian was responsible for deposition of clastic material over the entire basin (Dickins, Malone, and Jensen, 1964). After withdrawal of the Upper Permian sea, continental deposition persisted throughout the rest of the Permian and Triassic.

The Permian and Triassic sequence now forms a synclinorium with a steep eastern limb and gently dipping western limb. Strongly folded sediments lying mainly on the eastern side of the basin have been termed the Dawson Tectonic Zone (Derrington and Morgan, 1960), and the Folded Zone (Malone, 1964; Malone, Olgers and Kirkegaard, in press).

Stratigraphic nomenclature

In 1885 Leichhardt saw and described outcrops of Upper Permian coal measures at the confluence of the Comet and MacKenzie Rivers, during his journey from Moreton Bay to Port Essington. By the year 1872 enough information was available for the Bowen Basin to be roughly outlined on a map of Queensland (Daintree, 1872), and for the 'Bowen River Series' to be divided into a lower 'Carboniferous' marine sequence, and an upper sequence containing plant fossils. It was not long after that Jack (1879) divided the sequence into an upper (freshwater), middle (marine), and a lower series. This nomenclature was later revised by Jack and Etheridge (1892) to Upper, Middle, and Lower Bowen Formations. Since that time most authors have retained this three-fold division and as late as 1958 the most common usage was Lower Bowen Volcanics, Middle Bowen Group, and Upper Bowen Coal Measures (Smith, 1958). On the other hand, many names have been used in the description of the geology of small areas within the basin, and this naturally has led to some confusion of nomenclature. The history of each local system of nomenclature is discussed later with the geology of various parts of the basin.

As a result of a basin-wide joint survey by the Bureau of Mineral Resources and the Geological Survey of Queensland, recently there has been some attempt to formalize the nomenclature, and to replace local nomenclatural schemes with basin-wide terms, as far as possible. For example, the Middle Bowen Group has been replaced by the Back Creek Group, and the three subgroups of which it is composed have been recognized over most parts of the basin.

There is still no formal name which can be used instead of the Upper Bowen Coal Measures, and it could be argued that to replace such an old and well established term with a new formal name would be of little value. In fact the modern tendency and the scheme followed in this report is to split the Upper Bowen Coal Measures into two major units, the upper one being the Rewan Formation, which is now considered to be the basal unit of the Mimosa Group (Malone, Olgers, and Kirkegaard, in press), and the lower unit forming the Blackwater Group. In the Blackwater area, the Blackwater Group comprises the Rangal Coal Measures overlying the Burngrove Formation with the Fairhill Formation at the base. It has become apparent over the last decade that equivalents of these units can be recognized over the entire Bowen Basin. But it is advisable to restrict the usage of these and other local names to the areas where they were first used. For example it is best to restrict Rangal Coal Measures to the central parts of the basin where in detail the Rangal Coal Measures will be different from the coal measures such as the Baralaba and Elphinstone Coal Measures, in the same stratigraphic position elsewhere in the basin. However, despite the fact that these names are not used all over the basin, it is thought proper that the term Blackwater Group should be used on this scale.

Sedimentary rock nomenclature

Except in the case of sandstone, sedimentary rock names in this report have been used in the sense of Pettijohn (1957). Rocks consisting of material finer than silt size are termed mudstone unless they have a fissility, in which case they are termed shale. Mixtures of gravel, sand, and mud are named using Folk's (1954) scheme.

The classification of sandstone as devised by Pettijohn is unsatisfactory for reasons pointed out by Packham (1954) and Crook (1960). On the other hand there appears to be no satisfactory alternative, for sandstone nomenclature and classification has long been a subject of controversy, Klein (1963), seventeen classifications of sandstone were proposed in the North American literature between the years 1940 and 1960.

The solution to the problem lies in the establishment of a universally acceptable nomenclature which in itself does not involve classification, and which does not use terms already defined and re-defined such as greywacke and arkose. In this report the term sandstone is applied to any clastic sedimentary rock in which more than 50% of the grains are of sand size (i.e. between 2mm and 1/16mm), and this term is qualified by a statement of major mineralogical composition in the form of a statement of proportion of quartz to rock fragments to feldspar calculated on a matrix and cement-free basis. Indication of the amount of matrix may be added, the nomenclature being based on the simple classification:

A = $<$5% matrix
B = 5-15% matrix
C = $>$15% matrix

although it is realized that the limits taken for each class are somewhat arbitrary.

An example of the use of this system is that a sandstone composed of 40% quartz, 30% rock fragments, 10% feldspar and 20% matrix would in the text be described as a sandstone (50:38:12C). This system of nomenclature can be adjusted to suit the method of investigation and the accuracy of ones estimate of the mineralogical composition. For instance a field term for a quartz rich sandstone might be 'sandstone' (9:0:1A), and a laboratory term for the same rock after analysis (93:2:5A). Other minerals such as micas are ignored for the purpose of the nomenclature, although such terms as micaceous may be added.

Methods

The study of the Upper Permian and Lower Triassic sequence involved field work lasting about six months in four areas: the south-east part of the basin near Cracow; the south-west or Reid's Dome area; the central or Blackwater area; and the northern area, which includes the sequences exposed near Lake Elphinstone, and near Exmoor. Stratigraphic sections and sedimentary structures were measured in each of the areas, and during 1966 some shallow holes were drilled in the Cracow and Blackwater areas. Preliminary results of the field work were recorded by Jensen and Arman (1966), and the results of palynological examination of samples collected during 1965 were recorded by Evans (1966).

Acknowledgements

I am indebted to geologists of Utah Development Company, Mount Morgan Limited, New Consolidated Goldfields, the Geological Survey of Queensland, and in particular to Mr D. King of Associated Mining and Mr M. Johnson of B.H.P. for discussions on the geology of the coal measures in the Blackwater and Cracow areas. Broken Hill Proprietary kindly allowed me to examine core from their exploration holes drilled in the Blackwater area. I would also like to acknowledge the work of many colleagues at the Bureau of Mineral Resources and the Geological Survey of Queensland, who have been responsible for the recent mapping of the Bowen Basin; this work served as a basis for the present study.

Lastly I would like to record my gratitude to many people of the survey area, particularly those at Gyranda, Cracow, The Braes, Waitara, Turrawulla and Exmoor Homesteads, for their hospitality, and guidance in matters of access.

UPPER PERMIAN STRATIGRAPHY

South-east Bowen Basin

CRACOW AREA

Previous investigations

In his geological reconnaissance of country north of Roma, Jensen (1926) recognized that equivalents of the Lower Bowen Volcanics in the Cracow area are overlain by a Permo-Carboniferous sequence having as its basal member a 'Lower Marine Limestone'. Much later, geologists from Shell (Qld) Development Pty Ltd (1952) divided the Permo-Carboniferous sequence into a lower Back Creek Series comprising four units, and an upper Dawson Series comprising three. The same sequence was divided much the same way by geologists from Mines Administration (1959), as shown in Table 1, the main difference being the recognition of the Kia Ora and Gyranda Formations. The basal limestone unit was named the Oxtrack Formation, but it has since been realized by mapping and on faunal evidence that this limestone actually consists of two units, one being significantly older than the other (Wass, 1965). The name Oxtrack was restricted to the younger unit as this unit alone is present in the type section, and the older limestone is now known as the Buffel Formation.

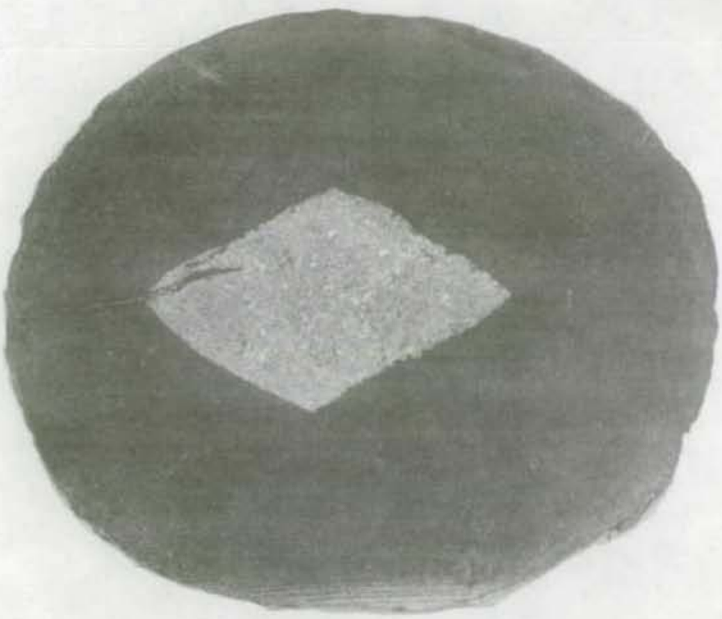
During the regional mapping of the western part of the Mundubbera 1:250,000 Sheet area, Jensen, Gregory, and Forbes (1964) suggested that the Orange Creek, Acacia, and Passion Hill Formations could be correlated with the Barfield Formation, an Upper Permian unit lying conformably on the Oxtrack Formation in the Banana area north of Cracow. They also equated the Mount Steel Formation with the Flat Top Formation. Jensen et al. (1964) regarded the top part of the Kia Ora Formation as equivalent to the Baralaba Coal Measures, and the sequence between the coal measures and the Mount Steel Formation was included in the Gyranda Formation, because it was found that the coal measures were underlain by a fine grained, biotitic tuff already reported by Mines

TABLE 1

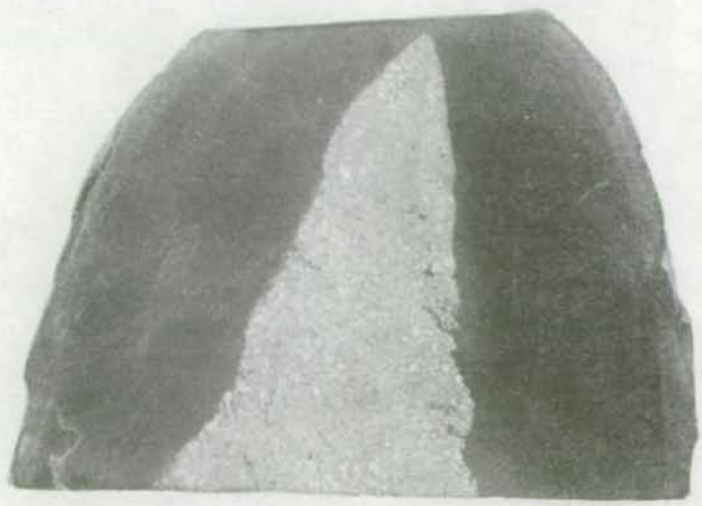
STRATIGRAPHIC NOMENCLATURE OF UPPER PERMIAN AND LOWER TRIASSIC SEQUENCE IN THE SOUTH-EASTERN PART OF THE BOWEN BASIN

Shell (Qld) Development Pty Ltd, 1952 (unpubl.)		Mines Administration Pty Ltd, 1959. West of Banana MONTO 1:250,000 SHEET	Mines Administration Pty Ltd, 1959. MUNDUBBERA 1:250,000 SHEET		Jensen et al. 1964 (unpubl.). MUNDUBBERA 1:250,000 SHEET		Dear et al. 1965 (unpubl.). MONTO 1:250,000 SHEET		This report	
				Clematis Sandstone		Clematis Sandstone				Clematis Sandstone
Dawson Series	Upper Dawson		Theodore Group	Isla Formation		Rewan Formation		Rewan Formation		Rewan Formation
Dawson Series	Middle Dawson		Theodore Group	Kia Ora Formation		Baralaba Coal Measures		Baralaba Coal Measures	Blackwater Group	Baralaba Coal Measures; Kia Ora Formation
Dawson Series			Theodore Group	-?--?-----?-				Kaloola Member	Blackwater Group	tuff member
Dawson Series	Lower Dawson	Wiseman Formation	Theodore Group	Gyranda Formation		Gyranda Formation		Gyranda Formation	Blackwater Group	Gyranda Formation
Back Creek Series	Upper Back Creek	Banana Formation	Back Creek Group	Mt Steel Formation	Back Creek Group	Flat Top Formation	Back Creek Group	Banana Formation	Back Creek Group	Mt Steel Fmn
Back Creek Series	Middle Back Creek	Flat Top Formation	Back Creek Group	Acacia Formation / Passion Hill Fmn.	Back Creek Group	Barfield Formation	Back Creek Group	Flat Top Formation	Back Creek Group	Acacia Formation
Back Creek Series	Lower Back Creek	Barfield Formation	Back Creek Group	Orange Creek Fmn	Back Creek Group		Back Creek Group	Barfield Formation	Back Creek Group	Orange Creek Fm
Back Creek Series	Basal Back Creek	Oxtrack Formation	Back Creek Group	Oxtrack Formation	Back Creek Group	Oxtrack Formation	Back Creek Group	Oxtrack Formation	Back Creek Group	Oxtrack Formation
Back Creek Series			Back Creek Group		Back Creek Group	Buffel Formation	Back Creek Group	Buffel Formation	Back Creek Group	

(i)



(ii)



(iii)

Glendonites, sideritic pseudomorphs after glauberite, from the Upper Permian of the Bowen Basin. i) Cluster of three crystals weathered out of enclosing sediment: ii) single crystal in a carbonate concretion; in plan view: iii) single crystal in longitudinal section. All figures natural scale.

Administration (1959) to be in the top of the Gyranda Formation.

Oxtrack Formation

The Oxtrack Formation (Mines Administration, 1959 & Jensen et al. 1964; Wass, 1965) lying unconformably on the Buffel Formation or Camboon Andesite, consists of very fossiliferous brown flaggy limestone which grades vertically and along strike to brown flaggy marl. The formation, which varies in thickness from 100 to 350 feet, extends from Cracow northwards to the Banana area. Although fossil shells form a high proportion of the limestone, Bastian (1965) reported a fine siliceous matrix and suggested the possibility of primary deposition of silica. The fossil fauna includes brachiopods, pelecypods, bryozoans, corals, and crinoid stems, but one of the most distinctive features is the abundance and the size of some of the crinoid stems some of which are as much as one inch in diameter and seven inches long. Some bryozoans appear to have been growing in situ, and many of the brachiopod valves are still hinged together.

One must assume that the rich and abundant fauna of the Oxtrack Formation lived in an area such as the sublittoral zone which is particularly suitable for marine life. The fact that the crinoid stems are preserved as long stems and not just as individual plates, and that some brachiopod valves are still hinged, indicates little or no transport, and this conclusion is supported by the presence of fine-grained, thinly-bedded clastic material, which bears evidence not only of gentle currents, but also of deposition below wave base. The combination of the fine-grained flaggy marls and the rich fauna then, suggests deposition in the infralittoral subzone .

Orange Creek Formation

Even though it is approximately 2,500 feet thick, very little is known about the Orange Creek Formation, because of the lack, and in most places the complete absence, of outcrop. On the western slopes of Mount Ox, the lower part of the unit can be seen as a transitional phase from the coquinitic limestone and marl of the Oxtrack Formation to a fossiliferous dark brown to black mudstone. Where drilled farther to the south, (Jensen, et al. 1964) this part of the sequence proved to consist almost entirely of purplish black mudstone with scattered marine fossils, and small specks of pyrite. The same lithology was encountered in a hole drilled near the top of the unit, and as the intervening lithology must be relatively soft, it is most likely to be the same type of black mudstone. Mines Administration (1959) indicated the presence of siltstone and minor feldspathic lithic sandstone in the unit, and Arman (1965) reported the presence of fine tuffaceous material.

Farther north, the Barfield Formation, the equivalent of the Orange Creek Formation, maintains approximately the same thickness, but east of the Banana Fault it increases rapidly to 7,000-14,000 feet, being represented by five formations (Derrington and Morgan, 1960).

To base an interpretation of environment on such meagre evidence is risky. However it is suggested that the change from the Oxtrack Formation to the lower part of the Orange Creek Formation, with the loss of an abundant marine fauna and an increase in the amount of fine terrigenous clastic material, represents an increase in the depth of water. Sedimentation possibly took place in moderately deep water, adjacent to the rapidly subsiding deep trough which must have existed east of the Banana Fault at this time.

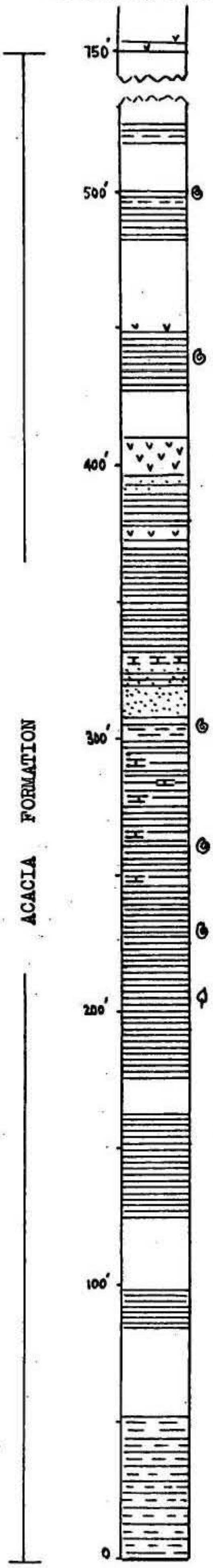
Acacia Formation

The Acacia Formation, 750 feet thick, lies conformably on the Orange Creek Formation (Mines Administration, 1959), and in this report it includes the Passion Hill Formation, a thin mudstone unit recognized by Mines Administration (1959) only south of Mount Steel. It is considered to be partly equivalent to the Flat Top Formation of the Banana area. The base of the unit is at the base of a vesicular flow, which crops out in Back Creek, on the track to Gyranda Homestead from Cracow. The lower

Figure 2

MEASURED SECTION M 1 - ACACIA FORMATION

Measured ½ mile north of Mount Steel, near Cracow



315' Hard, light brown argillite; partly massive and partly thin bedded; abundant burrows

9' Green-brown mudstone and grey siltstone Thin limestone near top

17' Black mudstone and muddy siltstone; crinoids, corals, bryozoa

21' Brown-grey mudstone, slightly silty; carbonate concretions up to four inches. Minor fine tuff

10' Light brown weathered coarse tuff

16' Dark grey mudstone with minor volcanic pebbles, and thin beds of laminated muddy sandstone

5' Lapilli tuff

54' Grey mudstone with minor thin beds of limestone and calcareous sandstone (0:8:2 B)

11' Grey, coarse sandstone(0:7;3 A) containing a few angular clasts up to 5mm.

5' Brown muddy siltstone with calcareous fossiliferous lenses

21' Brown thin bedded mudstone with thin layers of bryozoa and corals concentrated along bedding planes

6' Dark brown unfossiliferous mudstone; minor limestone

32' Green brown mudstone with thin layers of bryozoa and corals; calcareous concretions and glendonites; lenses of limestone

60' Green to dark brown mudstone with abundant plant material; churned in places

38' Green-brown mudstone, silty in places, with calcareous veins and rare shaly clasts: slightly laminated

13' Dark grey silty mudstone with calcareous veins; rare glendonites and pebbles: round concretions

57' Green-brown silty mudstone with minor thin beds of grey calcareous mudstone; shale clasts up to 4mm long. Minor brown white calcareous claystone near base

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part of the sequence (Fig. 2) is characterized by massive blue-green mudstone with large spherical calcareous concretions, and concretionary limestone lenses; this part is particularly fossiliferous, containing brachiopods, small corals, bryozoans, gastropods, conulariids, and crinoid stems and ossicles. Glendonites, carbonate pseudomorphs after glauberite (Plate 1), and small shelly fossils commonly form nuclei around which concretions have grown.

Near the top of the unit, sandstone (0:70:30A), interbedded with dark-grey to brown mudstone dominates the section. The sandstone consists of rock fragments, almost exclusively of volcanic origin, large plagioclase grains, hornblende, and pyroxene, in a matrix of re-crystallized micritic carbonate. The rock fragments, consisting mainly of porphyritic and even grained andesites and basalt, are generally angular, although sphericity is unusually high. The grains of plagioclase are subhedral and angular, commonly having a sheared appearance. Quartz is generally lacking in both the sandstone and its constituent rock fragments. There is no direct evidence that these rocks are tuffs, but their mineralogical composition, especially the presence of large grains of hornblende and pyroxene, together with the presence of volcanic rock fragments, and the lack of obvious signs of attrition, point to derivation from a volcanic pile by rapid erosion and transportation. The presence of fine grained vitric tuff in the unit, and of the volcanic flow at the base of the unit indicates the derivation of at least some of the material from contemporaneous vulcanism.

The Acacia Formation was deposited in a marine environment probably in water shallower than that of underlying Orange Creek Formation. The fauna, although abundant, does not necessarily indicate a shallow water environment because it is possibly transported, the shells lying as distinct thin horizons on bedding planes. Apart from the presence of shelly fossils, there is no evidence of persistent strong currents, most of the material being relatively fine grained, and there being no traction current structures. The thin fossiliferous bands and thin coarse beds presumably represent relatively short lived strong currents. The concretions, probably formed during diagensis of the sediment while porosity and permeability were sufficient to permit movement of lime rich solutions, do not appear to have any environmental significance, except that the increase of carbonate content of the sediments from the Orange Creek to the Acacia Formation suggests a shallowing of the sea.

The presence of glendonites has been shown to indicate the original formation of glauberite (David, Taylor, Woolnough, and Foxall, 1905), but the range of environmental conditions in which this salt may form are not known precisely. There are many reports of glauberite crystals forming in evaporite deposits (Clark, 1924; van Houten, 1965), but the presence of marine fossils in the Orange Creek Formation and the absence of any other associated evaporite deposits appears to rule out the formation of the glauberite simply by evaporation. Many of the beds bearing glendonites in New South Wales are thought to have been deposited during glacial or subglacial times (Brown, 1925), and it has been suggested that the growth of the crystals has been aided by cold temperatures. There is independent evidence of glacial or subglacial conditions existing in the northern part of the basin at the time of deposition of the Orange Creek Formation. However, there is some doubt that glauberite can form in sediments simply by freezing seawater.

Mount Steel Formation

Compared with most formations of the Bowen Basin the Mount Steel Formation is remarkably homogeneous being composed mainly of buff argillite with rare thin beds of mudstone. The change from dark grey mudstone and sandstone (0:70:30A) of the Acacia Formation to the buff coloured argillite of the Mount Steel Formation is distinct and sharp where exposed, although there is no suggestion of a significant disconformity.

The unit is approximately 2000 feet thick and yet the lithology is relatively uniform. It is almost everywhere thin to medium bedded, the bedding being distinctly regular. Cross-stratification is absent except on a small scale in large ripples. Small scale slump structures are common, but large slumps are rare. The argillite is composed of scattered feldspar, glass shards, and rock fragments rimmed by iron oxide, in a fine groundmass of interlocking feldspar crystals. Irregular patches of calcite replace the groundmass, and in some beds calcite forms as much as 35 per cent of the rock. There is no sign of flattened lapilli or flow banding, and the presence of marine fossils and cross-lamination confirms that the argillite is the product of an ash fall rather than a pyroclastic flow.

In marked contrast to the Acacia Formation, the Mount Steel Formation contains only scattered marine fossils, mainly large pelecypods and some gastropods. The argillite is commonly riddled with thin discontinuous organic burrows about 2mm in diameter, and by larger cylindrical pipes, possibly infilled burrows, which possess an internal scallop structure delineated by laminae of blue mudstone. These larger structures, here termed 'scallop structures', range up to 10mm in diameter and up to 5cm in length. Fine carbonaceous material is disseminated throughout the unit but it becomes more common near the top where fossil wood impressions also become common.

It is tentatively suggested that the Mount Steel Formation represents an accumulation of aerially distributed volcanic ash in a shallow sea with restricted circulation. The bulk of the rocks are recrystallized vitric tuffs of intermediate or basic composition, and the abundance of organic burrows and the presence of large scale ripple marks point to subaqueous accumulation. Although rare, the marine fossils scattered throughout the unit suggest that marine conditions existed throughout most of the time. The sedimentary structures preserved, namely regular, thin- to medium-bedding, cross-lamination, ripple marks, small slumps, and organic burrows, are not indicative of any specific depth of water, and the absence of terrigenous sediment could indicate distance from the shore, or deposition adjacent to a poorly drained hinterland. It appears that there were no strong currents operating, so the abundance of disseminated carbonaceous material may indicate proximity to the shore and therefore shallower water than that which existed during the deposition of the underlying Acacia Formation.

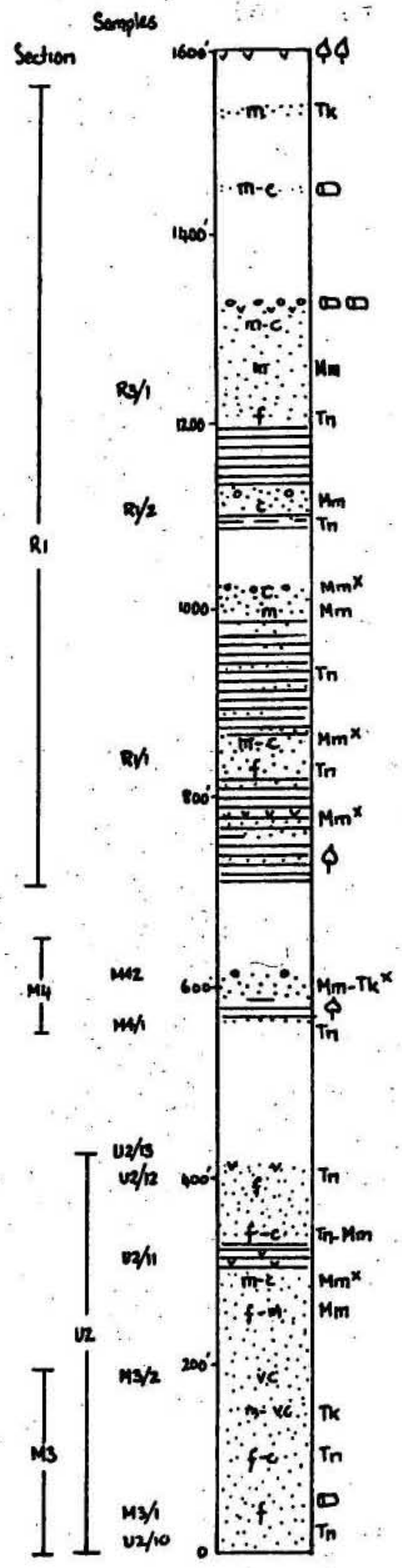
Gyranda Formation

The Gyranda Formation, approximately 1300 feet thick, is essentially a sandstone-mudstone sequence, with thin beds of conglomerate and conglomeratic sandstone. The base of the unit is marked by a conformable but sharp change from hard buff argillite of the Mount Steel Formation to green-brown sandstone. There is an overall change from sandstone in the lower part of the unit, to an interbedded mudstone-sandstone sequence in the middle part, to a sandstone and conglomeratic sandstone sequence at the top (Fig. 3). The top of the formation is taken just below a tuff and conglomerate horizon, in which is preserved an abundance of fossil logs. The tuff was formerly included in the Gyranda Formation, and the conglomerate in the Kia Ora Formation (Mines Administration, 1959). In order to avoid confusion and to facilitate lithological correlation in other parts of the basin, and rather than extending the Gyranda Formation to include the conglomerate, the tuff beds are here included in the Kia Ora Formation.

Grain-size and bedding characteristics vary widely, but there seems to be a repeated pattern of sedimentation, especially in the middle part of the unit. At more than one level mudstone grades up into fine, thinly and regularly bedded, sandstone, which is overlain by coarse grained, medium bedded, cross-stratified sandstone. This can be observed in section R1 (Fig. 3) about 800, 1000, and 1200 feet from the base. The same pattern is seen in UKA Cockatoo Creek No. 1. These cyclothems vary in thickness between 50 and 200 feet, and they average 100 feet. The basal 300 feet of the formation exhibits the same type of pattern, except that there is no interbedded mudstone, and the fine grained sandstone is cross-stratified. Outcrop was sufficient in only two places, both in the basal part of the unit, to enable the orientation

Figure 3

COMPOSITE SECTION OF THE GYRANDA FORMATION
CRACOW AREA



Hard white aphanitic biotitic tuff

Sandstone (1:6:3 B)

Sandstone, conglomerate and tuff, with abundant fossil logs up to one foot in diameter

Brown sandstone(16:60:24 A) with minor mudstone and shale

Poorly outcropping mudstone

Green-grey sandstone(0:54:46c)

Poorly outcropping green-brown mudstone with plant fragments; thin lenses fine brown sand.

Brown sandstone(1:6:3B)

Cherty mudstone; minor hard grey tuff

Brown carbonaceous shale

Green-brown lithic sandstone (0:78:22A) markedly lustre mottled near base

Light brn. sandstone with carbonaceous laminae

Vitric tuff

Grey tuffaceous sandstone

Pale green to buff argillite (recrystallized vitric tuff) with fine plant material

Green-brown sandstone(0:78:22B) with some fossil wood and minor conglomerate

To accompany Record 1968/55. F 55/A/92 of the cross-stratification to be measured. One set of measurements indicated a southerly direction of transport ($180^{\circ} \pm 30^{\circ}$), and the other, transport towards the east ($85^{\circ} \pm 13^{\circ}$).

Despite the variation in grain-size and bedding characteristics, sandstone in the unit has a relatively consistent mineralogical composition, being rich in volcanic rock fragments and plagioclase (andesine), and poor in quartz. The average composition is that of a feldspatholithic sandstone (2:66:32B)of Crook (1960). The most distinctive feature of the sandstone is however, the presence of large subhedral grains of clinopyroxene. Rock fragments are exclusively of volcanic origin - many porphyritic holocrystalline, some holohyaline with perlitic cracks and commonly replaced by chlorite. Small flakes of biotite and grains of euhedral apatite are common both presumably being derived from a volcanic source. Although sorting is moderate, most of the grains are angular. Sparry carbonate cement is common.

Although most of the minerals and all the rock fragments forming the sandstone have been derived from volcanics, the unit is not markedly tuffaceous when compared with the Mount Steel and Kia Ora Formations. Thin beds of vitric tuff however, are the only evidence of continuing vulcanism in the vicinity.

No marine fossils have been discovered in the Gyranda Formation, and the abundance of fine carbonaceous material, and the presence of fossil leaves and rare logs suggests a continental or transitional environment. The trough cross-stratified coarse sandstone represents dispersal by strong traction currents, presumably fluvial in this case, but it is doubtful whether fluvial deposition would account for the pattern of sedimentation. Allen (1964) describes cyclothems from the Anglo-Welsh Basin in which coarse cross-stratified channel sands are overlain by finer sediments representing vertical accretion deposits. But the cyclothems of the Gyranda Formation are composed of fine sediments which become coarser stratigraphically up the sequence, and the coarse sandstone does not lie on an obviously scoured surface. Assuming that the Gyranda Formation lies conformably on marine sediments, and that it is overlain by continental sediments, it is suggested that it was deposited in a transitional environment, such as a coastal plain. The fine sediments at the base of each cyclothem may represent tidal swamps and lagoons marginal to the coast. The coarser sandstones may represent channel and flood plain deposits possibly of the terrestrial portion of deltas which extended over the finer top-set sediment. It is suggested that minor marine transgressions in response to periodic subsidence were responsible for the recurrence of the mudstone-sandstone sequence, although it is not suggested that the base of each cyclothem in the Cracow area was necessarily deposited under marine conditions.

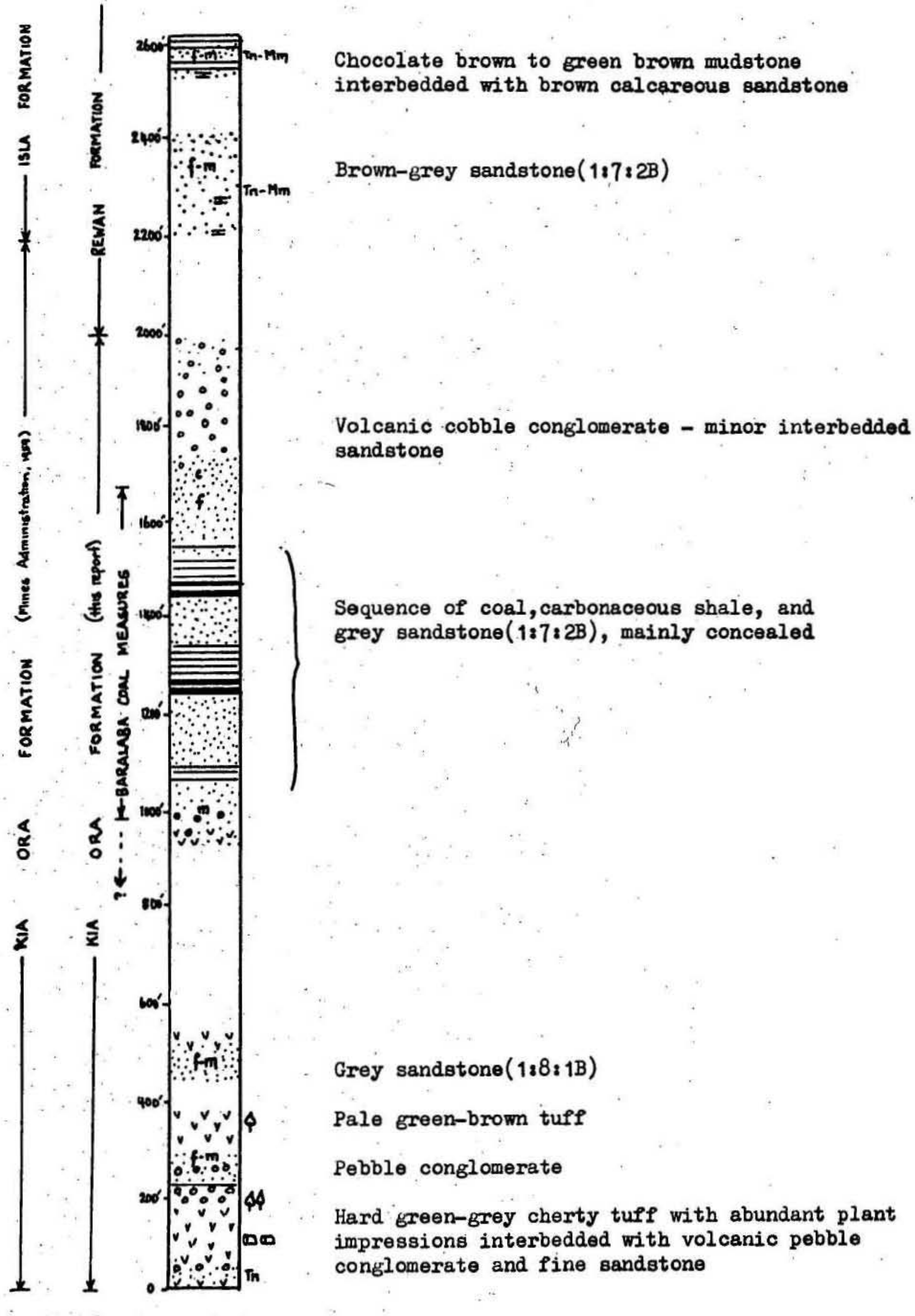
Kia Ora Formation

As originally defined, the Kia Ora Formation (Mines Administration, 1959), lying between the Gyranda and Isla Formations in the Cracow area, comprises: 970 feet of conglomeratic sandstone; 900 feet of locally cross-bedded, highly biotitic feldspathic, lithic sandstone, with sparse conglomerate pebbles; and 330 feet of coarse grained, feldspathic lithic, biotitic sandstone and conglomeratic sandstone. These units were not recognized in the course of regional mapping by Jensen et al. 1964, but it was realized at that time that the tuff beds placed at the top of the Gyranda Formation were overlain by a sequence containing coal, and that this was overlain by the Rewan Formation. The coaly sequence was correlated with the Baralaba Coal Measures even though at that stage the limits of the coal measures were not precisely defined in the type area. The tuff sequence was at that time included in the Gyranda Formation because in their original definition of the Gyranda Mines Administration (1959) mentioned a 'light grey, possibly tuffaceous siltstone' at the top of the unit.

In a preliminary edition of the Monto 1:250,000 Sheet, the Geological Survey of Queensland split the tuff sequence out of the Gyranda Formation, and named it the Kaloola Member of the Baralaba Coal Measures. The name Kaloola Member was subsequently published by Goscombe (1968) without formal definition.

SECTION M6 - KIA ORA FORMATION

One mile west of Kia Ora Homestead - Cracow area



To accompany Record 1968/55.

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Further work in the Cracow area has shown that the conglomeratic sandstone mentioned by Mines Administration is in fact interbedded with the hard cherty tuff beds formerly included in the Gyranda Formation (Kaloola Member). It seems reasonable to associate the Kaloola Member with the Baralaba Coal Measures because it contains thin coal seams, but it should not lose its separate identity. It is suggested that the term Kia Ora should be retained and that in the Cracow area it would include equivalents of the Baralaba Coal Measures and Kaloola Member which should be formally defined in areas to the north.

In the Cracow area, the Kia Ora Formation is about 2000 feet thick. The lower part of the unit consists of conglomerate, conglomeratic sandstone, siltstone, very thin coal seams and tuff (measured section M6, Fig. 4). Two types of conglomerate can be discerned, one closely associated with the fine tuff beds in the lower part of the formation, and the other distributed throughout the sequence, even above the uppermost coaly section. The conglomerate associated with the fine tuff beds is composed of a mixture of very angular and some rounded fragments of a light coloured banded acid volcanic rock up to two inches in diameter. It is probably a volcanic breccia, but in some places with the addition of rounded volcanic rock fragments, mainly biotite-rich flows and tuffs, it grades into a volcanic-lithic conglomerate. The volcanic breccia commonly has an open framework. The second variety of conglomerate, found throughout the sequence, also consists of volcanic clasts, mainly well rounded volcanic pebbles, but they are invariable imbedded in a lithic sandstone matrix. Banded flow rocks form the bulk of the pebbles, but perhaps the most interesting feature is the relative abundance of well rounded pebbles of biotite-rich tuff exactly similar to some of the tuff interbedded with the unit. Conglomerates of the Kia Ora Formation are generally thick bedded or massive, but thin lenses of cross-stratified sandstone have been observed within them in a few places.

The sandstone (5:75:20B) within the lower part of the sequence is commonly light brown to yellow in colour, in marked contrast to the green-brown sandstone (2:66:32B) of the Gyranda Formation, the difference probably being attributable to the lack of chlorite in the Kia Ora Formation and the alteration of the volcanic rock fragments. It is generally medium- to thick-bedded, medium-grained, moderately sorted, and pebbly. Rock fragments are either a mixture of volcanic and sedimentary types or exclusively volcanic. All rock fragments appear to be partly replaced by clay minerals, and showing various stages of replacement by iron oxides. Unweathered biotite flakes are common, and so also are small euhedral grains of apatite.

The tuff interbedded with the unit is undoubtedly the most spectacular rock in the Upper Permian sequence of the basin. In some places it has the appearance in hand specimen of a biotite microdiorite, consisting of grains of plagioclase and fresh dark brown biotite; but an extrusive origin is indicated where it grades into a biotitic chert containing fossil leaf impressions. In thin section the crystal tuff is seen to consist of subhedral crystals of andesine averaging 2mm in length and in many cases having a shattered appearance, together with deep reddish brown subhedral to euhedral biotite. The matrix, which forms up to 15 per cent of the tuff, consists of fine polycrystalline aggregates of feldspar, presumably original glassy volcanic dust. The crystal tuff grades vertically into finer vitric tuff with a conchoidal fracture, and into feldspatho-lithic sandstone described above.

Even the coarsest tuffs of this unit commonly contain well preserved fossil plant material, but it is in the very fine tuffs that one finds abundant fossil leaves and stems well preserved as impressions in what must have been originally a very fine volcanic ash. Very little of the carbonaceous material remains in these accumulations, but despite this, thin coal seams are interbedded with the tuffs, as shown by the thin seam exposed about 4 miles south-west of Theodore on the Theodore-Taroom road.

The upper part of the Kia Ora Formation is characterized by thick coal seams which are seldom seen at the surface, their presence being proved by exploratory drilling by private companies. Shallow drilling by B.M.R. revealed that part of the coal measures consists of sandstone (1:94:5A) consisting almost entirely of volcanic rock fragments, weathered plagioclase, and chalcedonic and clay matrix; chlorite is rare. In at least two places in the area, at Hill View Homestead, and near Lake Nash, cross-stratified sandstone and carbonaceous mudstone of the coal bearing sequence have been baked, fused, and brecciated at or near the surface. At both localities, large tors are to be found consisting of black and brown cross-stratified sandstone having a vesicular texture. In some cases the tors are composed of angular blocks of this sandstone fused together after brecciation. It has been postulated (King and Jensen, 1966), that this alteration was caused by the combustion of coal seams, which in turn generated enough heat and explosive force to 'bake' and shatter the surrounding sedimentary rocks. A modern example of such a phenomenon has been described by Rattigan (1967).

The top of the Kia Ora Formation in the Cracow area is marked by a distinctive thick bed of massive poorly sorted cobble conglomerate, consisting mainly of rounded flow-banded volcanic cobbles, and some rather more angular granite boulders and cobbles. This conglomerate is placed in the Kia Ora Formation because similar conglomerate is interbedded with the coal measures in this area. It is thought to be only of local extent and it probably lenses out northwards.

The Kia Ora Formation was deposited in a continental environment, probably on a vast flood plain over which was spread coarse channel sands and vertical accretion deposits as well as volcanic ash and piedmont deposits. The profusion of well preserved fossil leaves in the tuff constitutes strong evidence of a continental environment, and the complete absence of marine fossils in this case lends further support to the suggestion of non-marine conditions. The dominant dispersal agent must have been fluvial, although the drainage was poor for a considerable length of time. Thin beds of fine tuff containing the reed-like

Phyllotheca, so common in the lower parts of the unit, are evidence of local lacustrine or swampy conditions, as may be indicated also by the thick coal seams. The coal seams are relatively continuous but of variable thickness. Without examination of the coal and more detailed information concerning the thickness and lateral extent of the seams however, it is not possible to suggest any specific environments of deposition. The thick cross-stratified sandstone lying between the coal seams may constitute the only evidence of the existence of river channels.

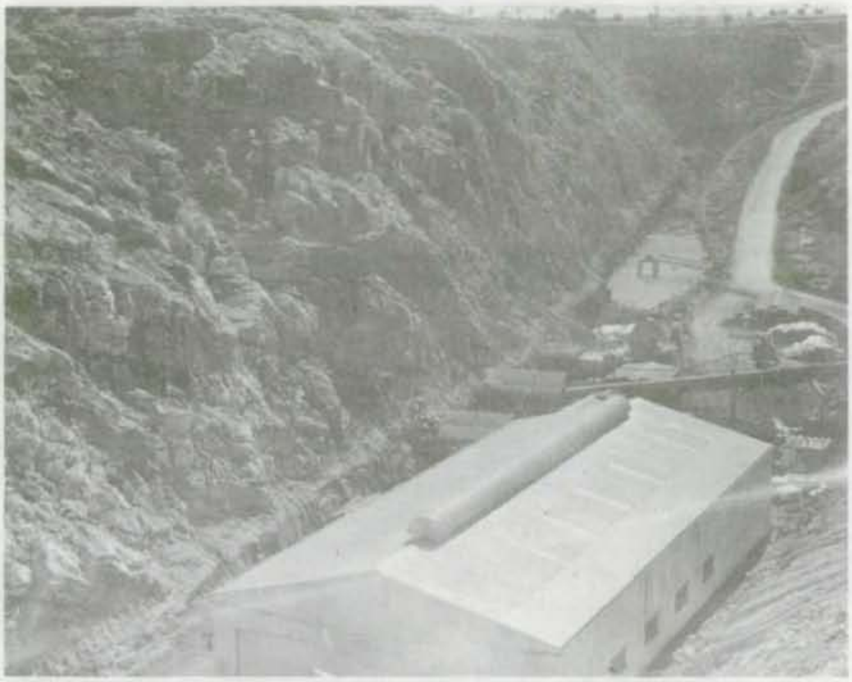
Contemporaneous vulcanism supplied much of the sediment deposited in the oldest parts of the formation,but vulcanism seems to have waned until by Rewan time it had probably ceased altogether. The thick unstratified conglomerate, composed of volcanic clasts many of which are of the same composition as the tuff in the lower part of the unit, indicates erosion of the site of vulcanism, and the spread of coarse piedmont fans from mountainous volcanic areas adjacent to this part of the basin.

BARALABA AND MOURA AREA

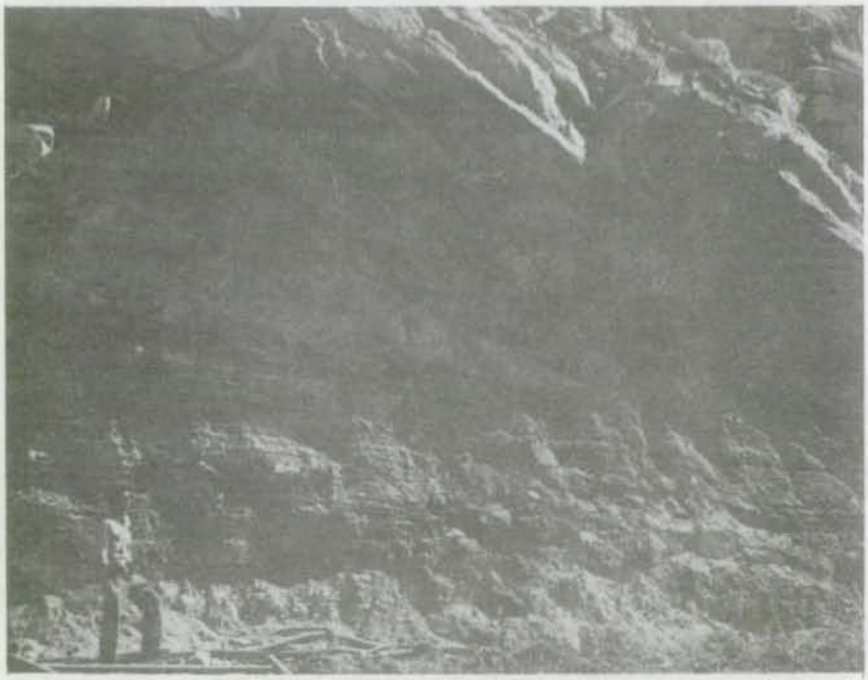
Apart from the exposures in the mines at Moura and in the Dawson River at Baralaba, the Upper Permian sequence was not studied during the present survey, and the following notes are included mainly to indicate the changes evident north of the Cracow area.

Previous investigations

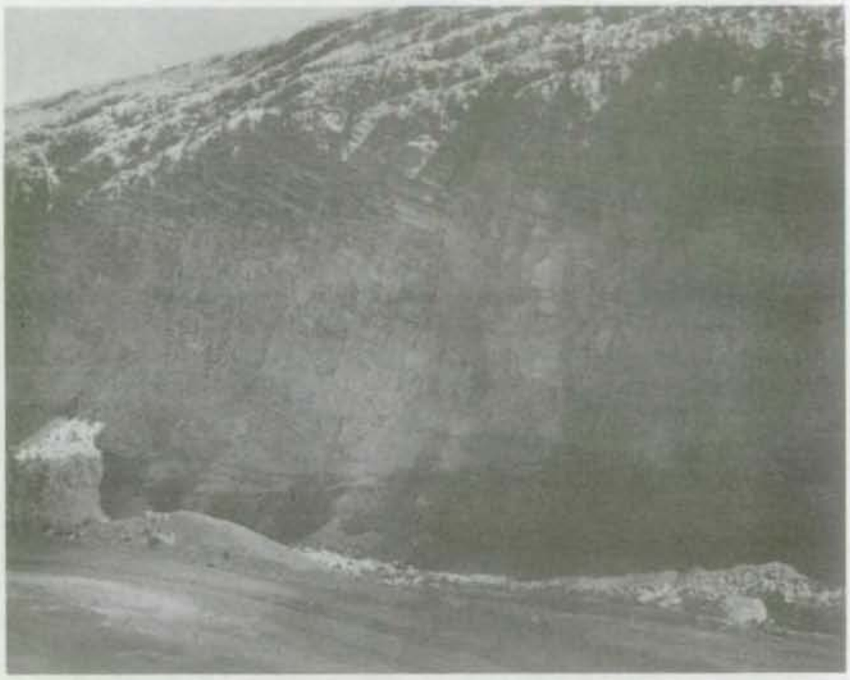
In the early part of the century, Dunstan (1901) in his survey of the geology of the Dawson and Mackenzie River valleys, distinguished a Lower Marine Series and a Lower Freshwater Series within the Permo-Carboniferous sequence in the area where Baralaba now stands. He went on further to describe the lithology and structure of the coal-bearing Freshwater Series from outcrops in the Dawson River. Reid (1939) summarized the results of drilling for coal in the area, and presented cross-sections, showing five seams in 450 feet of section, and indicating the existence of four others. Reid suggested that the massive thick-bedded



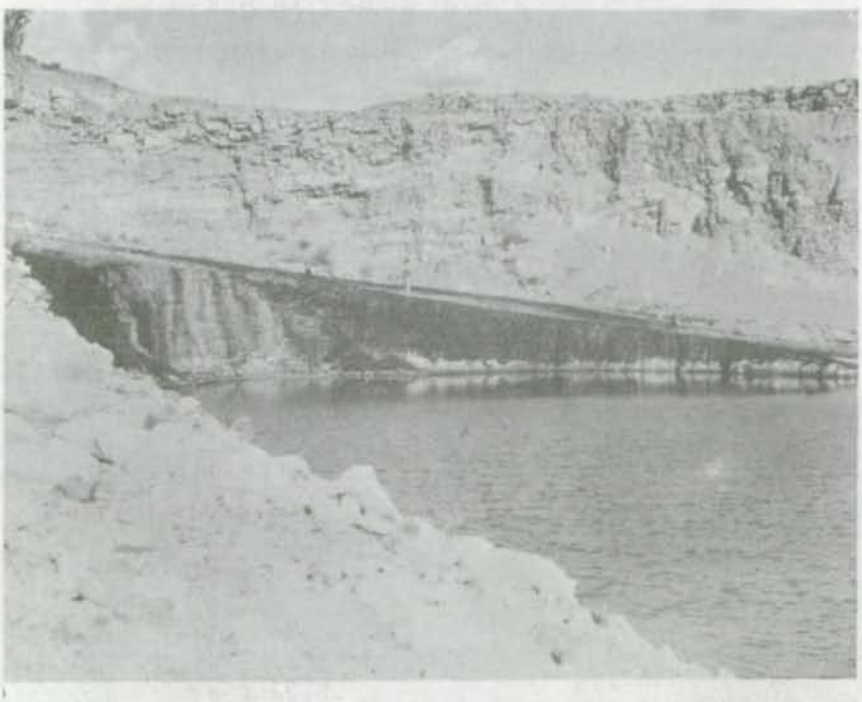
(i) Western wall of one open cut at Moura coal mine exposing foresets of thick bedded sandstone dipping north and overlying a thick coal seam which dips gently to the west.



(ii) Base of sandstone foresets on western wall. Solid coal extends downwards from level of man's head.



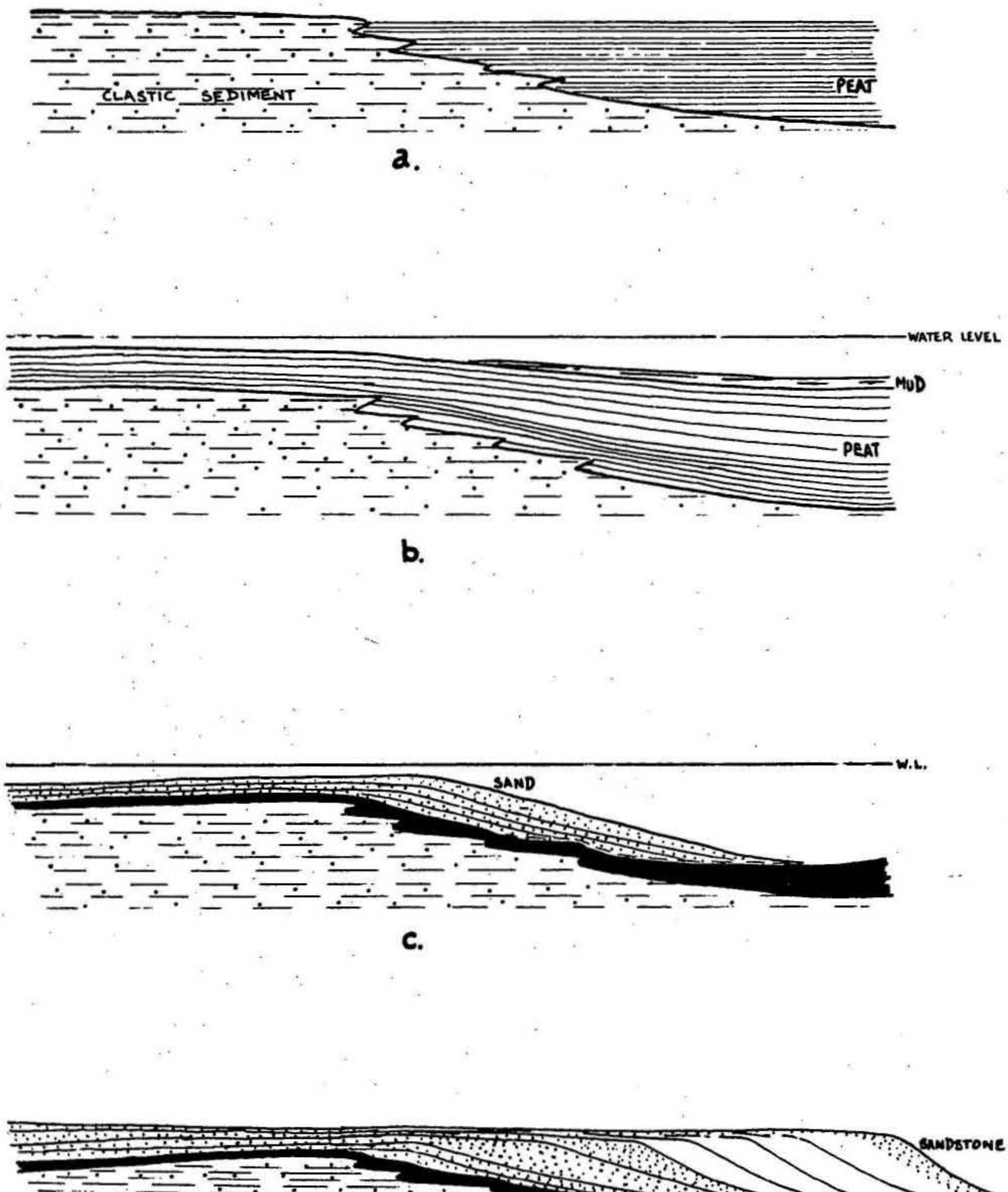
(i) Medium to thin bedded foresets overlying a coal seam at Moura. Coaly stringers extend from coal into sandstone. Wall about 80 feet high.



(ii) Foreset beds at Kianga open cut where coal dips to west and foresets to east.

Figure 5

An interpretation of the process responsible for the large cross-stratified units at Moura.



To accompany Record 1968/55. F 55/A/94

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sandstone at the traffic bridge over the Dawson River, which he called the 'bridge sandstone', could be used as a marker bed. Later (Reid, 1944) he coined the term Baralaba Coal Measures for the coal-bearing sequence, and indicated that it was underlain by a calcareous plant-bearing sequence. Drilling by the Department of Mines and Mount Morgan Pty Ltd has shown that the coal measures are approximately 1100 feet thick, with at least ten seams (Hawthorne, 1965). The Bridge Sandstone lies between the Dawson and Dunstan Seams. Hawthorne (1965) reports a number of tuff beds in the top 300 feet of the formation underlying the coal measures and he correlated these with the tuff under the coal in the Cracow area, and with those described by Reid (1946) in the upper part of the Fort Cooper Coal Measures. As in the Cracow area, the tuffs are interbedded with thin seams of poor quality coal, sandstone, and pebble conglomerate.

The Banana-Cracow area, south of the Baralaba area, was mapped by geologists from Mines Administration Pty Ltd between 1954 and 1958, and the following description is based on a brief summary of the geology given by Derrington and Morgan (1960).

The Oxtrack Formation can be traced for many miles north of Cracow with little change in lithology or thickness. West of the Banana Fault it is overlain by the Barfield Formation, 1600-2900 feet of olive green mudstone, and by the Flat Top Formation, 750 feet of grey clacareous feldspathic lithic sandstone with mudstone and with narrow bands of blue-grey limestone containing a rich marine fauna. East of the Banana Fault, equivalents of the Barfield Formation thicken considerably to an estimated thickness of between 7000 and 14000 feet. The thickness of the Flat Top Formation remains constant.

The Banana Formation, 2,100-3800 feet of olive green mudstone, siltstone, and minor lithic sandstone, overlies the Flat Top Formation, and is considered in this report to be equivalent to the Mount Steel Formation. Scattered marine fossils have been found in this formation north of Banana, and thin coal seams have been reported from bores near Banana. It is overlain by the Wiseman Formation (equivalent to the

Gyranda Formation) which consists of strongly outcropping calcareous feldspathic sandstone, with interbedded olive green mudstone and siltstone, and this sequence grades up into a tuff, conglomerate, and coal-bearing sequence, recognizable as the Kia Ora Formation. The thick coal seams mined at Moura lie within the upper part of this unit.

Baralaba Coal Measures at Baralaba

The Baralaba Coal Measures together with an underlying tuff-conglomerate sequence are regarded, in this report, as equivalent to part of the Kia Ora Formation. Outcrop of the Baralaba Coal Measures in what must be regarded as their type area, the Dawson River at Baralaba, is unsatisfactory because its relationship to the rest of the Permian and Triassic sequence is not clear owing to lack of outcrop and complicated structure, but exploratory drilling has revealed the general sequence. The coal is interbedded with mudstone, siltstone, and sandstone. The mudstone is generally dark grey and carbonaceous, and it contains thin 'ironstone' beds with abundant fossil leaf impressions. Sandstone of the unit is light coloured, calcareous, and cross-stratified. The Bridge Sandstone (Reid, 1939), essentially a litho-feldspathic sandstone (8:31:61B), of Crook (1960), is characterized by: a high proportion of feldspar; very fine-grained and commonly banded volcanic rock fragments replaced by silica and possibly montmorillonite; and a clay cement, which appears to have formed by the breakdown in situ of large mica flakes. Sandstone (3:80:17A) lower in the sequence lacks the clay cement but the constituents are also derived largely from a volcanic source. Measurement of the orientation of cross-stratification of sandstone in the unit at Baralaba, indicated currents moving towards the west or south-west.

Baralaba Coal Measures at Moura

The open cut mines at Moura, south of Baralaba, reveal that the coal measures are composed of thick seams interbedded with siltstone, soft carbonaceous mudstone, shale, fine to coarse sandstone (3:75:22B) and conglomerate. The thick-bedded sandstone (3:75:22B) above one of the seams being worked has a clay cement similar to that of the Bridge Sandstone at Baralaba, except that it is partially replaced by small rhombs of dolomite. This sandstone is cross-stratified on a very large scale (Plates 2i, 3i) the thickness of the sets being of the order of 100 feet. The sandstone stratification dips at a maximum of 30° towards the north, whereas the dip of the coal, the regional dip, is about 8° to the east. The base of the sandstone is conformable with the beds of carbonaceous mudstone and coaly shale directly above the coal seam (Plate 2ii), and in some places thin coaly bands extend from the seam into the sandstone along the bedding (Plate 3i). Sandstone above the coal in some parts of the mine is medium- to thin-bedded with graded units up to six inches thick. Although the coal dips on a regional scale to the west, local rolls and terraces are exposed at the top of the seams in the open cuts. The western wall of one open cut above the 'C' seam shows sandstone in which the thin bedding lies parallel to the top of the seam on an upper terrace, and oblique to the top of the seam on the lower terrace (Fig. 5d). This change apparently coincides with the edge of the terrace in the lowest beds.

The most likely explanation is the accumulation of sand in a lacustrine delta built out from the edge of a basin subsiding unevenly under the influence of differential compaction (Fig. 5). The interpretation in the figure relies on the inferred presence of a relatively incompressible sand or shale body, to create the higher terrace from which the delta extended. The formation of the cross-stratification by the movement of a sand dune across a peat swamp cannot be entirely dismissed but the relationship of the stratification to the present terraces supports the explanation based on the formation of a subaqueous delta. The relationship of seam thickness to the structure of the overlying sandstone would test this interpretation. Studies of grain-size distribution of the sand, aimed at proving or disproving an aeolian origin, will be hampered by post-depositional alteration.

Northern Bowen Basin

EXMOOR AND FORT COOPER AREAS

Previous investigations

The original three-fold division of the Permian sequence of the Bowen Basin into Lower, Middle, and Upper Bowen by Jack and Etheridge (1892) was adopted with little change by most subsequent authors, including Reid (1924-25, and 1946) who probably made the largest contribution to the geology of the northern part of the basin (Table 2). Reid (1946) proposed two tentative units within the Upper Bowen of the area - the Fort Cooper and Elphinstone Coal Measures, but it was not until 1964 that the Middle Bowen Beds were divided into three units (Dickins, Malone, and Jensen, 1964), the youngest of which was later named the Blenheim Formation (Malone, Jensen, Gregory, and Forbes, 1966).

Reid's (1946) division of the Upper Bowen Formation into two provisional units was apparently intended to apply to the sequence between the Middle Bowen Formation and the Carborough Sandstone. The lower unit, the Fort Cooper Coal Measures, was said to be characterized by ridges of limonitic sandstone and brown shale carrying an abundant fossil flora, and interspersed with white fossiliferous cherty shale. The overlying Elphinstone Coal Measures were said to be composed of yellowish to grey sandstone and shale, as well as conglomerate and coal. It is now apparent that the interval between the coal of the Elphinstone Coal Measures and the base of the Carborough Sandstone, includes an upper section devoid of coal and having the lithological characteristics of the Rewan Formation. It is also apparent that a thick sequence of shale, sandstone, and conglomerate, lithologically distinct from the limonitic sandstone and fossiliferous shale beds, underlies the Fort Cooper Coal Measures and rests conformably on the Blenheim Formation. The name Hail Creek Beds is proposed for this unit.

TABLE 2

CHANGES OF STRATIGRAPHIC NOMENCLATURE OF PERMIAN AND LOWER TRIASSIC SEQUENCE IN NORTHERN BOWEN BASIN

<table>
<tr><th>Jack & Etherdige 1892</th><th>Reid 1924-25</th><th colspan="2">Reid 1946</th><th>Malone, Jensen, Gregory & Forbes 1966</th><th colspan="2">This report</th></tr>
<tr><td rowspan="5">Upper Bowen Formation</td><td>Redcliffe Series</td><td colspan="2">Carborough Sandstone</td><td>Carborough Sandstone</td><td colspan="2">Carborough Sandstone</td></tr>
<tr><td rowspan="4">Upper Bowen Coal Measures</td><td rowspan="4">Upper Bowen Coal Measures</td><td rowspan="2">Elphinstone Coal Measures</td><td rowspan="4">Upper Bowen Coal Measures</td><td colspan="2">Rewan Formation</td></tr>
<tr><td rowspan="3"></td><td>Elphinstone Coal Measures</td></tr>
<tr><td rowspan="2">Fort Cooper Coal Measures</td><td>Fort Cooper Coal Measures</td></tr>
<tr><td>Hail Creek Beds</td></tr>
<tr><td rowspan="3">Middle Bowen Formation</td><td rowspan="3">Middle Bowen Marine Series</td><td colspan="2" rowspan="3">Middle Bowen Series</td><td>Blenheim Formation</td><td rowspan="3">Back Creek Group</td><td>Blenheim Formation</td></tr>
<tr><td>Gebbie Formation</td><td rowspan="2"></td></tr>
<tr><td>Tiverton Formation</td></tr>
</table>

Blenheim Formation

The type section of the Blenheim Formation (Malone et al. 1966) is in Blenheim Creek, about 40 miles south-south-east of Collinsville. In this area, the unit consists of micaceous, blue-grey or brown, calcareous mudstone, and siltstone, with minor thick bedded sandstone (70:20:10C). The unit is distinguished from the underlying Gebbie Formation by an abundance of mudstone, and the base is generally marked by a conglomeratic mudstone. The top of the unit is marked by a change from a dominantly mudstone sequence to a sandstone-mudstone sequence, and it also coincides in this area, with a change from quartz-rich to quartz-poor sandstone.

The lower half of the unit in the type area (Fig. 6) is characterized by blue-grey to brown mudstone, poorly sorted and containing large angular clasts up to 6 inches across of fine grained sediments and low grade metamorphics. Pebbles found in the mudstone higher in the sequence, are of volcanic rocks and schist. Thick lenticular beds of quartz-rich sandstone are common towards the top of the unit. Mudstone near the top of the unit is notable for its churned bedding (Plate 4ii), taking the form of small ovoid patches and elongate swirls. The unit is well bedded the bedding being quite regular. No graded units were observed, and the sands are cross-stratified.

The top part of the Blenheim Formation is exposed in the Bowen River at Exmoor Homestead (Fig. 6). At this locality the Big Strophalosia Zone (Reid, 1924-25), 100 feet of poorly sorted, muddy coquinite (Plate 5), is overlain by a thick sequence (1900 feet) of fossiliferous mudstone and sandstone. The lower 1500 feet of this unit appears to be mainly dark blue to brown, micaceous, muddy siltstone, with scattered shelly fossils, mainly pelecypods, and bryozoan. The mudstone contains scattered pebbles and boulders, some of which are quite large. These are particularly common about 1000 feet above the Big Strophalosia Zone, where there is at least one angular block (Plate 4ii) surrounded by small rounded pebbles and cobbles, measuring 3 feet in diameter. It consists of porphyritic flow-banded dacite, similar to rock types common in the Lower Permian Carmila Beds. Towards the top of the unit, cross-stratified thin to medium bedded sandstone is common. The highest beds in the sequence consist of blue-grey micaceous, calcareous silty mudstone with large discoidal calcareous concretions.

Sandstone of the unit varies from varieties rich in lithic fragments (55:35:10) to quartz rich varieties (92:2:6), but the average mineralogical composition (72:18:10) is close to that of a sublabile sandstone (Crook, 1960). The sandstone is generally medium- to fine-grained and poorly sorted, containing both scattered pebbles, and up to 35 per cent matrix. The origin of the smaller rock fragments as seen in thin section is unknown, but volcanic, metamorphic and plutonic varieties can be recognized. Iron-stained carbonate cement and bioclasts are common. Of the heavy minerals observed in thin section, small rounded grains of apatite are most common, but green, brown, yellow, and blue varieties of tourmaline have been observed in many samples.

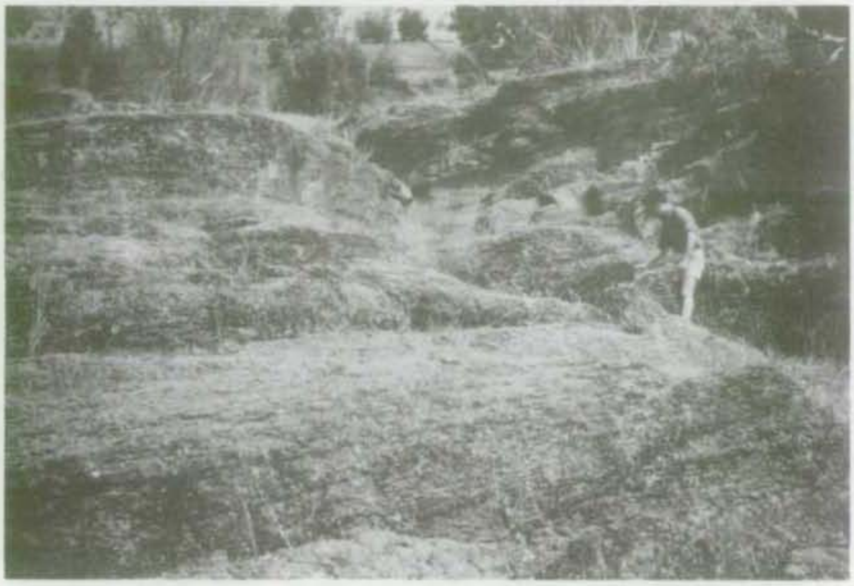
The presence of marine fossils at many levels in the Blenheim Formation is sufficient evidence to indicate that the unit is dominantly marine, and the abundance of these shelly fossils in places, especially associated with the Big Strophalosia Zone suggests deposition within the neritic environment. Thin beds of cross-stratified sandstone indicate the operation of traction currents, but most of the unit is composed of paraconglomerate, or pebbly mudstone. The method of deposition of this sediment is not known. There are no indications of the action of turbidity currents or subaqueous mudflows and the operation of such currents appears unlikely. An alternative mechanism is the supply of the coarser material by ice-rafting, and the only supporting evidence for this process is the fact that the clasts are commonly concentrated into patches on the bedding surface, suggesting simultaneous deposition. A third possibility, is that the Blenheim Formation was deposited in relatively shallow water in which traction currents and wave action were operative, close to a well drained hinterland which supplied mainly mud and silt, but which occasionally supplied sand or gravel. The gravel, especially the larger blocks, may have been moved by strong wave action to its present position.

PLATE 4

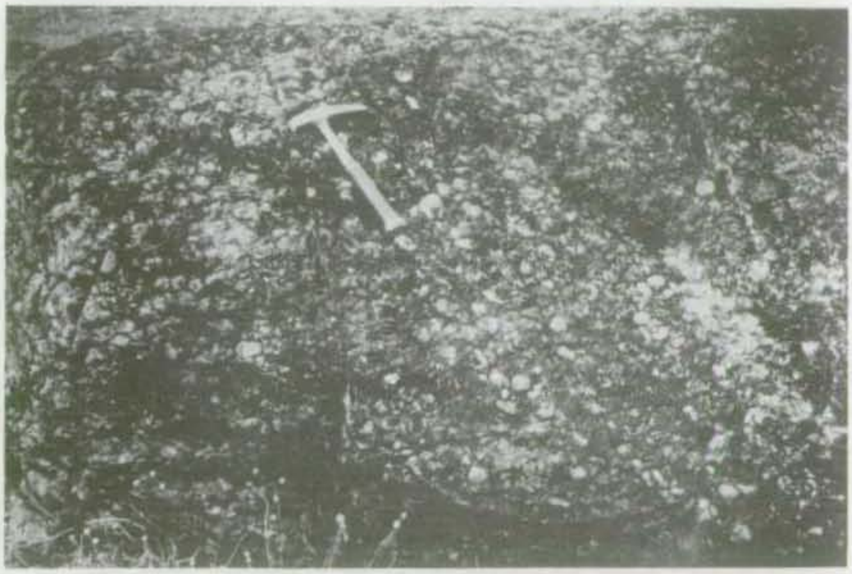
(i) A large angular block of flow banded porphyritic dacite similar to rocks in the Lower Permian Carmila Beds, preserved in Upper Permian Blenheim Formation. The block is surrounded by small subangular pebbles - mainly volcanics.

(ii) Dark blue-grey muddy siltstone at the top of the Blenheim Formation in Blenheim Creek, extensively churned by burrowing organisms.

PLATE 5



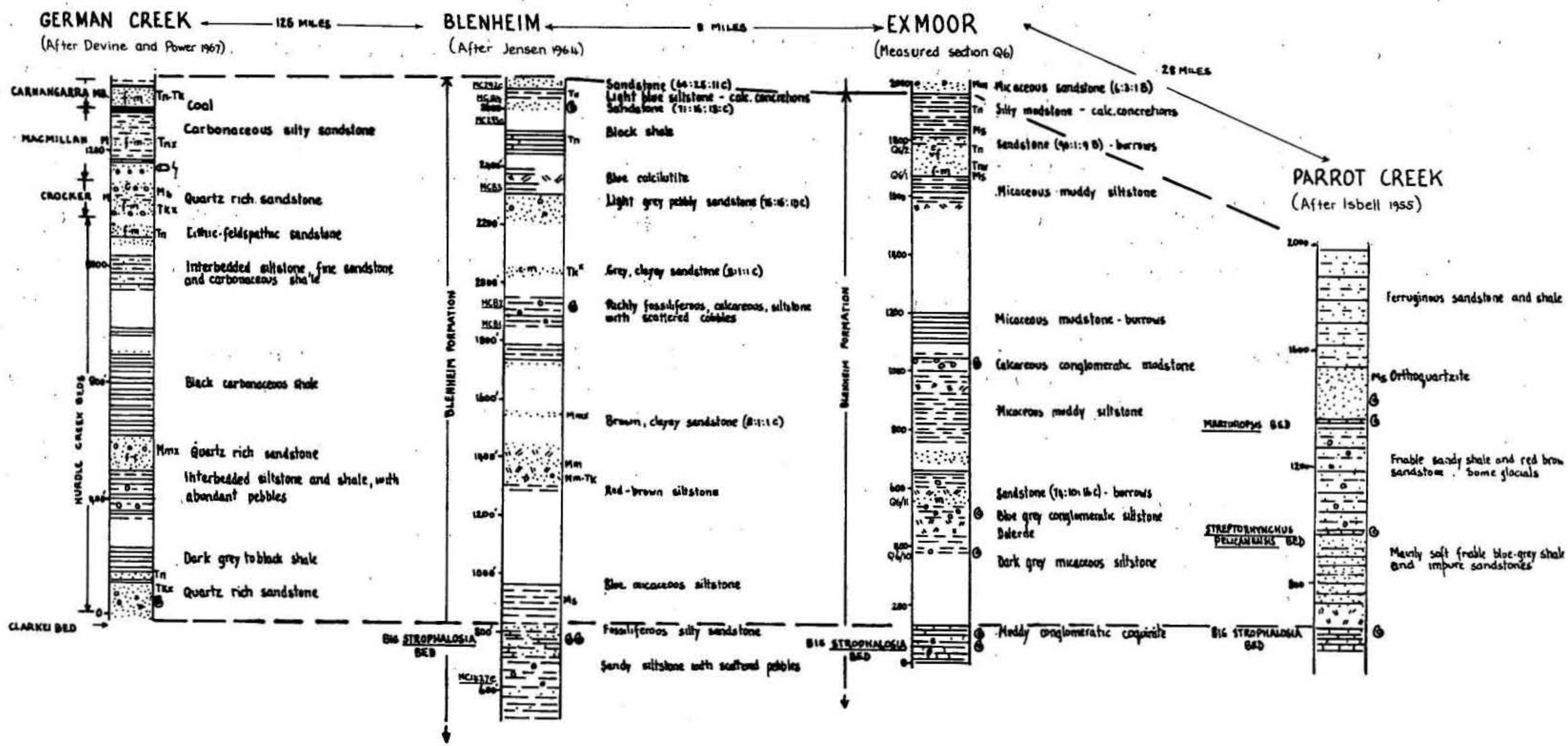
(i) The 'Big Strophalosia Zone' at Exmoor; medium to thick beds of pebbly muddy coquinite dipping at about 35° to the south-west.



(ii) Part of a bed in the 'Big Strophalosia Zone'; mainly brachiopod shells in a muddy matrix with scattered pebbles and cobbles.

Fig. 6

UPPER PART OF BLENHEIM SUBGROUP
COMPARISON OF SECTIONS IN CENTRAL AND NORTHERN BOWEN BASIN



To accompany Record 1968/55.

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The overall change in lithology within the Blenheim Formation - a change which can be recognized in the 'Passage Beds' and Hurdle Creek Beds farther to the south-west, is from fine-grained sediments, silts and muds with minor fine sandstone, to sandstone with minor siltstone. It appears most likely that the unit was deposited in a shallow epicontinental sea in which the depth of water became progressively less, and that the change of lithology reflects the eastward spread of quartz rich sands to replace the gravelly muds and silts.

Hail Creek Beds

The Hail Creek Beds is a new name proposed herein, derived from Hail Creek, a tributary of Bee Creek, in the headwaters of which outcrop of the beds is reasonably common. The proposed type section is along the Lake Elphinstone-Homevale road, between the grid points 67663169 and 68083179 on the Mount Coolon 1:250,000 Sheet area. The unit has not been mapped in detail, and its distribution is not known with any precision. It can be recognized in the Exmoor area, forty miles to the north-north-east of the type section.

In contrast to the Blenheim Formation, the Hail Creek Beds consist of brown carbonaceous mudstone and shale, lithic sandstone, and volcanic pebble and cobble conglomerate; a composite section of the sequence, totalling 4,500 feet, is shown in Figure 7. The unit lies conformably on the Blenheim Formation, and it is overlain conformably by the 'limonitic sandstone and brown shale' of the Fort Cooper Coal Measures (Reid, 1946).

In the Fort Cooper area, the base of the unit is marked by brown calcareous sandstone (15:60:25C), with scattered pebbles of mudstone and volcanics, and with some beds up to 40 feet thick of conglomerate. The conglomerate is composed of rounded pebbles and cobbles of volcanics and lithic sandstone, in a lithic sand matrix; pieces of silicified fossil wood are commonly preserved in these beds. Higher in the unit, in the upper parts of measured section Q4 (Fig. 7), there appears to be a regular alternation of sandstone (2:90:8A) and mudstone, somewhat similar to the pattern of sedimentation observed in the Gyranda Formation. The sandstone is commonly fine- to medium-grained, but bedding characteristics vary widely from thin to thick, and from regular to cross-stratified. The mudstone is generally dark grey to brown in colour, and in places it becomes exceedingly carbonaceous, suggesting the possibility of concealed interbedded coal seams. Large discoidal calcareous concretions are found at a few levels in this part of the sequence. Higher in the unit, in the lower part of measured section P7 (Fig. 7), green-brown silty mudstone predominates, interbedded with sandstone (0:75:25). At the top of the unit sandstone is more common, and this grades into the brown sandstone of the Fort Cooper Coal Measures.

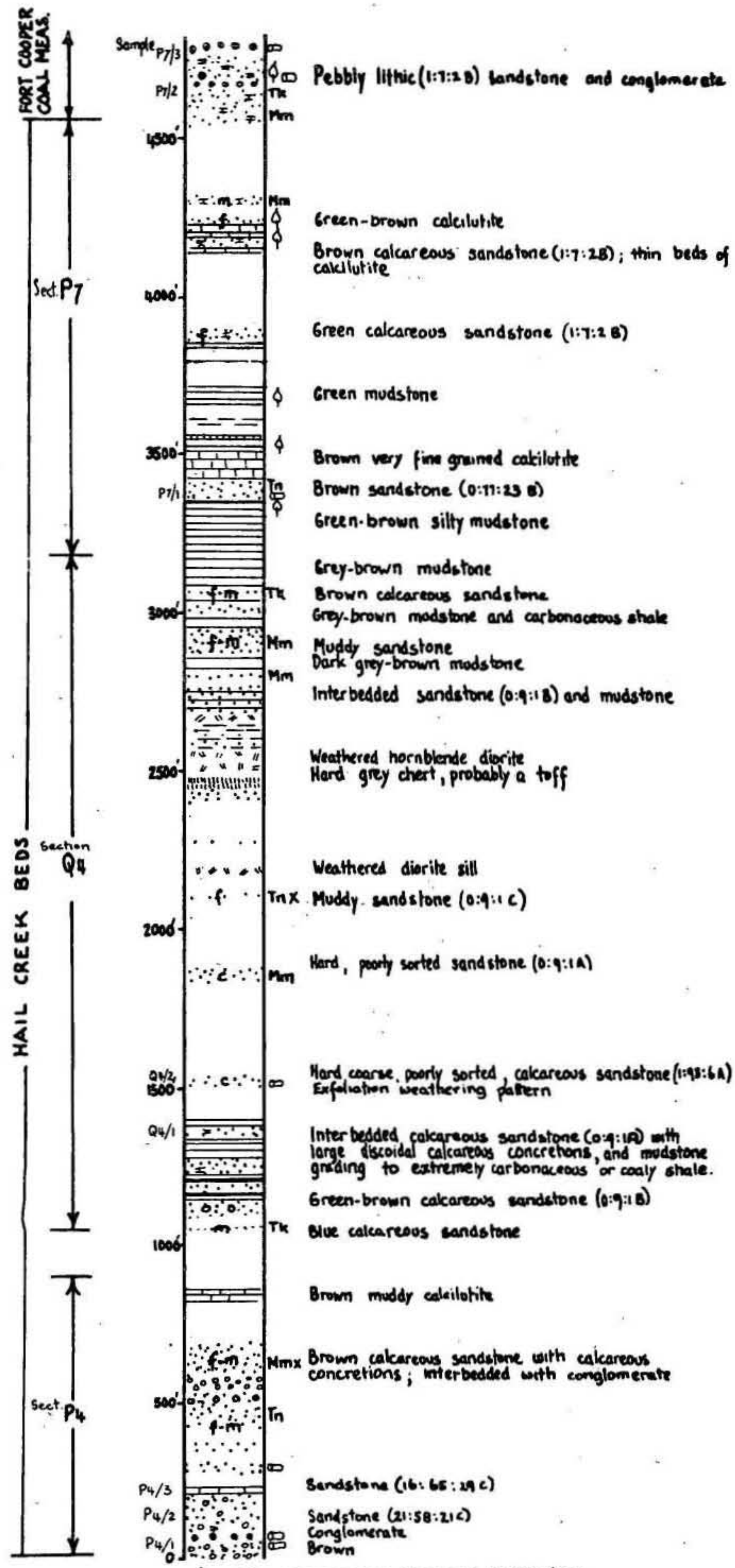
In the lower 800 feet of the unit, sandstone carries about 20 per cent quartz, whereas above that level quartz is rare. This change coincides with a change from a mixed, volcanic-sedimentary metamorphic provenance of the rock fragments, to a dominantly volcanic provenance, and which might indicate the lower part of the unit could be recognized as a separate formation.

The change from the Back Creek Group to the Blackwater Group is nowhere better exposed in the northern part of the basin, than in the Bowen River at Exmoor, where the Blenheim Formation is conformably overlain by the Hail Creek Beds. The lower 1400 feet of this unit (Fig. 8) are composed of brown mudstone interbedded with green-brown calcareous, moderately well sorted, sandstone (25:50:25B). The basal 200 feet consist of pebbly sandstone and brown slightly micaceous mudstone, in contrast to the topmost beds of the Blenheim Formation which are micaceous blue mudstone and sandstone. Richly carbonaceous mudstone and coaly shale is interbedded with shale and siltstone in the interval between 200 and 400 feet above the base of the unit, and in its unweathered state this part of the sequence might contain coal seams. Thin seams of coal appear higher in the sequence but they are commonly intruded (Plate 6). It is overlain by a thick moderately well sorted pebble conglomerate of porphyritic acid volcanics with glassy quartz phenocrysts, hornfels, and quartzite. Pebbly lithic sandstone and

Figure 7

HAIL CREEK BEDS

A composite of four measured sections
(See figure for locations)



To accompany Record 1968/55.

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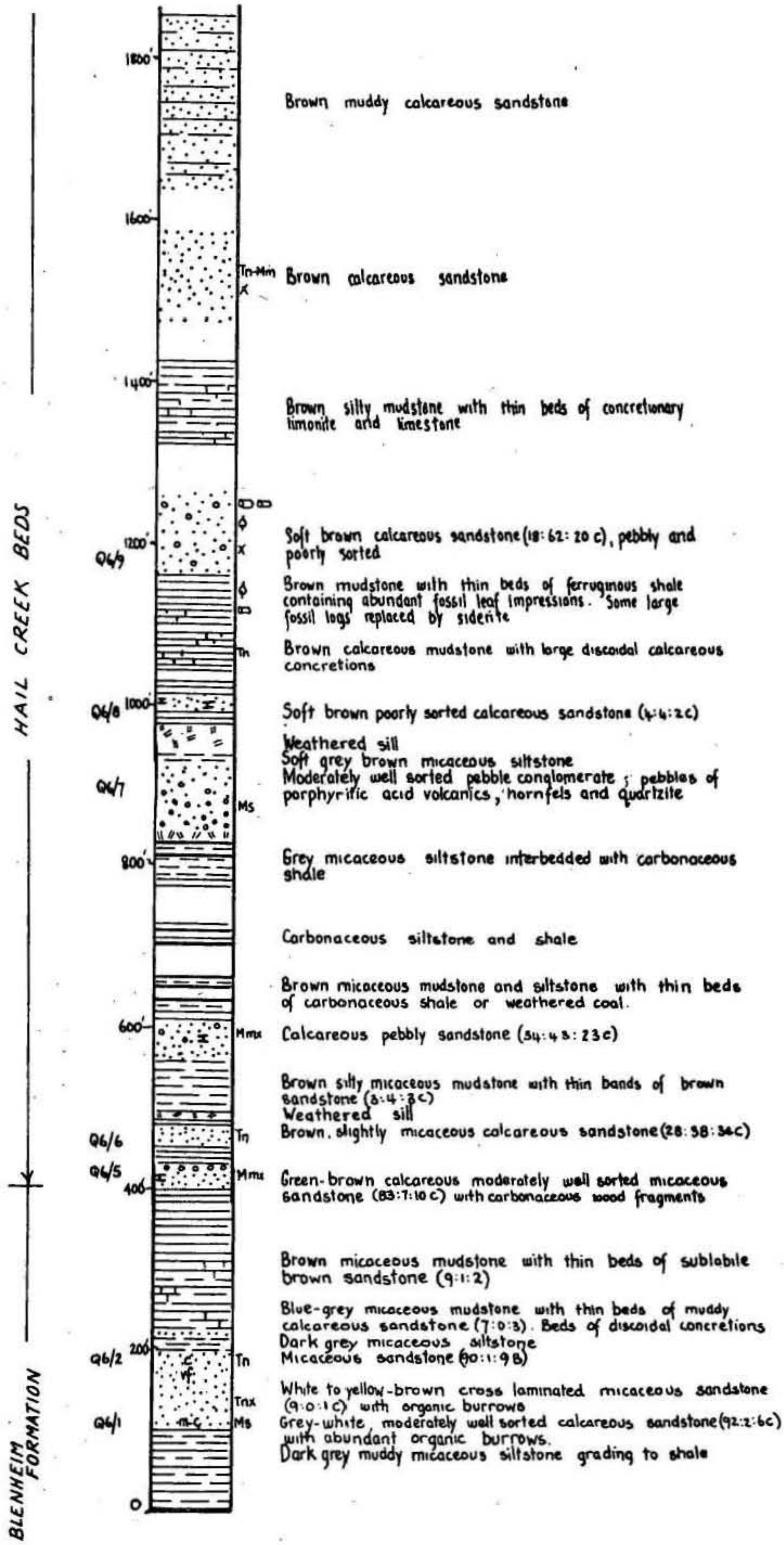
Figure 8

HAIL CREEK BEDS
Section Q6 measured in Bowen River and a small tributary near EXMOOR HOMESTEAD



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calcareous mudstone with lenses of concretionary limestone are common above this conglomerate, and fossil logs are common. Outcrop peters out above a thick sequence of dark brown muddy calcareous lithic sandstone which occupies the top of the exposed sequence (Section Q6, Fig. 8). Samples of sandstone from measured section at Exmoor show clearly the change in major mineralogical composition in the transition from the Back Creek Group to the Blackwater Group. Sandstone at the top of the Blenheim Formation (Samples Q61 and Q6/2, Appendix 1) contains little feldspar or rock fragments, the framework being composed of about 90% quartz. Samples from sandstone above the base of the Hail Creek Beds show a progressive decrease in the amount of quartz in the framework, and a corresponding increase in the amount of rock fragments and feldspar. Sandstone (83:7:10C) near the base of the unit appears to have a mixture of rock fragments, whereas a volcanic provenance is indicated in the sandstone (20:62:18B) taken from a position 800 feet above the base.

Cross-stratification is not common in the Hail Creek Beds, and only a few measurements were made. In the Fort Cooper area the average direction of sedimentation in two localities was found to be towards the south-south-east. In the Exmoor area cross-stratification in the base of the unit indicated various directions from south-east through south-west, to north-west.

No gradation from fine to coarse sediments has been recognized within the alternations of sand and mud, and it is not suggested, as in the case of the Gyranda Formation, that the Hail Creek Beds are mainly of coastal plain origin. Indeed, the abundance of fossil plant debris and the total lack of marine fossils suggests an overall continental environment of deposition, and the alternation of sandstone and mudstone is almost certainly the result of fluvial deposition. The abundance of coarse sediments near the base of the unit, particularly the thick beds of rounded conglomerate, suggest that the unit is partly a piedmont deposit.

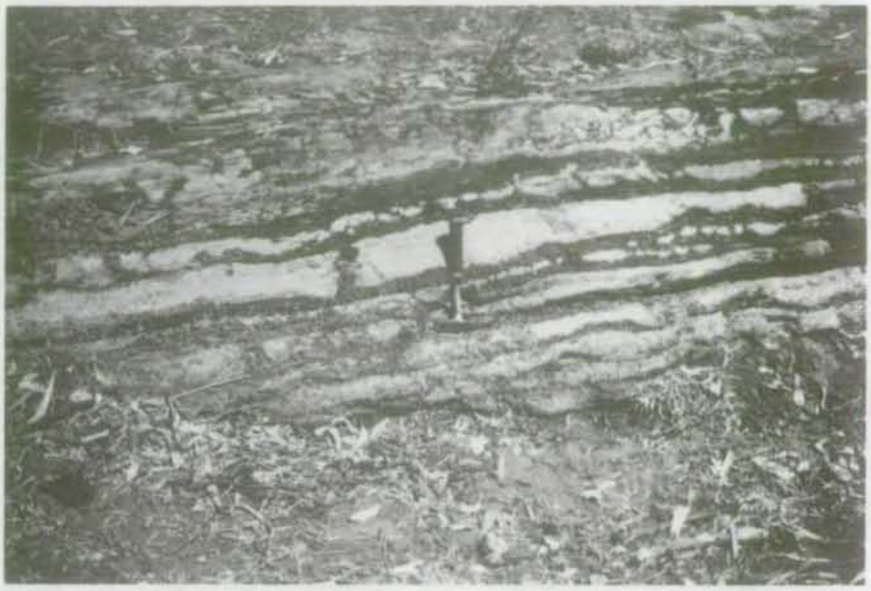
Fort Cooper Coal Measures

A type section of the Fort Cooper Coal Measures is proposed between points 67533209 and 67413188 Mount Coolon 1:250,000 Sheet area, in the headwaters of Hail Creek (Fig. 10) which is shown in Figure 8 (part of measured section Q5). The Fort Cooper Coal Measures so defined are 1250 feet thick.

In the Fort Cooper area, the unit is composed of green lithic sandstone, conglomerate, mudstone, carbonaceous shale, and coal, and thin beds of grey white cherty tuff bearing an abundance of fossil leaf impressions. Bedding varies from thin to thick, and some of the thick conglomerate and sandy conglomerate beds appear to be quite massive. The thick-bedded sandstone units are commonly cross-stratified; the fine sediments, shale, mudstone, and carbonaceous mudstone are generally thin-bedded. The base of the unit is taken as thick beds of pebbly sandstone lying conformably on sediments of the Hail Creek Beds at the base of section Q5 (Fig. 9). This is overlain by a thick alternating sequence of carbonaceous shale and pebbly lithic sandstone, but higher in the sequence the sandstone is interbedded with thin beds of grey-white cherty tuff (Plate 7ii), which bear a multitude of fossil leaf impressions. Only in a few places do these tuffs form thick beds. Carbonaceous shale and conglomerate are more common towards the top of the unit than in the middle part. Fossil logs are common throughout the Fort Cooper Coal Measures, but especially associated with the conglomerate and tuff beds. A few fossil stumps are standing in their growth position in the tributary of Hail Creek where section Q5 was measured (Plate 7i).

Pebble conglomerate and conglomeratic sandstone are common at the base and near the top of the unit. The pebbles are generally rounded, and composed of acid and intermediate volcanic rocks. Other rock types, quartz-rich sandstone (9:0:1A) hornfels, and phyllite are also present. The clasts are commonly cemented with calcite or fibrous chlorite, or both. The matrix is composed of the same type of rock fragments as the framework, with the addition of large subrounded feldspar grains, and minor quartz.

PLATE 6



(i) Coal, presumably mobilized by nearby intrusion, forming veins in sandstone of the Hail Creek Beds; Bowen River at Exmoor.

(ii) Large discoidal sideritic concretions in mudstone of the MacMillan Member, near Carnangarra Homestead.

Figure 9

FORT COOPER AND ELPHINSTONE COAL MEASURES

Measured in the headwaters of Hail Creek - Nebo area

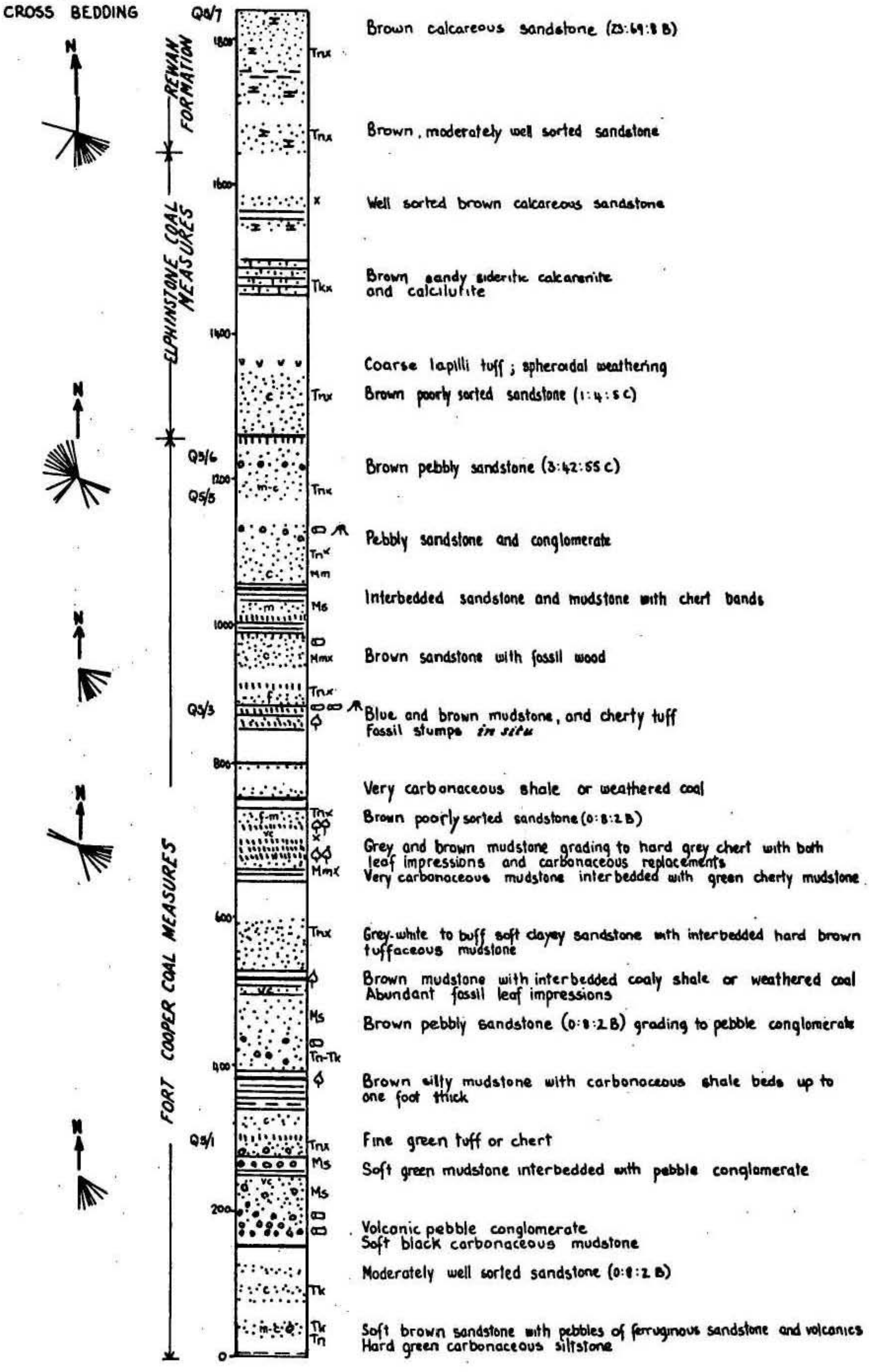


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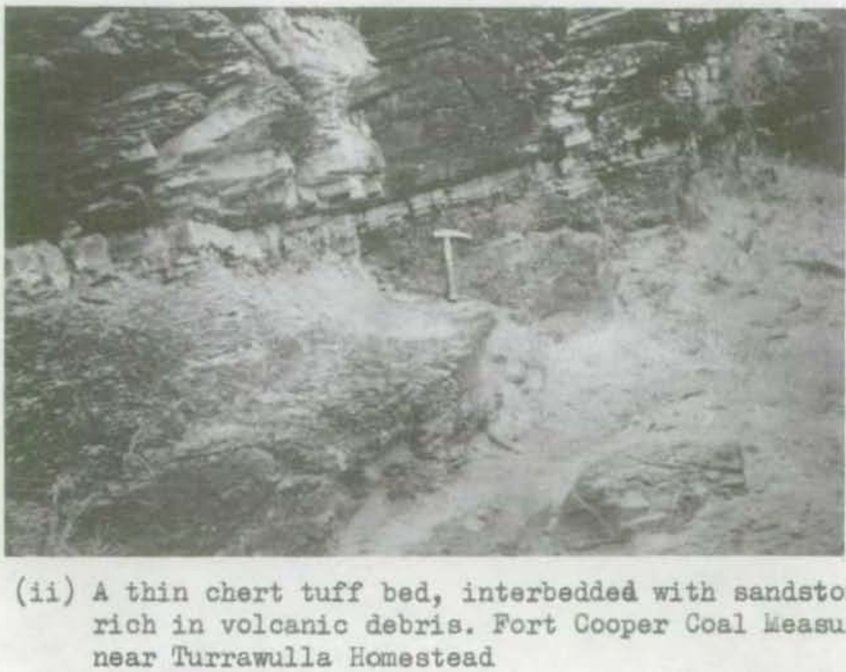
PLATE 7

(i) A fossil tree stump preserved in its growth position above a thin cherty tuff bed; circular structures on each side of trunk are concretions. Hail Creek area. Fort Cooper Coal Measures.



(ii) A thin chert tuff bed, interbedded with sandstone rich in volcanic debris. Fort Cooper Coal Measures near Turrawulla Homestead

Sandstone in the unit when weathered appears to be limonitic, and develops a distinctive rectangular 'onion skin' weathering surface. Beds up to 9 feet thick, apparently composed of red-brown limonite, have been observed near Saint Albans Homestead. In thin section, fresh sandstone (2:54:44B) has a green-brown fibrous cement which in some samples is probably stilphomelane, and in others possibly a chlorite. As in the conglomerate, the rock fragments composing the framework are mainly of volcanic origin, dominantly andesitic. Feldspar, forming a major part of the framework, is mainly plagioclase in the oligoclase-andesine range.

Some cherts interbedded in the sequence are not obviously tuffaceous, being composed of fine quartz, feldspar, and clay minerals. Other samples however, proved to be vitric tuffs, with devitrified glass shards and ragged pumice fragments in a fine chalcedonic matrix.

Cross-stratification measurements in section Q5 (Fig. 9) indicate a reasonably consistent movement of sediment towards the south-east during the deposition of most of the unit. An exception is the strong north-east facing on cross-beds in conglomeratic sandstone at the top of the unit. Almost the same spread of directions is noticeable in measurements made in the unit south-west of Mount Gotthardt (Fig. 11). The average direction however, in this area is towards the south-west.

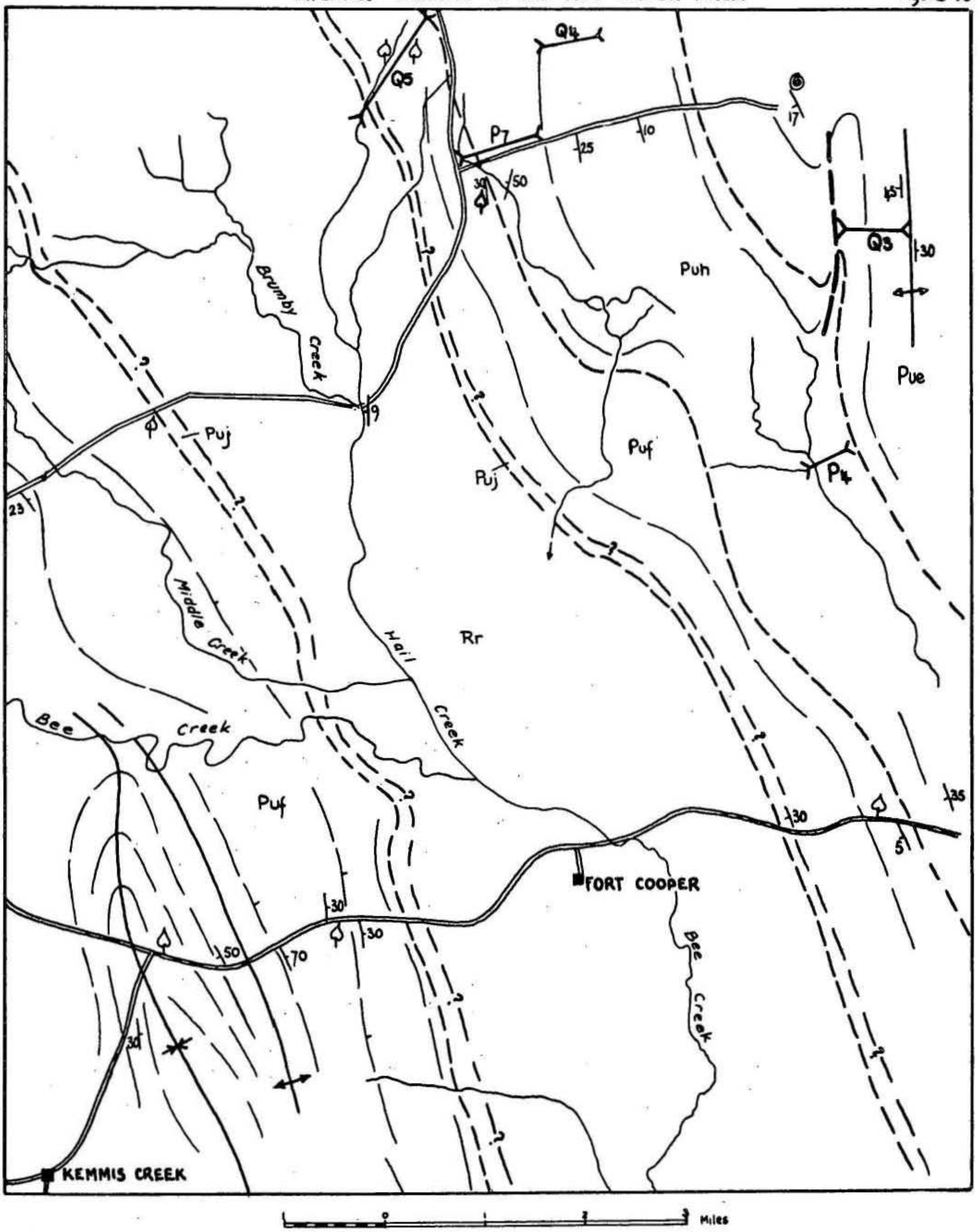
The Fort Cooper Coal Measures can be traced northwards into the Blenheim area, about 40 miles north of Kemmis Creek, by using the tuff and conglomerate beds as markers. Little is known of the overall sequence within this area despite measured sections (in Jensen, 1964) because of the lenticularity of the beds, few of which can be traced along strike. In large exposures it can be seen that beds of sandstone up to 40 feet thick can lens out within 120 feet. Only beds of tuff appear to be reasonably consistent.

In the Blenheim area the Fort Cooper Coal Measures are composed of sandstone, and impure limestone of the same type as described from the Fort Cooper area, but two are of particular interest - volcanic-lithic conglomerate, and flow rocks. The volcanic-lithic conglomerate consists mainly of subrounded clasts of about 5 to 10mm of hyalocrystalline acid and intermediate flows and tuffs, generally brown in colour and partially devitrified, and with an abundance of vesicles filled with chlorite, carbonate and silica. The rock is relatively well sorted, with a dearth of sand and finer grained material. The pore space is filled by sparry carbonate. The interbedded igneous rocks thought in the field to be flows proved to be rhyolite and dacite with up to 20% quartz occurring as interstitial patches. The relative abundance of small crystals of apatite in these flow rocks is of some interest, as small euhedral and subhedral grains of apatite are common in the sandstone in the sequence. It is not always possible to distinguish between flows interbedded with the sequence and sills intruded into it. In some cases the sills are slightly transgressive and intrusive relationships can be established. In other cases, where the igneous bodies are completely conformable with the sedimentary sequence, and where a trachytic texture is apparent, an extrusive origin is possible.

The particularly well preserved fossil leaves in the fine tuff and the fossil stumps buried in their growth position, indicate a continental environment for at least part and presumably all of this formation. Deposition was probably on an alluvial plain both as channel and overbank deposits. Small lakes and swamps allowed accumulation and preservation of vegetable matter represented today by discontinuous coal seams. By far the most important source of sediment in the Fort Cooper Coal Measures was Upper Permian or older vulcanism, although both sandstone and conglomerate in the unit contain sedimentary and metamorphic clasts. Fine tuff and volcanic flows constitute a small but significant part of the total thickness, indicating contemporaneous vulcanism in this area.

INFERRED GEOLOGY OF THE FORT COOPER AREA

Figure 10



Rr	Rewan Formation
Puj	Elphinstone Coal Measures
Puf	Fort Cooper Coal Measures
Puh	Hail Creek Beds
Pue	Blenheim Formation

Road	
P4	Measured section
	Abundant fossil leaf impressions
	Trend of bedding

To accompany Record 1968/55.

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Elphinstone Coal Measures

Reid (1946) did not define the Elphinstone Coal Measures precisely, so it is proposed that this term be applied to the sequence of coal-bearing rocks lying above the Fort Cooper Coal Measures, as defined in this report, and below the Rewan Formation. This consists of about 400 feet of yellow-brown sandy limestone, light brown calcareous sandstone, mudstone, carbonaceous shale, and coal. Drilling in the Lake Elphinstone area showed that there are at least three seams, the Hynds, the Elphinstone and an unnamed seam about 200 feet above the Elphinstone Seam (Hawthorne, 1961). The Hynds appears to be about 200 feet below the Elphinstone Seam.

Although outcrop of the Elphinstone Coal Measures near Lake Elphinstone and Kemmis Creek is reasonably good, a great deal of the sequence, especially the coal seams, is never seen in continuous section which can be related to other parts of the Blackwater Group. Probably the most satisfactory section exposed is farther west in the headwaters of Hail Creek, directly above the proposed type section of the Fort Cooper Coal Measures (Section Q5, Fig. 7). No coal is exposed, but the interbedded mudstone is richly carbonaceous in places; the sandstone is light brown, which is in contrast to the brown and green sandstone of the Rewan Formation and the Fort Cooper Coal Measures. Tuff and conglomerate appear to be absent or present in small amounts.

Sandstone (5:61:34B) collected from the unit is notable for the high proportion of plagioclase. One of the samples examined is similar to sandstone interbedded with the Baralaba Coal Measures, at Baralaba and Moura. Many of the rock fragments and grains of feldspar are replaced by a colourless or faintly yellow clay, possibly kaolinite. Small subhedral grains of dolomite are scattered through the kaolinite cement. Cross-stratification measurements on sandstone beds indicate a general south-south-easterly current flow in section Q5, and a southerly flow in the Lake Elphinstone area (Fig. 11).

The conglomerate Reid (1946) mentions, occurring at the base of the Elphinstone Coal Measures is now included in the Fort Cooper Coal Measures. The reason for this is that the conglomerate is interbedded with the white cherty tuff Reid originally said to be characteristic of the Fort Cooper Coal Measures. In revising the units the interbedded conglomerate and tuff had to be placed in the same unit and as similar tuffs are known to be present lower in the Fort Cooper Coal Measures; these beds were placed in the lower unit. Hawthorne (1961) mentions the difficulty of selecting this boundary when he quotes from Dimmick (1960).

Central-Western Bowen Basin

CHERWELL RANGE AREA

Information on the Upper Permian sequence of the Cherwell Range, has been supplied by Reid (1928), and Veevers, Randal, Mollan, and Paten (1964). The poorly exposed sequence consists of presumed freshwater and marine sediments, the Passage Beds of Reid (1928), overlain by the 'Upper Bowen Coal Measures'.

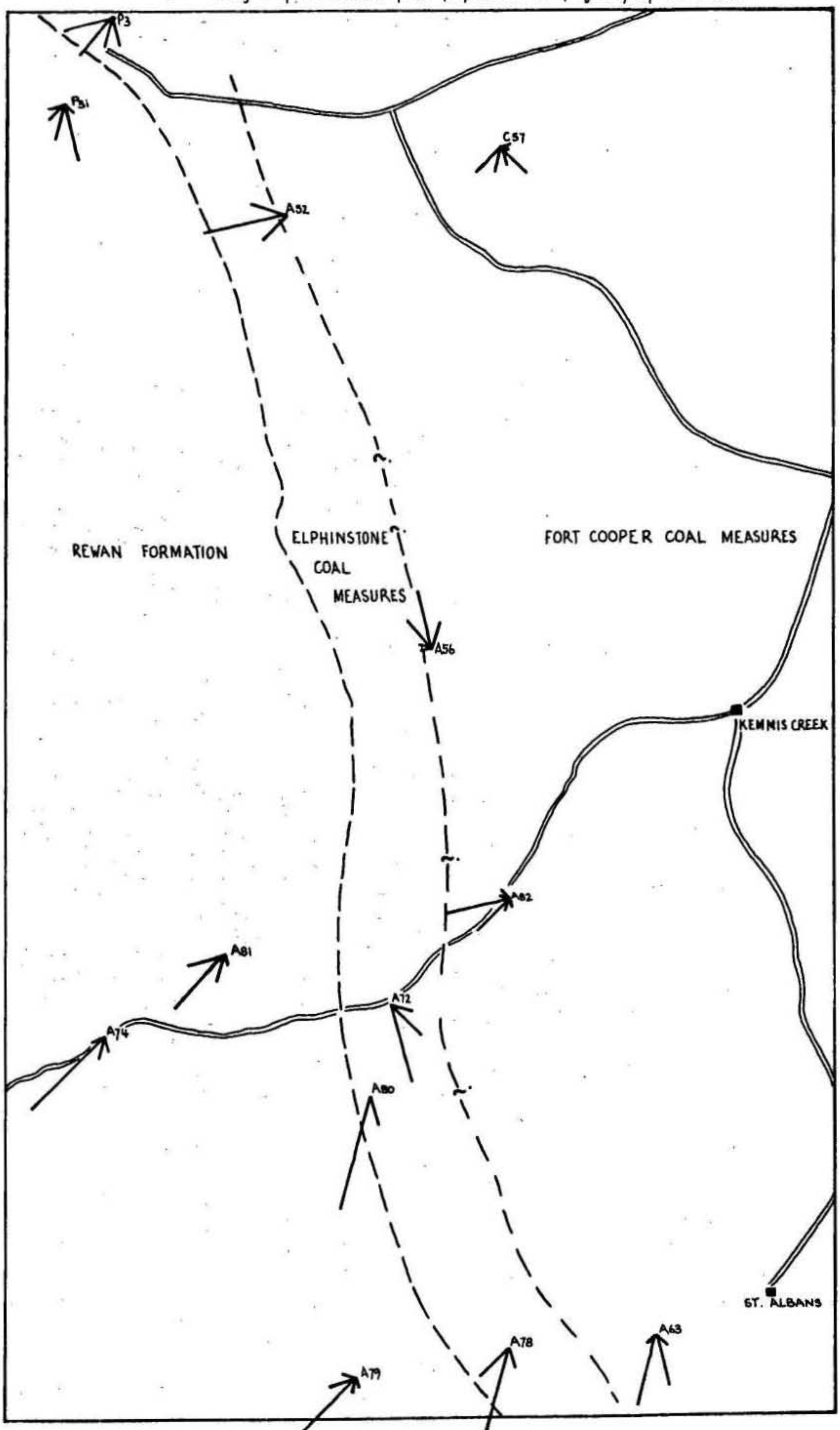
Veevers et al. (1964) report that the base of the Passage Beds is marked by a sandy coquinite, the clarkei-bed, and that the lower part of the formation is mainly siltstone with marine fossils, plant fragments, and traces of wood. Siltstone passes upwards to medium and coarse grained sandstone (9:0:1A) interbedded with thin beds of coal, carbonaceous mudstone and minor siltstone. The sandstone, is commonly cross-stratified, and exposures on the Peak Downs highway suggest a preponderance of low angle cross-stratification. Measurements of the orientation of cross-stratification indicate movement of sediment towards the north-east. Reid (1928) records the common occurrences of rootlets, vertical tubular structures coated by thin films of carbon in sandstone of the Passage Beds; the presence of these structures led to the idea of intermittent freshwater and marine conditions during deposition. While not denying the possibility of short periods of

Figure 11

ORIENTATION OF CROSS-STRATIFICATION

REWAN FORMATION AND UPPER PERMIAN UNITS - KEMMIS CREEK AREA

Length of line at each point proportional to frequency of orientation



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continental deposition, it is possible that the sequence is wholly marine and the 'rootlets', if they do have a plant origin, are the remains of a transitional flora such as one would find in an estuarine environment.

The basal part of the Passage Beds, especially that part associated with the clarkei-bed is noted for an abundance of pebbles, boulders and blocks, which have been regarded as glacial erratics dropped into marine sediments by melting icebergs. Veevers et al. (1964) pointed out that each clast could be matched with parts of the nearby outcropping volcanics or Anakie Metamorphics, suggesting derivation from a nearby steep shore. It is interesting to note that in a similar fashion the large angular clasts in the lower part of the Blenheim Formation can be matched with Lower Permian Volcanics lying east and north-east of the Exmoor area, and that a similar mechanism could be proposed for this situation (see page 25).

GERMAN CREEK AREA

The most complete section presented of the Upper Permian sequence of the German Creek area (Fig. 6) is that of Devine and Power (1967). The sequence begins close to the clarkei-bed, and includes the basal, newly defined Hurdle Creek Beds overlain by the Crocker Formation and the MacMillan Formation comprising the MacMillan Member and the Carnangarra Member of the Taurus Formation of Mines Administration, 1959, and the 'Bandanna Formation' (a synonym for the 'Upper Bandanna' of the Reids Dome area). Malone et al. (in press) have included part of the sequence, from the base of the Crocker Formation to the base of the 'Bandanna Formation', in their newly defined German Creek Coal Measures.

The succession through the Hurdle Creek Beds to the base of the 'Bandanna Formation' bears a close resemblance in thickness and lithology to that of the Blenheim Formation of the Blenheim and Exmoor areas, and to the Passage Beds of the Cherwell Range. The coquinite near the base gives way to a dominantly fine grained sequence with rare sandstone, which in turn is replaced higher in the section by quartz-rich sandstone and siltstone. Apparently the conglomeratic mudstone of the Blenheim Formation and does not occur in the Hurdle Creek Beds, although pebbles and cobbles up to 3 inches in diameter are recorded from fine sandstone near the base.

The Crocker Formation in German Creek as described by Devine and Power (1967), is similar to the Crocker Formation of the type section in the Blackwater area. At German Creek it consists of a basal fine to medium grained sandstone with a clay matrix and with abundant organic burrows, overlain by silty sandstone. The top of the unit is a coarser sandstone with less clay matrix; low angle cross-stratification is common.

The MacMillan Member of the Blackwater area was also recognized by Devine and Power (1967) although they extended it to include the Carnangarra Sandstone, raising MacMillan to formation status at the same time. As in the type section, the MacMillan Member is composed of very fine grained clayey sandstone interbedded with siltstone. Coal seams crop out immediately beneath the Carnangarra Sandstone Member in German Creek. At this locality, the Carnangarra Sandstone (90:8:2C) is flaggy to thick bedded, low-angle cross-stratified, and micaceous. Individual beds have a matrix composed of a green alteration product of mica similar to glauconite. Measurement of the orientation of 45 cross-beds at German Creek indicate a north-easterly movement of sediment. The unit is shown by Devine and Power (1967) to be much thicker than at the type section in the Blackwater area.

TABLE 3

CHANGES OF STRATIGRAPHIC NOMENCLATURE OF PERMIAN SEQUENCE OF THE BLACKWATER AREA

<table>
<tr><th colspan="2">Mines Administration 1959</th><th colspan="2">King et al. 1964
Malone et al. (in press)</th><th colspan="2">Devine and Power 1967</th><th colspan="3">This report</th></tr>
<tr><td colspan="2">Clematis Sandstone</td><td colspan="2">Clematis Sandstone</td><td colspan="2"></td><td colspan="3">Clematis Sandstone</td></tr>
<tr><td rowspan="7">Taurus Formation</td><td rowspan="5">Woodlands Member</td><td rowspan="2">Rewan Formation</td><td></td><td colspan="2" rowspan="2">Rewan Formation</td><td rowspan="2">Rewan Formation</td><td colspan="2"></td></tr>
<tr><td>Sagittarius Sandstone Member</td><td colspan="2">Sagittarius Sandstone Member</td></tr>
<tr><td rowspan="3">Blackwater Group</td><td>Rangal Coal Measures</td><td colspan="2" rowspan="3">Bandanna Formation</td><td rowspan="3"></td><td colspan="2">Rangal Coal Measures</td></tr>
<tr><td>Burngrove Formation</td><td colspan="2">Burngrove Formation</td></tr>
<tr><td>Fairhill Formation</td><td colspan="2">Fairhill Formation</td></tr>
<tr><td>Carnangarra Member</td><td rowspan="4">Blenheim Subgroup</td><td rowspan="3">German Creek Coal Measures</td><td></td><td>Carnangarra Member</td><td rowspan="4">Blenheim Subgroup</td><td rowspan="3">German Creek Coal Measures</td><td>Carnangarra Sandstone Member</td></tr>
<tr><td>MacMillan Member</td><td colspan="2">MacMillan Formation</td><td>MacMillan Member</td></tr>
<tr><td colspan="2">Crocker Formation</td><td colspan="2">Crocker Formation</td><td>Crocker Sandstone Member</td></tr>
<tr><td colspan="2">Maria Formation</td><td>Maria Formation</td><td colspan="2">Maria Formation</td><td colspan="2">Maria Formation</td></tr>
</table>

Central Bowen Basin

BLACKWATER AREA

Stratigraphic nomenclature

Recent systems of stratigraphic nomenclature applied to the Upper Permian and Lower Triassic sequence in the Blackwater area are shown in Table 3, together with the nomenclature adopted for this report.

Maria Formation

The basal unit of the Blenheim Subgroup in the Blackwater area has been termed the Maria Formation (Mines Administration, 1959). The type section being $2\frac{1}{2}$ miles east-south-east of Myrtle Park Homestead near Comet in the Duaringa 1:250,000 Sheet area. At this locality the unit is said to be composed of at least 175 feet of "fine to medium grained, white buff and purple, fairly well cemented, kaolinitic, slightly lithic, quartz sandstone; white, buff, and purple, sandy, micaceous siltstone; and grey, purple, carbonaceous silty shale". It is said to be overlain conformably by the Crocker Sandstone Member of the German Creek Coal Measures but relationships with underlying rocks are not known.

Devine and Power (1967) report that the unit is 480 feet thick from subsurface data.

German Creek Coal Measures - Crocker Sandstone Member

Two hundred and seventy feet of section are exposed at Mount Crocker, the type locality for the Crocker Sandstone Member, which lies six miles east of Comet (Fig. 12). The original definition of the unit states that the unit is 180 feet thick in this type section so it is presumed that only the top 180 feet, the sandier part of the exposed sequence, can be taken to be the Crocker Sandstone. Presumably the lower part of the hill, composed mainly of micaceous siltstone and mudstone, is part of the Maria Formation.

The basal sandstone (96:2:2B) of the unit is hard, white, fine to coarse grained, cross-bedded, and has a significantly high proportion of organic burrows. It is composed mainly of angular quartz grains with minor rock fragments, mainly metamorphic, and a little weathered feldspar, in a sericitic clay matrix; large muscovite flakes are common. Unfortunately much of the sequence between this basal sandstone and the uppermost bench-forming sandstone is not exposed at Mount Crocker. A shallow stratigraphic hole, Duaringa (BMR) No. 10, drilled 2½ miles east-south-east of the type section revealed that this poorly exposed interval consists mainly of medium to fine grained, grey-white, micaceous and in places carbonaceous, sandstone and silty sandstone (8:1:1B) interbedded with grey micaceous siltstone, and thin beds of carbonaceous shale or coal and minor clayey mudstone.

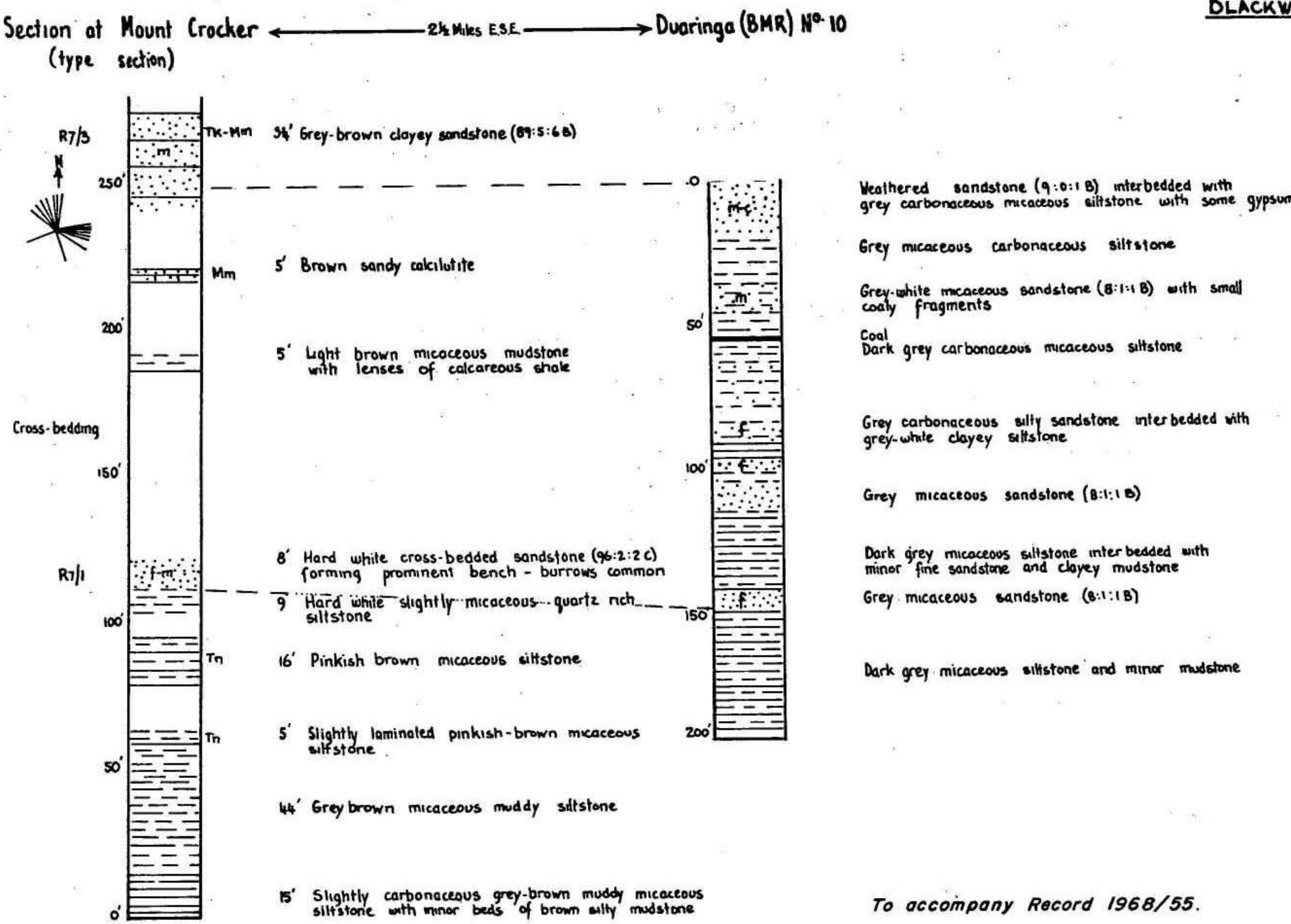
The uppermost sandstone (89:5:6A) exposed at Mount Crocker, is coarser than the basal sandstone, and lacks organic burrows. Twenty measurements of the orientation of the low angle cross-stratification preserved in this sandstone revealed a bi-modal distribution (Fig. 12) the most common orientations being toward the north-north-west and the east.

Brachiopods, corals, and pelecypods are reported to have been found in possible equivalents of the unit elsewhere (Mines Administration 1959), and yet it contains a significant amount of carbonaceous material. If exclusively marine, the unit must have been deposited near-shore and presumably in reasonably shallow water. It could also represent deposition in a transitional environment, a mixture of shallow marine and coastal environments. Low angle cross-stratification and the bimodal distribution of orientation could be evidence for beach deposits; however the angularity of the grains somewhat detracts from this theory.

Figure 12

SECTIONS IN THE CROCKER SANDSTONE

BLACKWATER AREA



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German Creek Coal Measures - MacMillan Member

The MacMillan Member (Mines Administration, 1959), normally only seen in the steep face of cuestas topped by gently dipping Carnangarra Sandstone, is reasonably well exposed in the type section, the north face of Mount MacMillan a small butte, near Cooroorah and Carnangarra Homesteads. In this section (Fig. 13), it consists of 200 feet of brown sandy siltstone, sandy mudstone with calcareous concretionary lenses, fine brown sandstone and very thin beds of light green bentonitic claystone. Siltstone at the top of the unit grades upwards into fine sandstone in the lower part of the Carnangarra Sandstone. Scattered marine fossils, mainly pelecypods, were found in the type section.

In other areas where the unit has been recognized, only incomplete sections are exposed, but from these it appears that two distinctive lithologies are characteristic of the unit in outcrop; flaggy, brown fine, muddy sandstone (40:30:30C), which is slumped in some localities; and yellow brown, concretionary, muddy limestone, commonly ferruginized, and containing an abundance of fine fossil plant debris. Thin coal seams were detected in the lower part of the unit in BMR shallow hole (Duaringa) No. 5 (Fig. 13), and these are probably equivalent to the thick bed of coaly shale cropping out in the Mackenzie River at Carnangarra. Discoidal concretions of cone-in-cone limestone, similar to those described by Gilman and Metzger (1967), form a distinctive horizon above this coaly shale at this locality.

The fine grained nature of sandstone in the unit makes identification of rock fragments forming the framework difficult, but many appear to be volcanic; some are almost certainly metamorphic. A volcanic provenance is also indicated by the relative abundance of fresh plagioclase and small grains of apatite.

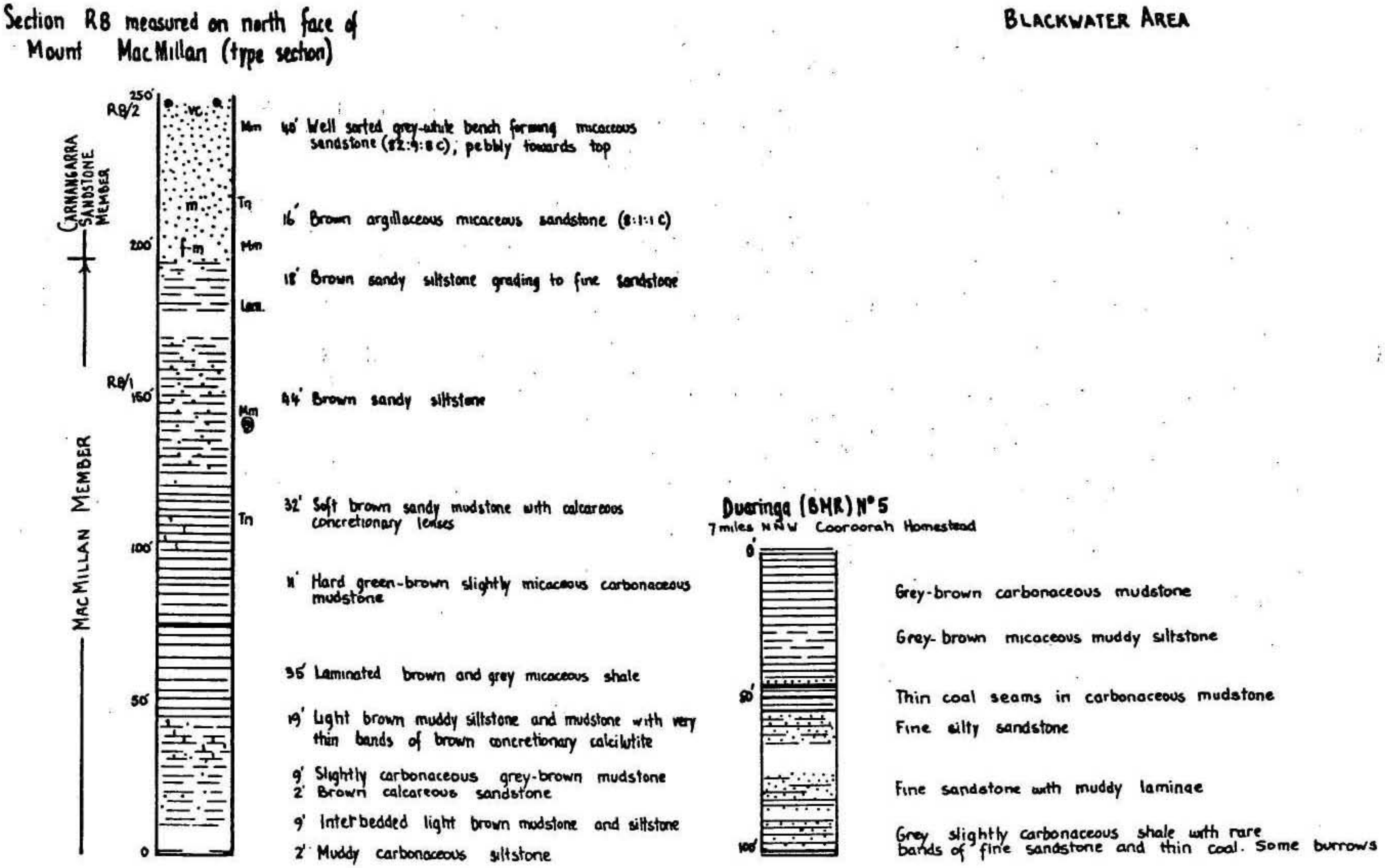
Marine fossils indicate that at least part of the MacMillan Member is marine, and the presence of abundant transported plant debris points to deposition relatively close to shore. The general environment was probably coastal. In the areas examined around Blackwater much of the unit could have formed in an estuarine environment, by slow moving distributary currents. Some deposition of flaggy and slumped sand, however, took place in shallow water with strong tidal currents. The volcanic content of the coarser sediments indicates changing provenance from the underlying units, and the few measurements of cross-stratification support the idea of changing provenance. These suggest movement of sediment from the north rather than from the south-west as in the underlying sediments. Interbedded, thin bentonitic claystone beds suggest minor additions of fine volcanic ash to the sequence.

German Creek Coal Measures - Carnangarra Sandstone Member

The Carnangarra Sandstone Member (Mines Administration, 1959) is a convenient marker bed in the Blackwater area because it is thin, crops out well, and has a simple mineralogical composition. The type section is in a low cuesta near Carnangarra outstation where the unit consists of 25 feet of sandstone (76:8:16A). It makes up part of the sandstone capping Mount MacMillan, and forms long sandy ridges near Cooroorah Homestead.

The sandstone is moderately well-sorted, medium- to coarse-grained, cross-stratified, and medium- to thin-bedded. In the type section it becomes finer and more thinly bedded towards the top. The cross-stratification is high to low angle, medium-scale, and planar (McKee & Weir, 1953). The composition ranges from sublabile (76:8:16) to quartzose (83:9:8). Feldspar consists of both weathered and relatively fresh K-feldspar and plagioclase. Rock fragments are metamorphic and sedimentary, with rare plutonic and volcanic types. Quartz overgrowths are common on the quartz grains, and authigenic feldspar is present. The quartz grains were originally subround, an unusual feature in quartz of the Upper Permian of the Bowen Basin, most of which is angular to subangular.

Figure 13
Sections in the MacMillan Member
Blackwater Area



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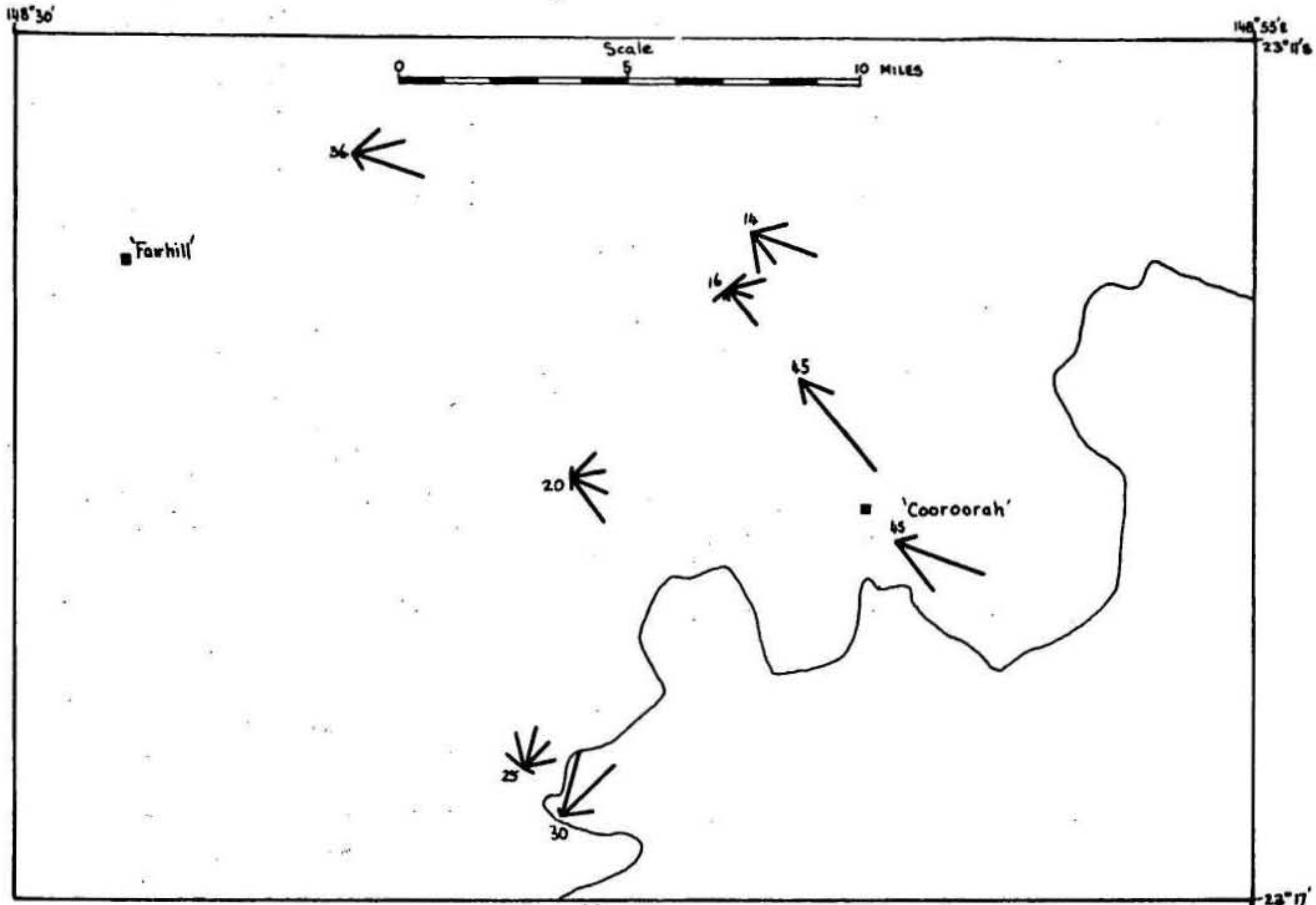

Figure 14
Orientation of cross-stratification - Carnangarra Sandstone Member
Length of line proportional to fequency of azimuth
Number of readings at each point indicated

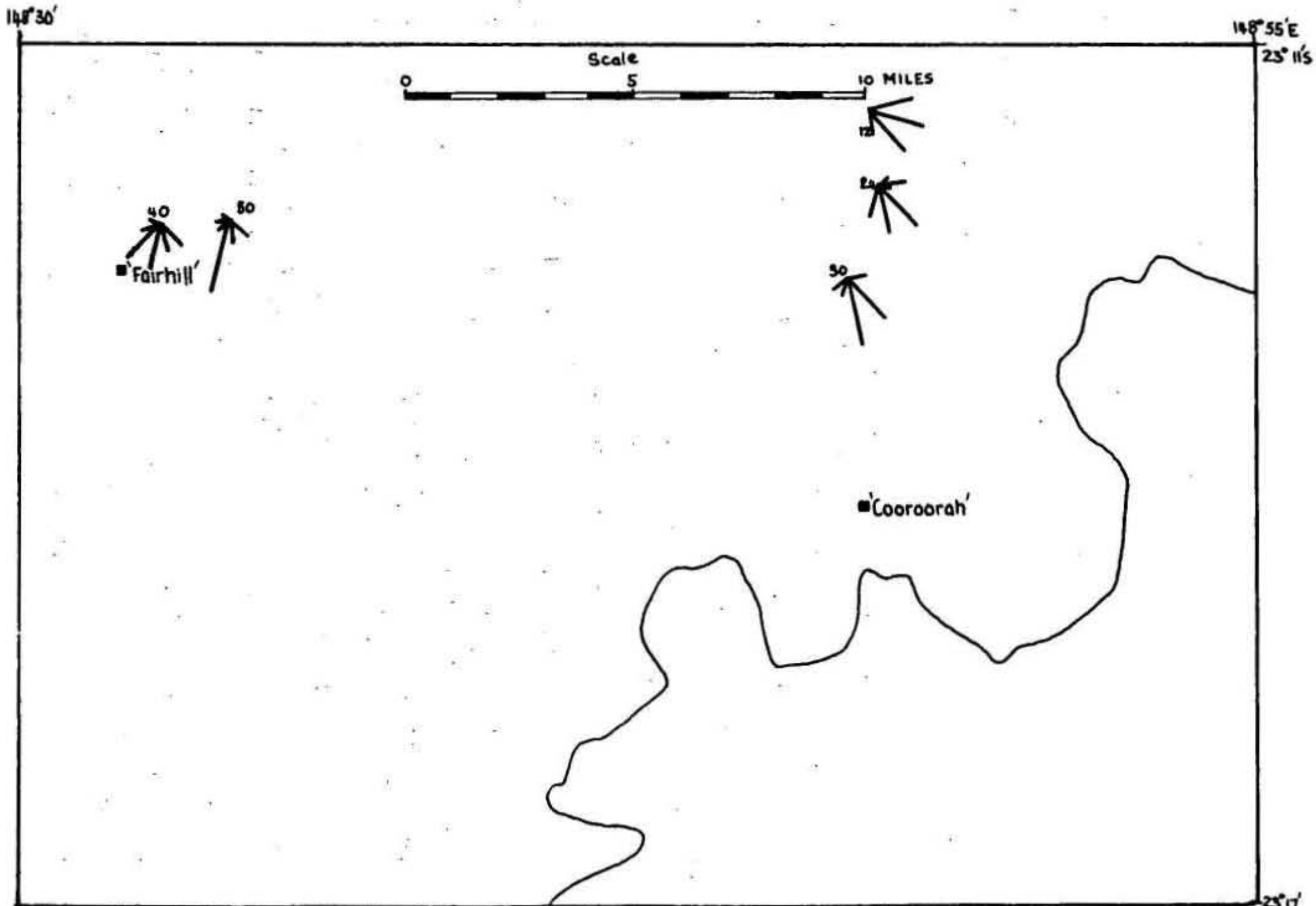

Figure 15
Orientation of cross-stratification - Fairhill Formation
Length of line proportional to frequency of azimuth
Number of readings at each point indicated

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The contact of the Carnangarra Sandstone and the overlying Fairhill Formation is not exposed, but the two units are structurally conformable, and there is no evidence of a disconformity.

Measurements of cross-stratification at eight localities near the type section (Fig. 14) indicate transport towards the east. Measurements on the sandstone equivalent to the Carnangarra Sandstone south of the railway in the Tolmies area, where the unit is very thin and conglomeratic, indicate an east-north-east movement.

Marine fossils, referred to only in unpublished reports, are not common in the Carnangarra Sandstone Member. Fossil wood impressions are rare. The combination of low angle cross-stratification seen in places with higher than average roundness of the quartz grains, good sorting, and rare marine fossils, suggests a beach or coastal marine environment of deposition.

Fairhill Formation

The term 'Fairhill' was originally used by Utah Development Company in their unpublished reports in the Blackwater area, for a unit lying between their Burngrove Shale and German Creek Coal Measures. The name was later published (Malone et al., in press) as Fairhill Formation, with the type section in a small gully about 4 miles north of Cooroorah Homestead.

The Fairhill Formation is a relatively homogeneous unit consisting of about 280 feet of fine- to coarse-grained micaceous, calcareous sandstone (40:40:20B) which is conglomeratic in places, interbedded with very minor brown calcareous mudstone. Pebble conglomerate is restricted to thin beds in the sequence, but scattered pebbles are found throughout the unit. Fossil logs are also common, generally replaced by siderite or limonite; they lie in the bedding plane, and have not been buried in situ.

Sandstone of the unit varies from fine- to coarse-grained. It is thin- to medium-bedded, and in places flaggy; trough cross-stratification is a common feature. The sandstone is generally rich in rock fragments and feldspar (40:40:20B), although it grades to sediments richer in quartz (67:16:17B). The features which distinguish the sandstone from that of underlying units are the abundance of relatively fresh volcanic rock fragments, and carbonate, which in some cases forms as much as 48% of the rock. Metamorphic and sedimentary fragments are also present.

Measurements of cross-stratification in the Fairhill and Cooroorah areas indicate transport towards the south and south-east (Fig. 15).

The Fairhill Formation was deposited by relatively strong traction currents, presumably in a continental or transitional environment probably in fluvial channels on a coastal plain. The change in mineralogical composition reflects a change from the westerly provenance of underlying formations, to northerly for the Fairhill Formation, where there must have been an adequate supply of volcanic material as well as minor amounts of sedimentary and metamorphic rock fragments.

Burngrove Formation

In the Blackwater area the Blackwater Group, the interval between the Fairhill Formation and the Rewan Formation, comprises two distinct units, the Burngrove Formation and the Rangal Coal Measures. As in the south-east part of the basin, although two reasonably distinct units can be differentiated, the change from one unit to the other is gradational and the boundary correspondingly difficult to select.

The type section of the Burngrove Formation, the lower formation (Malone et al., in press), is exposed in a small creek about 6 miles north of Cooroorah Homestead where the unit is 300 feet thick.

The change from the Fairhill Formation to the overlying Burngrove Formation in this area is quite sharp from cross-bedded calcareous sandstone, to grey brown carbonaceous mudstone with thin beds of green chert, very carbonaceous shale or shaly coal, and light green montmorillonitic clay (Plate 8i). The overlying part is characterized by hard, fine-grained, thinly bedded, tuffaceous, clastic sediments, changes being mainly variations in grainsize, hardness, and the amount of carbonaceous material. The unit consists mainly of light grey, laminated, hard, tuffaceous, fine sandstone with mud-laminae which grades into fine- to medium-grained sandstone, and hard green mudstone. The contact with the Rangal Coal Measures is not exposed in the type area. The upper parts are best seen near Taurus Homestead, south of Blackwater, where green mudstone with abundant plant impressions, mainly Phyllotheca, is interbedded with thin beds of shaly coal. Fossil logs, with both simple growth rings, and with the complex structure of tree-ferns, appear to be restricted to one horizon at the top of the unit.

In outcrop, the most striking feature of the unit is its hardness, and its thin and regular bedding, ranging from a few inches to about a foot in thickness. Many of the beds, no matter how thin, are themselves laminated, and cross-stratified only on a very small scale. Slumping, mainly small scale, is common, and some laminae are graded. The uniform bedding, hard lithology, and low dip, combine to form flat platforms of rock in parts of Burngrove Creek and in the type area.

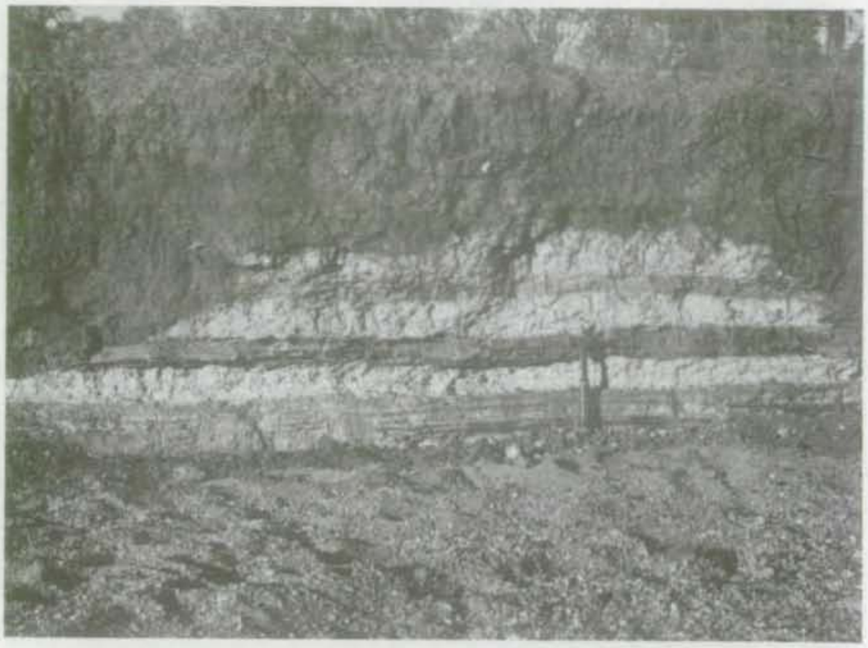
One such platform, about six miles north of Cooroorah Homestead, bears a multitude of trails and impressions (Plate 8ii). The most common impressions, current crescents, consist of small scoop-shaped depressions about 2 inches long, which in many cases have an elongate median platform. They are randomly distributed over the whole exposure, about 20 per square yard, and are oriented north-south with the shallow, fanned out part of the depression at the southern end. Measurements at two other localities indicate that small fossil wood fragments are roughly aligned in the same direction. No pebbles or obstructions which may have caused the current crescents are visible but the bed immediately above consists of angular mud clasts and water flowing around mud pellets lying on a muddy surface may have scoured out the depressions. Two main varieties of tracks are preserved on the surface, one evidently made by fish, and the other possibly by a small reptile (E.N. Milligan, pers. comm.).

The rock most typical of the Burngrove Formation in outcrop, fine grey sandstone with black mud laminae, is composed of highly altered, green-brown, volcanic rock fragments, and angular grains of quartz and feldspar, cemented by microcrystalline silica. The black mudstone laminae are composed of dark green phyllosilicates, and cryptocrystalline material; glass shards are common, but they may be just as common in the coarser, silicified, parts of the rock. Sandstone (25:30:45B) samples from the unit are cemented by carbonate or silica.

Much of the hard, grey, laminated, cherty mudstone, is devitrified vitric tuff, consisting of 'phenocrysts' of quartz and feldspar in a groundmass of microcrystalline feldspar and silica, and brown cryptocrystalline material. The quartz phenocrysts are euhedral crystals of quartz surrounded by a rim of secondary silica. The microcrystalline groundmass consists of anhedral clots of clear, intergrown, feldspar and possibly tridymite, presumably produced by devitrification of the brown cryptocrystalline glassy groundmass. Glass shards are common in some cherty mudstone.

The consistently fine-grained nature of the Burngrove Formation, an unusual feature for any Upper Permian unit in this area, is at least partly the result of provenance, as much of the material is fine volcanic ash. It also reflects an environment of deposition where the accumulating sediment was normally unaffected by waves or strong currents. The abundance of organic burrows precludes a subaerial accumulation of tuffaceous material, although certain thin bands may have been deposited this way. The abundance of fine carbonaceous material, indicates deposition on or close to land, and the

PLATE 8



(i) Montmorillonitic clay beds at the top of the Burngrove Formation, possibly representing ash fall deposits; Taurus Homestead area

(ii) Current crescents and possible fish trails in the Burngrove Formation, Cooroorah area (Neg.g/5349) complete absence of marine fossils suggests a continental environment, although as for the Fairhill Formation, a marine environment is possible for the lower part of the unit. Such a fine-grained, thinly and regularly bedded unit, must have been deposited in reasonably still water, and a lacustrine environment seems to be the most likely. Green chert containing abundant Phyllotheca, and thin seams of coal constitute evidence of shallower, possibly paludal, conditions at some stages of formation of the unit. Thin layers of mud clasts possibly represent brief periods of subaerial exposure and desiccation.

Rangal Coal Measures

The Rangal Coal Measures are nowhere well exposed, and the following summary is based on a few field observations supplemented by information from drilling. In the type section in Deep Creek, south of Blackwater, outcrop is poor, and little of the total thickness of 250 feet can be seen.

The coal measures consist mainly of grey to black carbonaceous shale and mudstone, interbedded with coal, sandstone, and limestone. In contrast to the thin and regular bedding of the Burngrove Formation, the coal measures bedding is characterized by lateral impersistency and irregularity in thickness. The shale is generally thinly bedded, and in many places it is laminated. The coal seams vary widely in thickness from about 30 feet to a few inches, and apparently from drilling results seam splits are common. The sandstone appears to form thick beds which are commonly cross-stratified, but measurement of the orientation of cross-bedding has yielded no consistent direction of transport. Concretionary limestone in the unit appears to be confined to lenses in calcareous mudstone.

Sandstone (30:40:30B) of the Rangal Coal Measures is generally moderately sorted, and fine- to coarse-grained. The abundance of kaolinitic and clay cement, and the apparent replacement of many of the rock fragments by colourless clay minerals, probably explains the grey-white colour common in the sandstone. Those rock fragments which can be identified are mainly volcanic, but fine-grained sediments are also present.

Rock fragments vary from rounded to subrounded and angular but the shape of many of the grains is difficult to ascertain, no doubt because of the post-depositional alteration. The most striking feature of these rocks, however, is the relative abundance of feldspar, most of it plagioclase, and this is exemplified by the change in mineralogical composition in sandstone encountered by BHP bores 1 and 2 . The average content of feldspar in the framework of sandstone of the Rewan Formation is 9 $\pm$ 4%, whereas in the coal measures it is 27 $\pm$ 4%.

In outcrop, limestone of the unit is generally light brown and even-grained. It is composed of recrystallized calcite with a large admixture of quartz, feldspar, and rock fragments. Much of the carbonate could be secondary, especially as the limestone lenses rapidly, suggesting a concretionary origin. A few small brown sideritic pellets seen in thin sections have a vague internal structure, and originally these may have been algal pellets.

The environment of deposition was probably much the same as that of the underlying Burngrove Formation, the main differences being the waning or complete cessation of vulcanism, and the decrease in the supply of terrigenous material. The thick seams of coal were formed in a continental paludal environment, and there is nothing to suggest marine incursions between the formation of each coal deposit. In fact the impersistent nature of the seams indicates a fluvial domain, with rivers constantly changing their channels and flood plains.

TABLE 4

CHANGES OF STRATIGRAPHIC NOMENCLATURE IN UPPER PERMIAN AND LOWER TRIASSIC SEQUENCE OF SOUTH-WEST BOWEN BASIN

Reid 1930	Oil Search 1936 (unpubl.)		Woolley 1944 (unpubl.)		Hill 1957		Mollan et al. in press	This report
Upper Bowen Series including Carnarvon Red Member	Carnarvon Sandstone		Carnarvon Series		Clematis Sandstone		Clematis Sandstone	Clematis Sandstone
	Upper Bowen	Variegated clay-shale	Rewan Formation	Upper	Rewan Formation		Rewan Formation	Rewan Formation
		Brumby Sandstone		Lower Malta Grit		Lower Rewan	Lower Rewan	Sagittarius Sandstone
		Coal Measures	Bandanna Series	Upper Group	Bandanna Formation	Upper part	Blackwater Group Undifferentiated	'Upper Bandanna' Formation
				Lower Group		Lower part	Black Alley Shale	Black Alley Shale
	Middle Bowen		Productus Bed		Mantuan Productus Bed		Mantuan Productus Bed	Mantuan Productus Bed
			Catherine Series		Catherine Sandstone		Peawaddy Formation	Peawaddy Formation
							Catherine Sandstone	

South-Western Bowen Basin

REID'S DOME AREA

Previous stratigraphic nomenclature

Most of the present day stratigraphic nomenclature used in the Reid's Dome area is based on the work by Reid (1930), and Shell (Queensland) Development Pty Ltd (1952), as published by Hill (1957). Hill (1957) divided the sequence now regarded as Upper Permian, the Mantuan Productus Bed and the overlying Bandanna Formation which in turn was subdivided into two parts (Table 4). The nomenclature was revised in the light of more recent mapping by Mollan, Dickins, Exon, and Kirkegaard (in press), who recognized the Peawaddy Formation (Mollan, Kirkegaard, Exon, and Dickins, 1964), containing the Mantuan Productus Bed, and proposed the new name Black Alley Shale for the lower Bandanna Formation. The 'Upper Bandanna' Formation has been referred by Mollan et al. (in press) to the Blackwater Group and use of the term 'Bandanna' to cover this 'Upper Bandanna' interval is confusing.

Peawaddy Formation

No study was made of the Peawaddy Formation, and the following notes are based mainly on the work of Mollan, Kirkegaard, Exon, and Dickins (1964), and Mollan et al., (in press). This unit is regarded as the lower of two formations comprising the Blenheim Subgroup in this part of the basin, the other being the Black Alley Shale. The name is derived from Peawaddy Creek on the south-east part of the Springsure 1:250,000 Sheet area, and the type section, 450 feet thick, is in the same creek 3½ miles west-north-west of Consuelo Homestead.

The unit consists mainly of thin-bedded siltstone, carbonaceous, micaceous shale with abundant plant debris, and sandstone. The sandstone which predominates at the top of the unit is commonly fossiliferous, and in places it contains coquinitic lenses with brachiopods, pelecypods, corals, and bryozoans. The lenses are known collectively as the Mantuan

Productus Bed. West of the type area, clayey siltstone in the upper half of the unit contains scattered cobbles of hornfels, slate, and volcanics. Large calcareous concretions are common.

Three types of arenite were recognized by Bastian (1964) in his examination of samples collected from the unit: (a) kaolinitic sandstone, (b) volcanic sandstone (20:60:20A), and sutgreywacke (25:50:25B), and (c) orthoquartzite (85:15:0A). Most of the rock fragments in these arenites are of volcanic origin, generally andesite, with a significant admixture of metamorphic grains.

The unit is at least partly, and probably entirely marine, as fossils have been found at various levels within the sequence. Proximity to land is suggested by the amount of carbonaceous material, and the occurrence of large fossil logs; and in the upper part the abundance of shelly fossils support the idea of moderately shallow water. The pebbles and cobbles in fine sediment in this formation are taken to indicate movement by waves and strong traction currents in shallow water, rather than the action of turbidity currents or ice rafting.

Black Alley Shale

The Black Alley Shale (Mollan et al., in press) is the formal name for the lower part of the Bandanna Formation (Hill, 1957). The unit is named from Black Alley Peak in the south-eastern corner of the Springsure 1:250,000 Sheet area. In the type section, the western branch of Dry Creek, about 2 miles south-east of Black Alley Peak, it is 310 feet thick.

Near Early Storms Homestead, the unit is composed of dark grey to black shale, and mudstone which grades to dark brown, calcareous, ferruginous mudstone, and grey micaceous siltstone. Thin beds of light green montmorillonitic clay are common towards the base of the sequence (Thompson and Duff, 1965), and thin beds of cross-laminated lithic sandstone crop out towards the top. The top is also characterized by thin bedded, cross-stratified, brown, calcareous siltstone, which grades into light brown silty limestone.

Fossils are rare but plant fragments and organic burrows have been noted in the top part of the sequence, and rare fish scales were reported by Mollan et al. (in press). The lower part of the unit is apparently characterized by the presence of acritarchs (Evans, 1965).

The Black Alley Shale was possibly deposited in the sea and the acritarchs in the lower part may indicate marine or transitional conditions; the alteration of volcanic glass to montmorillonite, a transformation that is helped considerably by the availability of Mg^{++} ions, presumably from sea water, supports the idea of marine conditions (Slaughter & Earley, 1965).

'Upper Bandanna' Formation

In contrast to most areas of the Bowen Basin, outcrop of the Upper Permian Coal Measures is reasonably complete in the Reids Dome area (Fig. 16). Thin beds of sandy limestone at the top of the Black Alley Shale are overlain by fine sandstone and thin beds of grey-white, siliceous, leaf-bearing tuff, similar to the cherty-tuff of the Cracow area. This horizon also has an abundance of silicified fossil logs, and it has been used to mark the base of the unit (Mollan, Exon, and Kirkegaard, 1964). The log horizon is overlain by a few feet of soft shale which in turn is overlain by a distinctive, grey, coarse-grained to conglomeratic, carbonate cemented sandstone (12:75:13A), with a framework consisting mainly of subangular to rounded volcanic rock fragments and rare metamorphics. Fine sediments above this horizon contain at least one bed 2 feet thick of green montmorillonitic clay (sample G, in Thompson and Duff, 1965). Above this level thin very carbonaceous shale beds and shaly coal are interbedded with cross-laminated siltstone and very thin 'ironstone' bands. Most of the coal in the section is a dull grey colour with few bright laminae. The highest seam in Oil Shale Gully, however, consists of about 4 feet of bright coal.

The unit is about 320 feet thick in the Reid's Dome area; its relationship to the overlying unit is discussed in the section on the Rewan Formation. Plants are the only fossils found in the sequence.

THE REWAN FORMATION

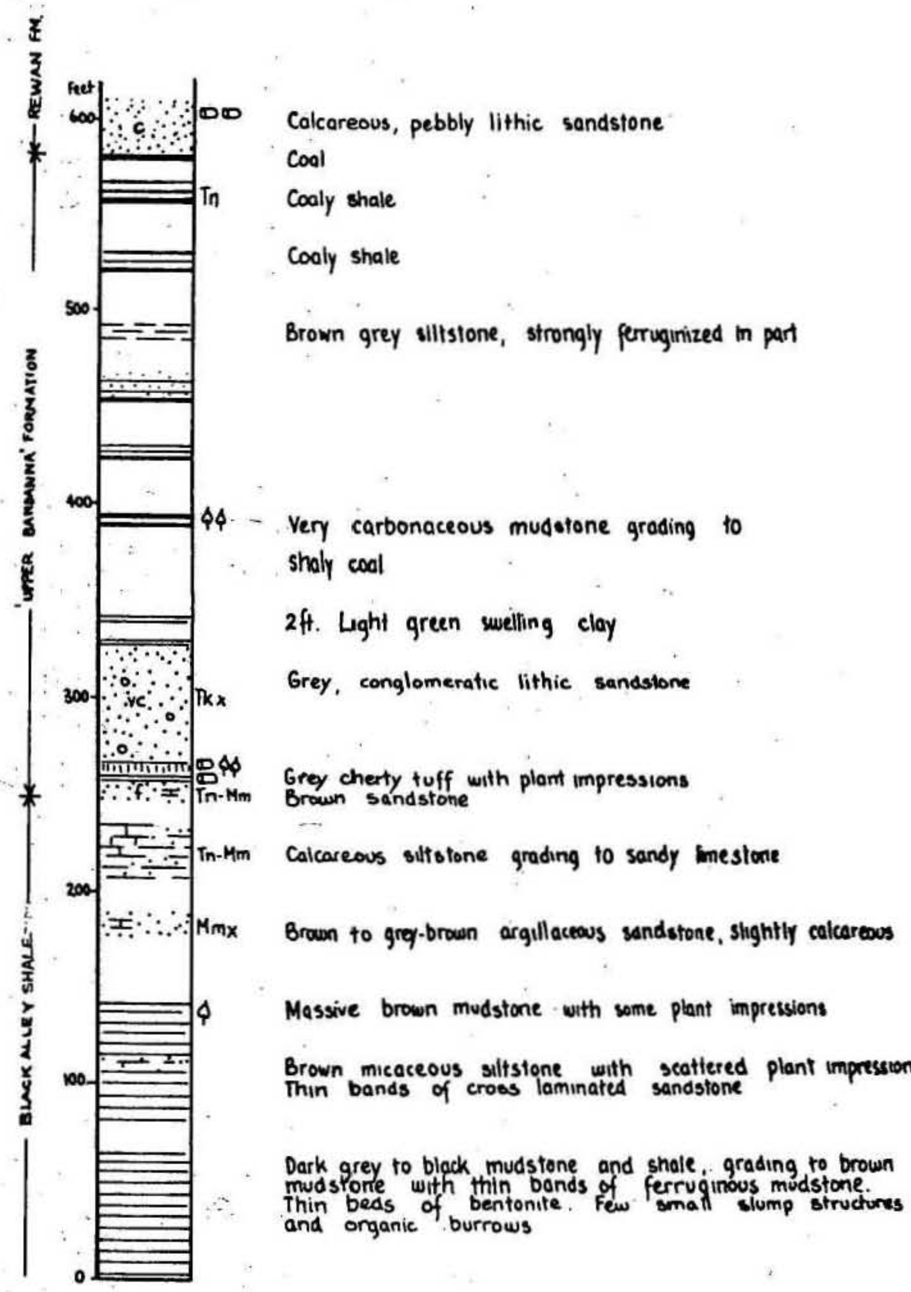
The Rewan Formation lies between the Blackwater Group below and the Clematis and Carborough Sandstones above. Its lower boundary is taken in this report immediately above the youngest coal of the Rangal Coal Measures and their equivalents, at the change from a coal, shaly coal, and very carbonaceous shale sequence to a sandstone-mudstone sequence with only scattered carbonaceous laminae. The formation is best known for its chocolate brown or red mudstones, but in fact the division of the unit into a lower sandy part and an upper muddy part is apparent and has been described both in the type area and in other southern parts of the basin. It is intended here to deal mainly with the lower part of the Rewan Formation in order to define the lower boundary and to present some observations made in the course of the present study. Because the Rewan Formation forms part of what was formerly included in the Upper Bowen Coal Measures, and because interpretations of the lithology possibly hold clues to the tectonic and climatic regimes which influenced the formation of the coal measures, some description of the upper part of the unit is also presented, although this will be the subject of a future study.

Previous investigations

As a result of field studies in the Serocold Anticline, Reid (1930) divided the exposed sequence into Upper, Middle, and Lower Bowen Formations. Oil Search Limited (1936) revised Reid's mapping of the Upper Bowen Formation and split out the Carnarvon Sandstone, and the Moolayember Shale, recognizing that the Upper Bowen equivalents lie between the Middle Bowen Formation and the base of the Clematis Sandstone. Oil Search pointed out that the Upper Bowen so defined consisted of an upper unit of variegated clay shale, a middle unit mainly of sandstone, and a lower unit of interbedded sandstone, carbonaceous shale, and coal. Although not defined in words, diagrams in Oil Search's unpublished reports show that a coarse grained sandstone forming a prominent bench near the base of Mount Brumby, was called

Fig. 16

COMPOSITE SECTION THROUGH BLACK ALLEY SHALE AND 'UPPER BANDANNA' FORMATION - REIDS DOME



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the Brumby Sandstone and this name was later published but not defined (Reeves, 1947). The term Brumby Sandstone should not be applied to the entire sequence exposed at Mount Brumby as in Smith (1958). Shell (1942) in the investigation of the Reid's Dome area used the term 'Rewan Series' for the sequence included in Oil Search's upper and middle units. The name was later published, but not precisely defined, by Isbell (1955). The unit was named after Rewan Homestead, on the eastern flank of Reid's Dome, and a specific type section is designated by Mollan et al. (in press).

Woolley (1944) in his detailed mapping of the Arcadia area, recognized basically the same units as described earlier by Oil Search and he correlated the upper clay-shale unit with the Upper Rewan Group of the Reid's Dome area, the middle sandstone unit with the Lower Rewan Group, and the coal measures with the Upper Bandanna Group. He called Brumby Sandstone of Oil Search the Malta Grit, regarding this as the base of his Lower Rewan Group and he found that it is separated from the sequence stratigraphically beneath it by a slight but distinct angular unconformity. Judging from Woolley's description, the magnitude of the unconformity beneath the Brumby Sandstone varies considerably from place to place within the Arcadia area. In many places it is marked by a slight divergence of strike above and below the sandstone. In two places where the overlying Brumby Sandstone is horizontal, the lower unit is reported to dip up to 15 degrees to the west.

Elsewhere in the Bowen Basin the Rewan Formation has often been included in the Upper Bowen Coal Measures or within other smaller locally named units. In the northern part of the basin early workers (Jack and Etheridge, 1892; Reid, 1924-25) included equivalents of the unit in their Upper Bowen Formation. Later, Reid (1946) included it in his Elphinstone Coal Measures presumably assuming that coaly sediments continued to the base of the Carborough Sandstone. In the Cracow area, the Rewan Formation has been called the Isla Formation (Mines Administration, 1959): it was defined as a unit consisting of interbedded olive green mudstone, siltstone, sandy siltstone, and locally cross bedded biotitic feldspathic lithic sandstone lying conformably between the Clematis Sandstone and the Kia-Ora Formation. (The Kia-Ora Formation is discussed in the section on the Baralaba Coal Measures).

In the Blackwater area, the Rewan Formation was included in the Woodlands Member of the Taurus Formation by Mines Administration (1959). Later work by geologists of Utah Development Co. and the Bureau of Mineral Resources (King, et al. 1964; Malone, et al. 1963) showed that the Woodlands Member included at its top the Rewan Formation, the lower part of which was called the Sagittarius Sandstone Member. This member was formally named and defined by Malone et al. (in press), who designated adjacent stretches of Blackwater, Taurus, and Deep Creeks near Blackwater as the type section (co-ordinates 15660435 to 16300501). The top of the Sagittarius Sandstone Member, the base of the lowest thick bed of red-brown mudstone, is concealed in the type section, but is said by Malone et al. (in press) to be exposed in Two Mile Creek, five miles to the south-east (16730385). The base of the member was taken to be at the major lithological break between the coal measures and the red bed sequence which is supposedly devoid of carbonaceous matter. The Sagittarius Sandstone does not appear to contain 'red beds'.

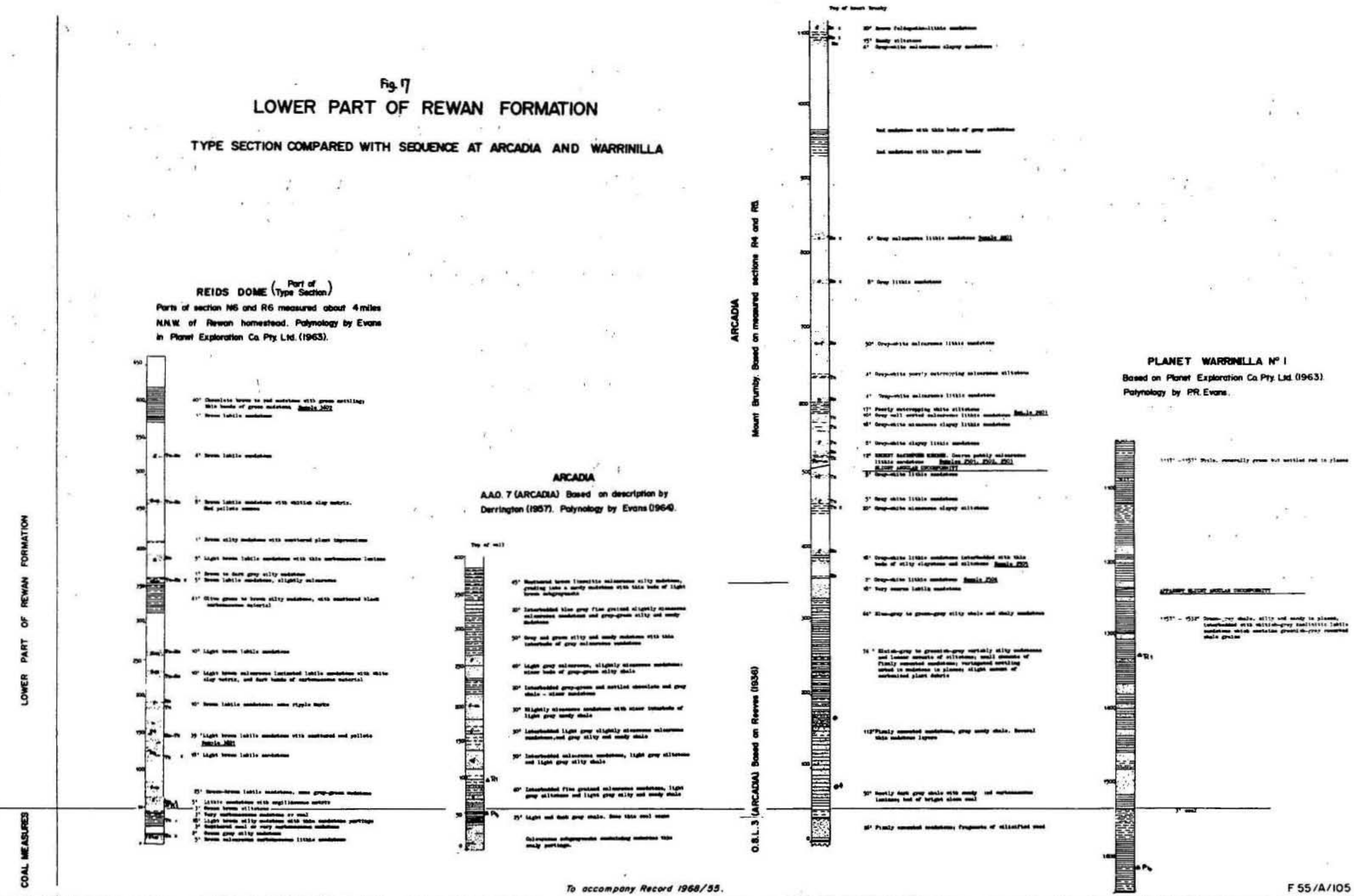
South-West Bowen Basin

In the sequence taken as type (Mollan et al., in press), cropping out on the eastern flank of Reid's Dome, the division of the Rewan Formation into a lower sandstone and an upper mudstone is relatively clear-cut. The lower 600 feet of section consists mainly of sandstone (20:70:10B), interbedded with olive-green to brown silty mudstone which contains scattered carbonaceous plant impressions. Above the level, chocolate-brown to red mudstone is the most common lithology, but it is interbedded with fine sandstone (35:55:10B). The mudstone continues to the top of the sequence where it is overlain, possibly unconformably, by the Clematis Sandstone.

Fig. 17

LOWER PART OF REWAN FORMATION

TYPE SECTION COMPARED WITH SEQUENCE AT ARCADIA AND WARRINILLA



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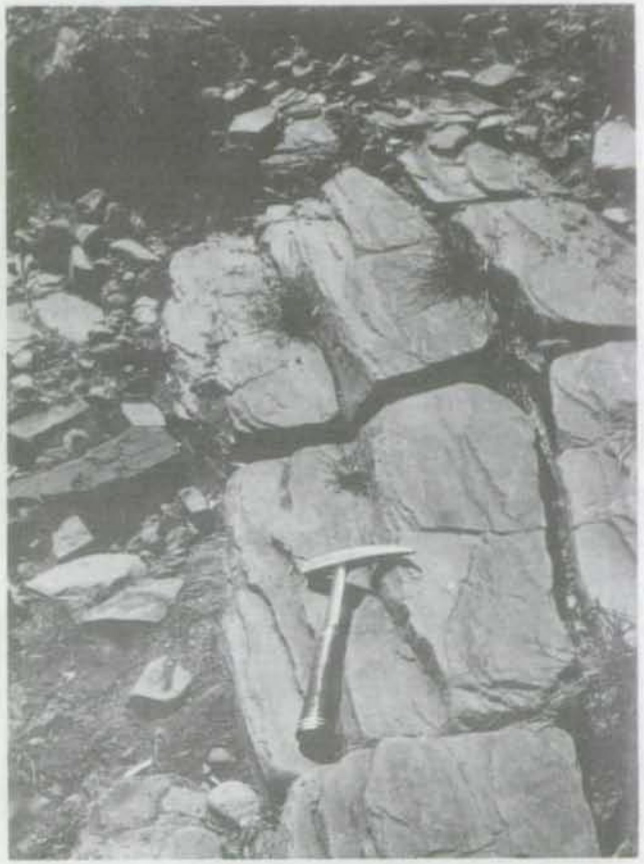
At Arcadia, 35 miles south-east of the type section, roughly 1100 feet of section lie between the youngest coal of the coal measures and the base of the upper part of the Rewan Formation (Fig. 17). This interval includes Woolley's Lower Rewan Group, which he reported thins rapidly away from Brumby Mountain. The lower 300 feet, known only from wells, O.S.L. 3 (Arcadia) and A.A.O. 7 (Arcadia), consist mainly of grey mudstone interbedded with beds of fine sandstone, with thin intercalations of mottled red mudstone; small shelly fossils were reported but not described from this interval in O.S.L. 3. The overlying 150 feet of section consists of fine grained, grey-white, sandstone (30:60:10B), interbedded with grey-white micaceous clayey siltstone. This is overlain at Brumby Mountain by the Brumby Sandstone (or Malta Grit), which consists of about 12 feet of grey-white, lustre mottled, pebbly, kaolinitic, sandstone (21:75:4B). In places the hand specimen has a most spectacular appearance with red-brown mud clasts and pellets, together with green volcanic rock fragments, and large glassy quartz grains, in a dark red hematitic cement. Many of the larger clasts are rounded 'ironstone' pebbles. Lithic fragments forming the framework of the rock are commonly acid plutonic, but fine grained sedimentary rocks, spherulitic volcanics, and meta-sediments are also present.

Over an interval of 600 feet above the Brumby Sandstone, the outcrop is mainly very fine grained, grey, sandstone (42:43:15A) which grades into a more feldspathic and lithic sandstone (15:50:35A). Lithic fragments are of volcanic, sedimentary and metamorphic origin, and hematitic cement is common. Little is known of the rest of the sequence, which Woolley (1944) correlated with the Upper Rewan Formation. It is assumed to consist mainly of red mudstone, although Woolley noted a few beds of light coloured sandstone near the top of the unit.

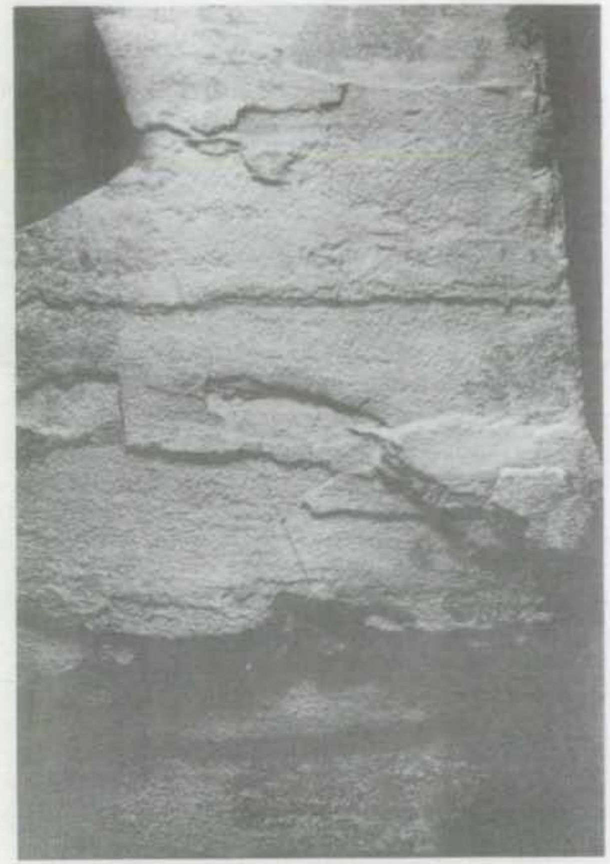
Part of the sequence beneath the Brumby Sandstone at Arcadia is apparently missing in the Reid's Dome area. The coal seam highest in the Permian sequence exposed in Oil Shale Gully, about 10 miles south of the type area, is directly overlain by a 3 inch bed of very fine grained sandstone strongly cemented by hematite; a layer of round pebbles and mud pellets is set into its upper surface. The hematite matrix is vaguely oolitic when viewed in thin section. This bed is overlain by a thick cross-stratified kaolinitic sandstone (7:92:1B) which contains at its base angular clasts of carbonaceous shale and coal. This bed is overlain, at the top of the ridge overlooking Oil Shale Gully, by a light brown calcareous pebbly sandstone (12:84:4A) which contains large fossilized logs up to 3 feet in diameter and 15 feet long. The fossil wood is replaced by silica and iron oxide, and in some cases the growth rings are marked by lines of small limonitic oolites. A sparry carbonate cements the framework of the sandstone, which consists mainly of lithic fragments - spherulitic volcanics, fine sediments and metamorphics as well as granitic fragments. Large round 'ironstone' pebbles are common. This interval is about 20 feet thick whereas the corresponding interval at Arcadia is about 450 feet thick.

In both the Reid's Dome and Arcadia areas, the medium- to coarse-grained sandstone of the Rewan Formation almost always exhibits trough cross-stratification (McKee and Weir, 1953) or the cross-stratification (Allen, 1963), and the direction of sediment transport (in the Reid's Dome area based on a total of 240 measurements from eight localities) is consistently towards the north. In good exposures (Plate 10) the troughs can be seen oriented north-south, and extending for at least fifteen feet; they are generally about four feet wide, and the average dip on the sets is 20°. Finer sandstone commonly exhibits rib- and -furrow cross-stratification (Stokes, 1953; Pettijohn, 1957), or fairly distinct primary current lineation (Cloos, 1938; Stokes, 1947; Pettijohn, 1957), or ripple marks. The rib-and -furrow structure consists of cross-stratified laminae of sand roughly a millimetre thick, which dip about 20°, and form small shallow troughs from 2-10cm wide. The troughs or 'furrows' are parallel, and are separated from one another by cross-stratified 'ribs'. The primary current lineation is preserved in fine flaggy laminated sandstone. When split open the edges of laminae produced by the breakage are straight and parallel, producing a striking lineation (Plate 9) unrelated to jointing.

PLATE 9



(i) Outcrop of flaggy SagittariusSandstone in the Blackwater area displaying well developed primary current lineation



(ii) Closer view of primary current lineation. Scale approximately x$\frac{2}{5}$

PLATE 10

(i) Trough cross-stratification in the Sagittarius Sandstone - Carnarvon Creek.

Southern-Central Bowen Basin

Marathon-Continental Glenhaughton No. 1, drilled on the west limb of the Mimosa Syncline, shows that the formation can be divided into three units. The uppermost unit, which is similar to the overlying Clematis Sandstone, is 575 feet thick. It consists mainly of light coloured, medium- to coarse-grained, quartz-rich sandstone, and grey siltstone, interbedded with grey, and in rare cases red, shale. The middle unit, 2385 feet thick, consists mainly of red shale, interbedded with grey to green siltstone and sandstone. The basal unit (713 feet thick) is a sequence of interbedded grey and greyish-green siltstone, shale, and sandstone, the shale being red only at a few levels.

South-East Bowen Basin

Little is known of the stratigraphic sequence within the Rewan Formation in the south-eastern part of the Bowen Basin because of the lack of outcrop. Some field observations have been made near Cracow at the base of the formation, and further information has been won from four shallow holes drilled in the area, two at the base of the unit, one near the middle, and one at the top. The conglomerate at the top of the coal measures is overlain by green, pebbly, calcareous, lithic sandstone interbedded with red-brown mudstone, and these lithologies are thought to form the bulk of the unit in this area.

U.K.A. Cockatoo Creek No. 1 well (Union Oil Development, 1963) reveals that the formation, unconformably overlain by the Jurassic sequence, and consists of grey-green conglomeratic sandstone, interbedded with red-brown, and grey-green shale. Red-brown shale was encountered from the top to a level 150 feet above the base. Tuff and minor coal are also recorded in the sequence. As the unit thins markedly towards the west, it seems probable that much of the Rewan Formation in this area was derived from a source lying to the east or north-east. Some support of this idea is found in the fact that at one large outcrop west of Theodore 50 measurements of cross-stratification indicated currents moving towards the west-south-west.

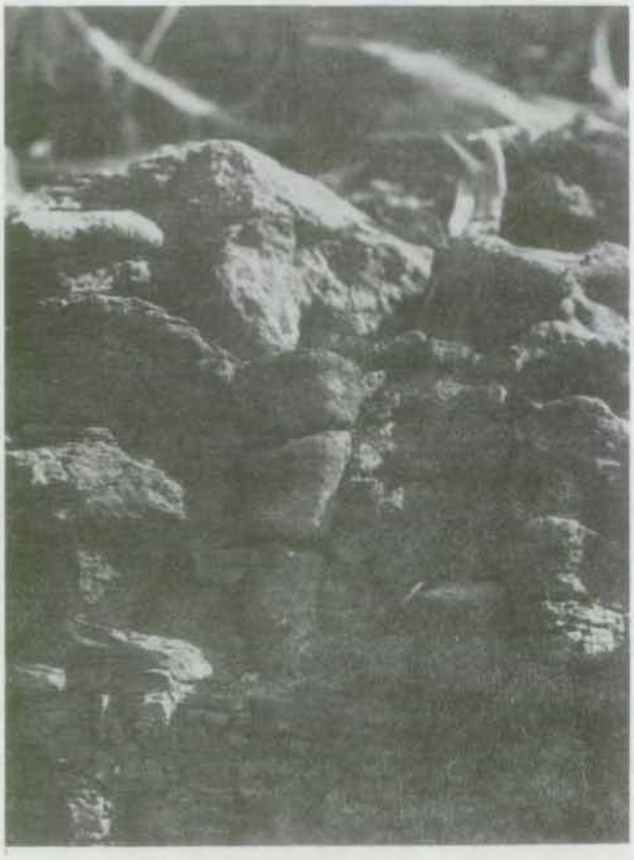
Central Bowen Basin

In the Blackwater area, only the lower part of the Rewan Formation, known in this area as the Sagittarius Sandstone Member, has been studied in any detail. Malone et al. (1963) report that chocolate shale is the dominant lithology in the upper part. The sequence immediately above the coal measures as seen in outcrops south of Blackwater consists mainly of calcareous sandstone, and calcareous mudstone, both of which grade into sandy limestone and intraformational conglomerate (Plate 11i) of brown calcareous pellets commonly containing conchostracans. Samples from the base of the formation consist of quartz and rock fragments in a brown carbonate, possibly sideritic matrix, with irregular patches of colourless oolitic chlorite. The simplest oolites, measuring about 1 mm in diameter, have a core of colourless chlorite surrounded by a thin shell of calcite and then a shell of yellow brown limonite. Variations on this theme are common. In some samples the chlorite has been replaced by siderite, and the oolitic structure is outlined by shells of limonite, but in many others two or more oolites form clusters around quartz grains or rock fragments. The sideritic matrix is spherulitic. Interestingly similar oolites were observed in a very coarse calcareous sandstone (38:53:93) near the base of the Rewan Formation in the type section at Reid's Dome.

Two of the continuously cored holes drilled by B.H.P. from the Sagittarius Sandstone into the coal measures indicate the nature of the sequence. The change from the coal measures to the Sagittarius Sandstone is quite abrupt and must be placed just above the highest coal seam in both cases; above this the amount of carbonaceous material falls off considerably, although carbonaceous plant fragments are not altogether lacking in the Sagittarius Sandstone. The sequence consists of thinly bedded shale, siltstone, and fine sandstone, apparently without marker beds. Intraformational conglomerate is common in both holes from 100 to 200 above the base of the Sagittarius Sandstone; it also occurs in at least one horizon within the coal measures, and in the Sagittarius Sandstone, at 150 feet from the surface in B.H.P. No. 1. Conchostracans

PLATE II

(i) Intraformational conglomerate overlying carbonaceous mudstone and overlain by cross-stratified sandstone; near the base of the Sagittarius Sandstone, Blackwater area.



(ii) Small cylindrical pipes about 1½ inches in diameter, in a fine calcareous sandstone, near the base of the Sagittarius Sandstone near Blackwater.

are present in both wells at about 150 feet from the surface.

Sandstone in the Sagittarius Sandstone, from the two B.H.P. holes, is medium- to very fine-grained, and moderately to very poorly sorted. The framework, roughly 65% of the sandstone, consists mainly of quartz and lithic fragments, with relatively minor feldspar (33:56:11). Rock fragments are difficult to distinguish from the green-brown chloritic matrix, as many of them have been replaced by chlorite, possibly before burial. Volcanic and sedimentary rock fragments are the most common, but probably metamorphic rocks types are also present. Plutonic fragments are almost completely absent, which may be a function of grain size. Hematite pellets and the replacement of carbonate and matrix by iron oxide is not as common as in the sandstone of the northern part of the basin. The carbonate petrology of the sandstones is complex, and it has not been studied in any detail. Dark brown possibly sideritic pellets with vague internal structures, common towards the base of the formation, might have been derived from algae. Dolomite rhombs appear to replace calcite in some samples.

As in the Reid's Dome area, sandstone in the unit exhibits trough cross-stratification and primary current lineation. Measurement of the cross-stratification at seven localities in the Taurus Homestead area, a total of 126 measurements, reveals a relatively consistent north-north-west direction of sediment transport. Primary current lineation where seen reinforced this conclusion. Other inorganic structures present in the unit include small sand-filled mud cracks, and rarely, ripple marks.

The presence of conchostracans is not the only sign of life within the formation. Core near the top of B.H.P. No. 2 hole shows small irregular burrows in shale bands which have been filled with sand similar to small burrows in the coal measures; their original shape may have been modified by compaction. About 3 miles north-west of Taurus Homestead, at the base of the unit, a calcareous sandstone is riddled with small vertical cylindrical bodies $\frac{1}{4}$ inch to 3 inches in diameter and up to 4 inches long (Plate 11ii). Although single cylinders are most common some are joined in pairs. Their internal structure is obscured by concretionary banding, but the outer third of the cylinder wall appears to be composed of fine and which surrounds a core of very fine calcilutite. Probably these structures represent infilled organic burrows, but they could also have been formed by water rising as springs to the surface.

Northern Bowen Basin

In the northern part of the basin the sequence has been examined in the Nebo area and west of Blenheim and Turrawalla. In the Nebo area, the base of the Rewan Formation is marked by a prominent strike ridge east of Lake Elphinstone. The lower part of the sequence consists mainly of green-brown sandstone (60:20:20C) with minor green-brown to red-brown mudstone. Thick beds of red mudstone interbedded with green lithic sandstones are known to be present 1800 feet above the base of the unit, but the division of the unit into an upper dominantly red mudstone unit and a lower more sandy unit is not clear-cut. Farther north, in the Blenheim area, pebbly sandstone (35:55:10C) is the most common lithology in the lower part of the Rewan Formation. The upper parts are covered by sand shed from the Redcliffe Tableland, but thick beds of red mudstone crop out near the top of the unit west of Turrawalla, and red mudstone was encountered in every hole drilled for coal west of Exe Creek.

Sandstone of the Rewan Formation in the Nebo area is moderately to poorly sorted and ranges from very fine to coarse, medium to fine grained sandstone being the most common. The composition of the framework does not vary greatly, and the ratio of quartz to rock fragments and feldspar is fairly constant (50:27:23), except at the base of the formation where lithic fragments are more common (24:70:6) and feldspar noticeably lacking. Volcanic, sedimentary, and metamorphic rock fragments are common in sandstone throughout the unit; plutonic fragments appear to be confined to the oldest parts. Roughly 40% of each sandstone is composed of material other than the framework, and much of this is green brown chloritic matrix, possibly altered biotite and clay minerals. In some cases a vague oolitic structure can be observed in this matrix. Hematite and hydrated iron oxide is present in much of the sandstone of the Rewan, occurring as replacement of the chloritic matrix, replacement of individual rock fragments before burial, replacement of carbonate, and as small ragged pellets and void filling cement. Kaolinitic clay, carbonate, and secondary silica act as minor cementing agents in some places. By far the most common non-opaque heavy mineral is epidote, which occurs as discrete grains or as subangular grains composed of epidote and polycrystalline quartz.

Lithic fragments, mainly of sedimentary and volcanic origin, are dominant, and feldspar lacking, in sandstone at the base of the Rewan Formation in the Blenheim area as well as the Nebo area. Sandstone higher in the sequence is less labile (50:40:10), despite an increase in feldspar content. Matrix and cement are the same as in sandstone of the Nebo area.

Measurements of trough cross-stratification, the only common sedimentary structure, in the Nebo and Blenheim areas indicates a relatively consistent transportation of sediment towards the south-west (Fig. 11), and the same direction of sedimentation was observed in the Turrawulla area farther north.

Environment of deposition

The overall scarcity of fossils and outcrop in the Rewan Formation hinders the reconstruction of the environment of deposition. Definite marine fossils are lacking. Conchostracans, found only in the Sagittarius Sandstone and its equivalents, indicate freshwater conditions. Most present-day conchostracans live in shallow pools in inland basins with a warm temperate climate (Kobayashi, 1954), although cold water forms are known. The presence of plant material, albeit scarce in the upper parts of the unit, supports a continental environment, but it is conceded that plant debris can accumulate in a marine or transitional environment. The presence of acritarchs in the upper part of the unit in the Eromanga Basin (Evans, 1965) appears to be only of minor importance in the determination of the environment of deposition for the unit as a whole. Some doubt has been cast by Varms (1964) on the significance of the discovery of hystrichospheres (and acritarchs) in non-marine sediments (Churchill and Sarjeant, 1962), but the reliability of these fossils by themselves as indications of marine conditions is still questionable. In any case, the overall lack of these fossils in the Rewan Formation is probably a more important indication of the general environment of deposition than their rare occurrence.

Some light is thrown on the problem by the interpretation of sedimentary structures, and the nature of the sediment. Sandstone of the Rewan Formation on the western side of the basin is characterized by trough cross-stratification, rib and furrow markings, and primary current lineation. Sandstone in the sequence elsewhere in the basin exhibits trough cross-stratification, but the other structures have not been observed. Although it is generally agreed that trough cross-stratification is the product of scour and fill, it is not known if it is restricted to any particular aqueous environment. Clearly, there must be vigorous turbulent currents carrying a load of sediment, and Stokes (1953) postulates scour by a vortex action and subsequent deposition of the material picked up, in a scour farther downstream. A fluvial environment would seem the most likely place for this type of action. In this connection it is interesting to note the poor sorting of the sandstone of the Rewan Formation.

Primary current lineation is reported by Stokes (1953) to indicate deposition under shallow sheets of flowing water, and although similar markings can be observed on sandy beaches. He had no doubt that they commonly indicate deposition in a fluvial environment, in such places as along the shelving banks of a river. Similarly, rib and furrow markings are probably formed under slowly moving currents in fairly shallow water, and Stokes (1953) suggests as a possible mechanism of formation the return of water into the channel after a flood.

One of the main clues to the environment of deposition probably lies in the presence of red beds within the sequence, but it is doubtful if this rather controversial feature can be interpreted reliably. The formation falls into the red bed category because of the presence of thick beds of red mudstone, and because sandstone of the unit commonly contains either a ferruginous matrix or cement, or ferruginous framework material, such as rock fragments partially replaced by hematite. There has been no attempt to identify the clay minerals of the formation, but thin section observations suggest the presence of kaolinite, especially in the lower part of the unit, and interlayered chlorite-illite, possibly derived from biotite. Some of the clay appears amorphous.

The origin of the Rewan Formation red beds must be closely related to provenance and environment of deposition, and ultimately to climate. The presence of ferruginous rock fragments testifies to alteration, probably lateritization, in the source areas prior to erosion, transportation and deposition. Unfortunately the presence of laterite does not indicate specific climatic conditions (Maignien, 1966) except that laterite always corresponds to climates in which the rainy period is a warm season, and that the lower limit of precipitation is around 30 inches per year. Maignien also notes that most contemporary lateritic soils develop at a mean annual temperature of around 77°F.

The deposition and preservation of ferric oxides is not only regulated by the supply of iron rich material from the source areas, but also by the physical and chemical conditions of the depositional environment. The formation of chamositic oolites and hematite cement, as well as siderite, requires an alkaline oxidizing environment (Krumbein and Garrels, 1952), and for this one would envisage the well drained flood plains and channels of an extensive river system.

The overall character of the Rewan Formation indicates that it was deposited in a dominantly fluvial environment. The coarse, trough cross-stratified sandstone bodies represent channel sands, and the finer sediments with primary current lineation, and rib and furrow markings probably represent vertical accretion deposits within flood channels. Much of the fine mainly red sediment represents the broad sheets of overbank deposits. Intraformational conglomerate of mud clasts, so common in the formation, is evidence of desiccation during dry periods, and subsequent erosion and deposition at flood times. The climate was probably warm to hot and the rainfall seasonal. The presence of pollen and larger plant material would seem to rule out the possibility of extreme aridity in the surrounding provenance areas, and probably in the basin of deposition. The depositional environment of any particular bed within the formation may not necessarily be fluvial. One would imagine that aeolian deposits and even minor marine transgressions were possible, but as yet undetected.

INTERPRETATION OF STRATIGRAPHIC AND PETROLOGICAL DATA

Correlation

LITHOSTRATIGRAPHIC UNITS

The first section of this report outlined lithostratigraphic subdivisions of the Upper Permian and Lower Triassic sequence in five areas of the basin taking into consideration new information gathered during the present study, and previously published nomenclature. The next step is correlation of these units, and a suggested scheme is illustrated in Figure 18.

In attempting a correlation of lithostratigraphic units the aim has been to select boundaries already established in each area which could be traced throughout the basin if outcrop permitted. In the past, the south-west part of the basin has been taken as the reference section, and lithostratigraphic correlation of units were keyed into this area. Because this section is so thin compared with that of the northern and south-eastern parts of the basin, this practice has helped to introduce errors. For example, the 'Upper Bandanna' Formation has been regarded as equivalent to the whole of the Blackwater Group whereas in reality it is equivalent only to the uppermost part. In this report, broad lithostratigraphic units in the northern part of the basin, where the section is thickest, are correlated with parts of the sequence as they are exposed in the south-eastern, central, and south-western parts of the basin.

The base of the sequence in the north is the base of unit C (of Dickins, Malone and Jensen, 1964) which was traced into other parts of the basin on lithological and palaeontological evidence. The upper boundary of the basal unit, the Blenheim Formation, is marked by a change of lithology which can be correlated with the top of the German Creek Coal Measures at a position close to the top of the MacMillan Member south of Blackwater. This boundary coincides with the top of the

Black Alley Shale in the Reids Dome area. Recognition of the part of the sequence equivalent to the top of the Blenheim Formation in the south-east part of the basin is not easy. There is no change from a quartz rich to a quartz poor sequence in the Cracow area, the whole Upper Permian sequence containing volcanic rock fragments and little quartz. In the past the top of the Mount Steel Formation has been correlated with the top of the Blenheim Formation, presumably because both are the youngest Permian units which contain marine fossils in each area. Although this correlation could ultimately prove to be correct more evidence is required to confirm the correlation. It is suggested that the top of the Acacia Formation is just as possible, and perhaps more likely in terms of thickness and lithology, to be the lithostratigraphic equivalent of the top of the Blenheim Formation in the northern part of the basin.

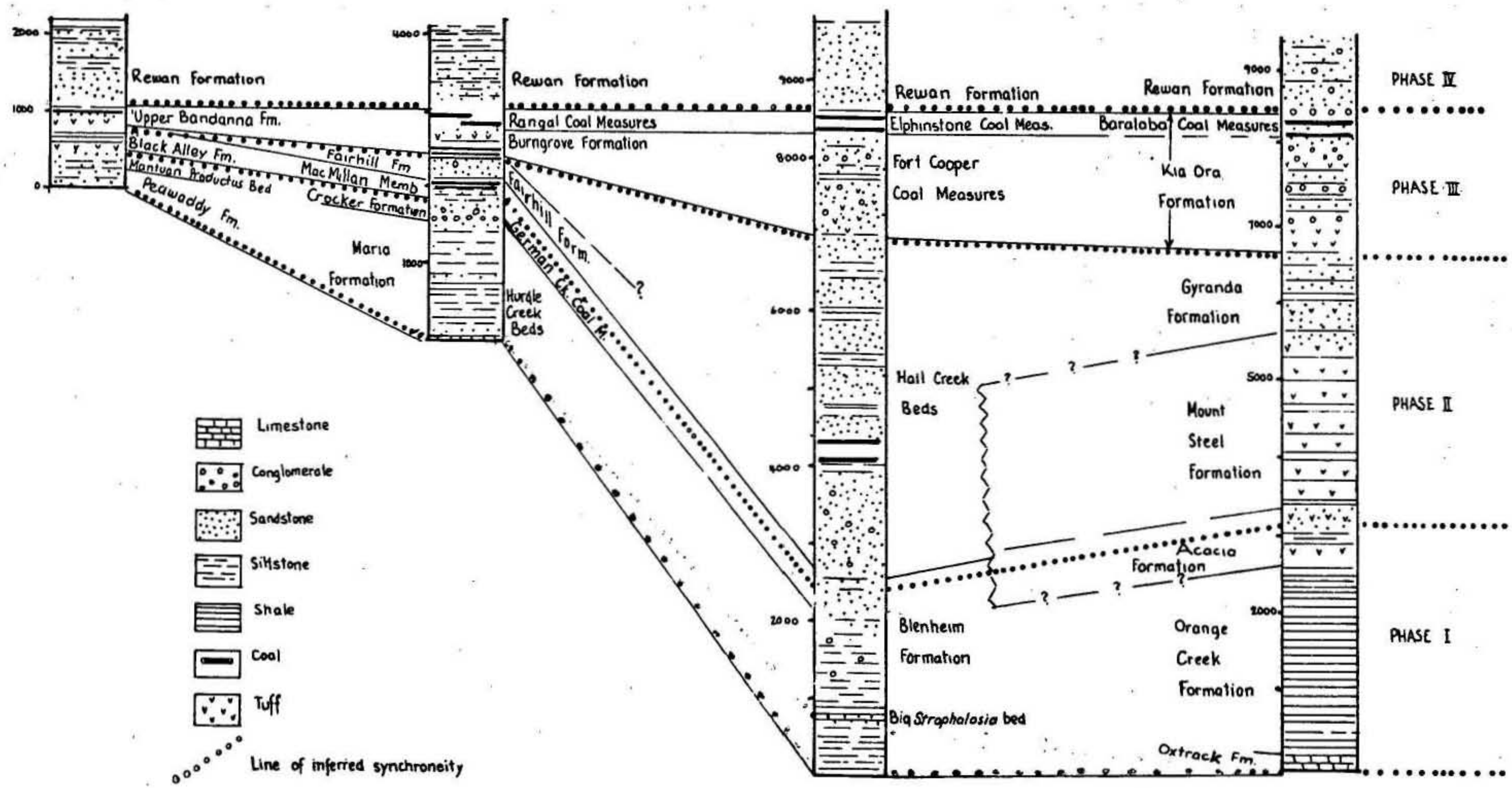
By contrast, the top of the overlying unit, the Hail Creek Beds, can be easily correlated all over the basin, because it is marked by the incoming of fine tuff beds so characteristic of the Fort Cooper Coal Measures and the Bungrove Formation. Correlation within the Hail Creek Beds is more difficult. The Mount Steel Formation has no obvious correlate within the Hail Creek Beds, but the Gyranda Formation is similar to the upper part of the sequence. On the western side of the basin the equivalent section is so reduced in thickness that it is unlikely that obvious correlates can be found without more exposure at the surface. The Fairhill Formation is a reasonably homogeneous unit which could be correlated with sandstone around the base of the Hail Creek Beds, or alternatively, it could be correlated with the whole of the Hail Creek interval. The only evidence of a disconformity immediately above the Fairhill Formation is that it appears to wedge out towards the south-west, and it is not present at Reid's Dome.

The top of the Fort Cooper Coal Measures is marked by the increase in size and number of coal seams and, by other minor changes of lithology. Similar lithological changes and increasing coal content

Fig 18

BROAD CORRELATION OF UPPER PERMIAN AND LOWER TRIASSIC UNITS IN PARTS OF THE BOWEN BASIN

Scale 1" = 2000'



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can be found in an equivalent part of the sequence in other parts of the basin and there can be no doubt that the Elphinstone Coal Measures can be correlated with the Baralaba and Rangal Coal Measures and with the 'Upper Bandanna' Formation.

In the past, there has been some confusion as to the nature and position of the boundary between the Rewan Formation and the underlying coal measures in the south-western part of the basin. Shell (Qld) Development Pty Ltd (1951) took the boundary to be at the base of the Brumby Sandstone (their Malta Grit) because the chocolate or red-brown mudstone characteristic of the Rewan Formation was not known below this marker bed, and probably because of the unconformity recognized beneath the Brumby Sandstone. At the same time it was assumed on the basis of fossil plants that this boundary separated Permian from Triassic rocks. However, purplish green and reddish clay was encountered in O.S.L. No. 3 (Arcadia) about 250 feet below the level of the Brumby Sandstone, and Derrington (1957) recorded mottled chocolate and grey shale about 350 feet below the Brumby Sandstone in A.A.O. 7 (Arcadia). It is now evident that there is little difference between the lithology directly above and below the Brumby Sandstone, so it appears that the interval between the Brumby Sandstone and the youngest Permian coal should be included in the lower part of the Rewan Formation and not in the Bandanna Formation. Furthermore, this interval, which Shell originally took to be Permian, is Triassic, as Evans (1962) has found a Triassic spore assemblage just 50 feet above the youngest coal. The boundary between the two units should be taken where there is a change from a sequence of coal and coaly shale to a sequence without coal or carbonaceous shale. This would normally be just above the highest coal seam.

Roughly the same situation was encountered in Planet Warrinilla No. 1 (Figure 17), where the highest coal seam is overlain by about 400 feet of grey-white clayey sandstone, interbedded with grey shale with carbonaceous laminae (Planet Exploration Co. Pty Ltd, 1963). This interval, the top 40 feet of which consists of mottled green and red shale, was correlated by Planet with the interval above the youngest coal at Arcadia, and therefore termed Bandanna Formation, using Shell's terminology. This seemed to create some problems as the interval in question appeared to be lithologically transitional between the coal measures and the Rewan Formation, and because it yielded Triassic microfossils (Evans, in Planet Exploration Co. Pty Ltd, 1963). To complicate matters, dipmeter observations indicated an angular discordance within the interval (see Figure 17 for the position of the angular discordance, the youngest coal, and the Triassic microfossils). It was wondered at the time if the Bandanna/Rewan boundary should be placed at the unconformity as the Arcadia area. In fact, the interval above the youngest coal termed Bandanna Formation is part of the Rewan Formation.

The angular discordance indicated by dipmeter observations may be real. Readings on beds above the discordance average $8\frac{1}{2}^{\circ}$ to the south, and those below average 2° to the north. These measurements are unlikely to have been made on cross-stratification, which is more likely to be steeper and dipping north; the maximum dip recorded is 15°.

TIME STRATIGRAPHIC UNITS

Correlation of time-stratigraphic units within the Upper Permian sequence is hampered by a deficiency of time markers. Some overall control has been gained by a combination of palaeontological and palynological studies, and by the assumption that certain lithostratigraphic boundaries are essentially coeval on a regional scale.

Palynological correlation is possible in the south-western and central parts of the basin, but carbonization appears to have destroyed the microflora in the northern areas (Evans, 1963), and very few studies have been made of the sequence in the south-east. Evans (in Mines Administration Pty Ltd, 1962a, 1962b, and 1963) devised a scheme of palynological units for the Permian and Triassic succession from outcrop and subsurface studies, units P_3b, P_3c and P4 covering the Upper Permian section; these units were subsequently grouped into one stage (Evans, 1967). In the south-west part of the basin, unit P_3b is associated with the sequence from the Aldebaran Sandstone to the Peawaddy Formation, unit P_3c with the base of the Black Alley Shale, and unit P_3d with the remainder of the Black Alley; unit P_4 appears to be constantly associated with the overlying coal measures. The Rewan Formation contains a very different palynological assemblage divided into units Tr1a, Tr1b and Tr2a (Evans, 1965). These Permian and Triassic units can be traced about as far north as Blackwater, but farther north time correlation has to rely on marine macrofossils and the recognition of regionally isochronous units.

Marine fossils preserved within the Blenheim Subgroup constitute Fauna IV of Dickins (in Malone, Corbett and Jensen, 1964). Various units within the Blenheim Subgroup, such as the Big Strophalosia Bed, have distinct faunal assemblages, but no satisfactory faunal subdivisions have been established as yet.

Despite the lack of time control, a possible interpretation of the history of deposition is made in the following pages, based on isopach maps on three time-rock subdivisions of the Upper Permian sequence. The base of the oldest subdivision (Phase I, Fig. 18) is taken at the incoming of Fauna IV and this is assumed to be essentially contemporaneous over the entire basin. Recognition of the base of Phase II relies on correlation of the Crocker Formation with the Mantuan Productus Bed and the Streptorhyncus pelicanensis Bed. It also relies on the assumption that vulcanism commenced at the same time in the south-eastern part of the basin as in the south-western part.

For the purposes of the history of deposition, phase II is split into two parts which are assumed to be time-rock units although evidence is lacking. The dividing line between phase 11a + 11b is placed at the base of the Gyranda Formation in the south-east part of the basin, and on the assumption that vulcanism ceased temporarily all over the southern central parts of the basin at the same time, this is correlated with the base of the Fairhill Formation in the Blackwater area.

This line is correlated southwards to a position at the top of the Black Alley Shale in the Reid's Dome area, and to the base of the upper part of the Hail Creek Beds in the north which bears a strong lithological similarity to the Gyranda Formation. The selection of the precise stratigraphic position of this boundary in the south-western part of the basin makes little difference to the isopach maps because the sequence is so thin.

The selection of the base of phase III as a time marker is based on the assumption that the tuffs so characteristic of the Fort Cooper Coal Measures, Burngrove Formation, and Kia Ora Formation were widespread and deposited at roughly the same time all over the basin. In a similar fashion the top of phase at III is based on an isochronous lithostratigraphic marker, the top of the coal measures. It is assumed that climatic changes were the most important control on the cessation of coal measure formation; the climatic changes may of course have been related to regional tectonic movements.

A Possible Interpretation of the Depositional History

The Upper Permian marine transgression first noted by Dickins, Malone and Jensen (1964) resulted in deposition over a greater area than earlier Permian transgressions. Marine deposition appears to have spread rapidly from the eastern to the western parts of the basin, possibly reaching its greatest areal extent about the time of deposition of the Big Strophalosia 'Zone' and the clarkei-bed. The first phase (Fig. 19) of the depositional history commences at the time of this transgression and continues until about the time of formation of the Black Alley Shale. Maximum subsidence was on the eastern side of the basin east of the present position of the Banana Fault, where a deep trough formed; sedimentation could have taken place in relatively deep water in this area at times. Farther west, the isopachs (Fig. 19) show a hinge area, considerably compressed now by subsequent folding, which extended from the Comet Ridge to the Banana Fault, and northwards into the Exmoor area. Deposition of mud and pebbly mud in the northern part of the hinge area was in relatively shallow water adjacent to an

Fig. 19 a. Inferred thickness of sequence deposited during PHASE I

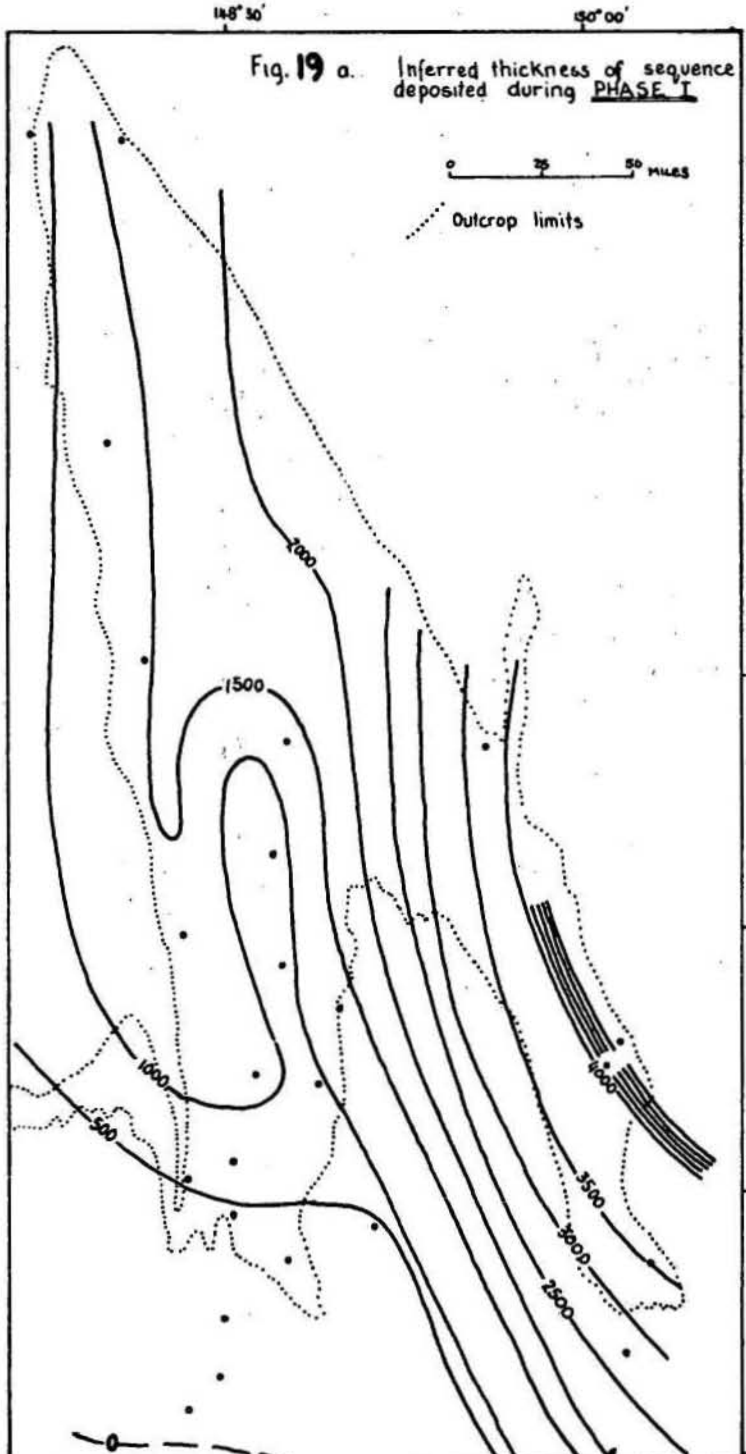
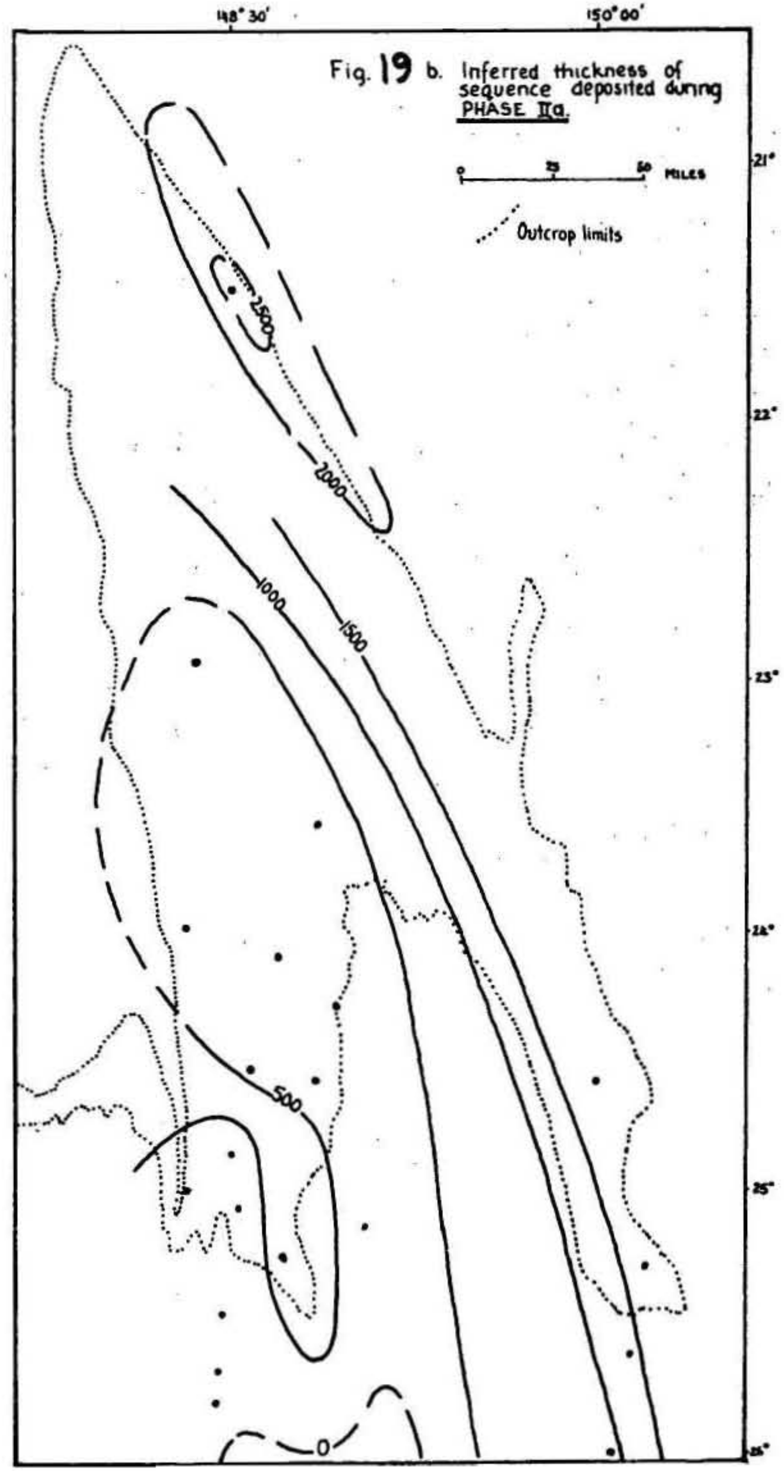


Fig. 19 b. Inferred thickness of sequence deposited during PHASE IIa.



Figure

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inferred eastern volcanic hinterland and western plutonic, volcanic and metamorphic hinterland. The replacement of this sequence by quartz rich sandstone bodies such as those at the top of the Blenheim Formation, indicate an infilling of the basin in the area, and the advance of regressive sands from the western margin of the basin. Farther south, in the Cracow area, after initial shallow water biogenic deposition on a submerged volcanic basement, fine muds accumulated in moderately deep water adjacent to the rapidly subsiding eastern trough.

Along the western side of the basin, west of the hinge area, paralic sedimentation resulted in the deposition of the Peawaddy, Maria and Crocker Formations. Perhaps the most striking feature of the pattern of sedimentation and relative subsidence on this area during this time, was the existence of a trough (probably the Denison Trough of Derrington and Morgan, 1960) extending from Rolleston to German Creek, and a narrow platform, the Comet Ridge, lying to the east. Most of the sediment accumulated on the western shelf area was derived from areas to the west composed of a mixture of volcanic, metamorphic, and plutonic rocks.

The deposition of pebbly mudstone with large angular blocks on the western shelf and northern hinge area, suggests the possibility of transport of much ice rafted material from an as yet undetected continental glacial environment.

Not long after the commencement of phase II (Fig. 19) the northern hinge area subsided rapidly west of the rising Connors Arch. Conglomerates of volcanic rock debris were deposited to the west of the rapidly rising mountain chain. While the sea retreated towards the south-east, quartz rich regressive sands extended from the western shelf forming part of the present day Passage Beds and German Creek Coal Measures. Marine conditions prevailed in the south-east part of the basin, accompanied by extensive vulcanism, possibly from volcanic areas from the east or south. Fine pyroclastic deposits were spread at least as far as Reid's Dome in the west, Blackwater in the north and Banana in the east. The Comet Ridge and Comet Platform still existed as part of the western shelf, although their size and position changed somewhat.

Withdrawal of the sea was probably complete by the early part of phase IIb (Fig. 20), although traces of marine fossils in this part of the sequence in UKA Burunga No. 1 (within the interval from 4500 feet - 6380 feet) suggest the possibility that the sea covered parts of the southern areas now beneath the Surat Basin. The trough forming in the southern area, where a coastal plain environment appears to have been established, was probably the forerunner of the Taroom Trough. Vestiges of the Comet Platform and Denison Trough are vaguely discernible, but there are signs of non-deposition on this side of the basin in the Reid's Dome area. Sedimentary processes continued over the west of the basin within one or more large drainage systems moving material southwards. Mixed provenance areas contributed to the sediment of the western shelf (Fairhill Formation) in contrast to the dominantly volcanic provenance of sediments deposited in the north.

Basin configuration and lithology reflect distinct changes in sedimentation in phase III (Fig. 20). The basin consisted of two well marked elements, the eastern or Taroom Trough, and the western shelf: the sharp contrast between these two elements is probably related to post depositional folding. The trough zone lay immediately west of a rising hinterland, already well established in the north and now present in the south was well. Mild uplift in the south-west produced a north-draining fluvial system. The rapidly subsiding trough which was to play an important part in subsequent Triassic continental deposition was filled by coarse and fine clastic sediments. Periodic intercalations of fine tuff spread over the whole basin, and were deposited without the coarse epiclastic material on the western shelf, commonly in a lacustrine environment. Although not shown in the isopach maps, the coal bearing sequences equivalent to the Rangal, Baralaba, and Elphinstone Coal Measures are all approximately the same thickness. This is taken to indicate a temporary cessation of uneven rates of subsidence - a gentle warping over the entire basin and the establishment of an extensive fluvial plain with associated lacustrine and paludal

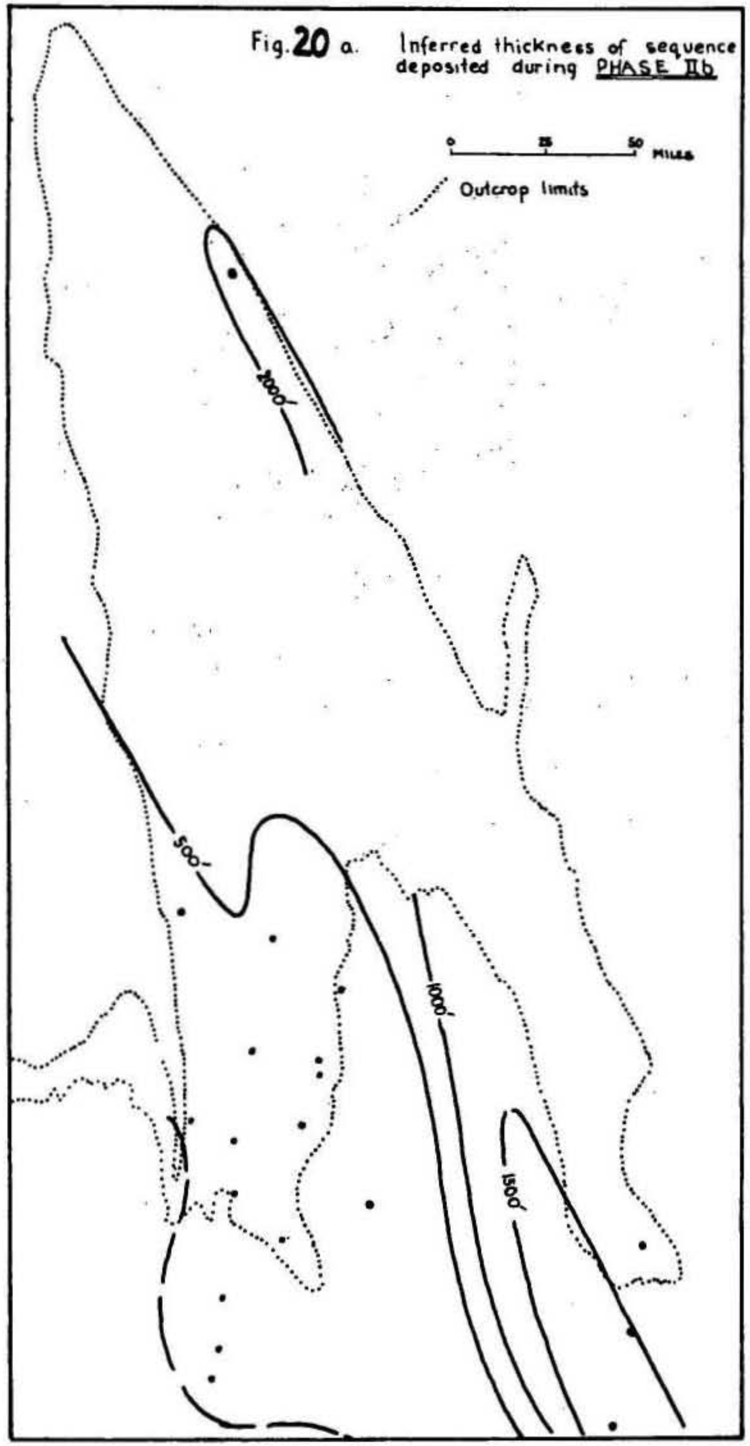

Fig. 20 a. Inferred thickness of sequence deposited during PHASE IIb

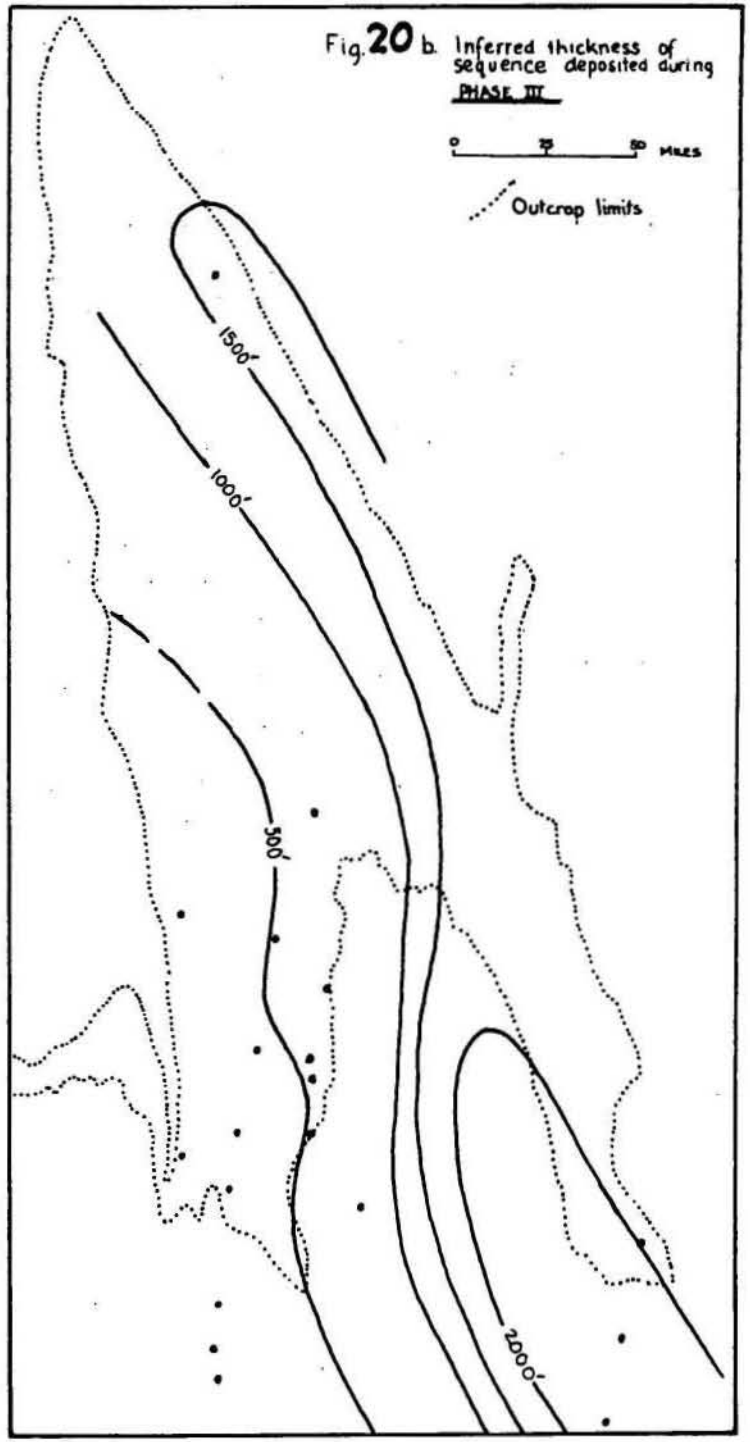

Fig. 20 b. Inferred thickness of sequence deposited during PHASE III

Figure

To accompany Record 1968/55.

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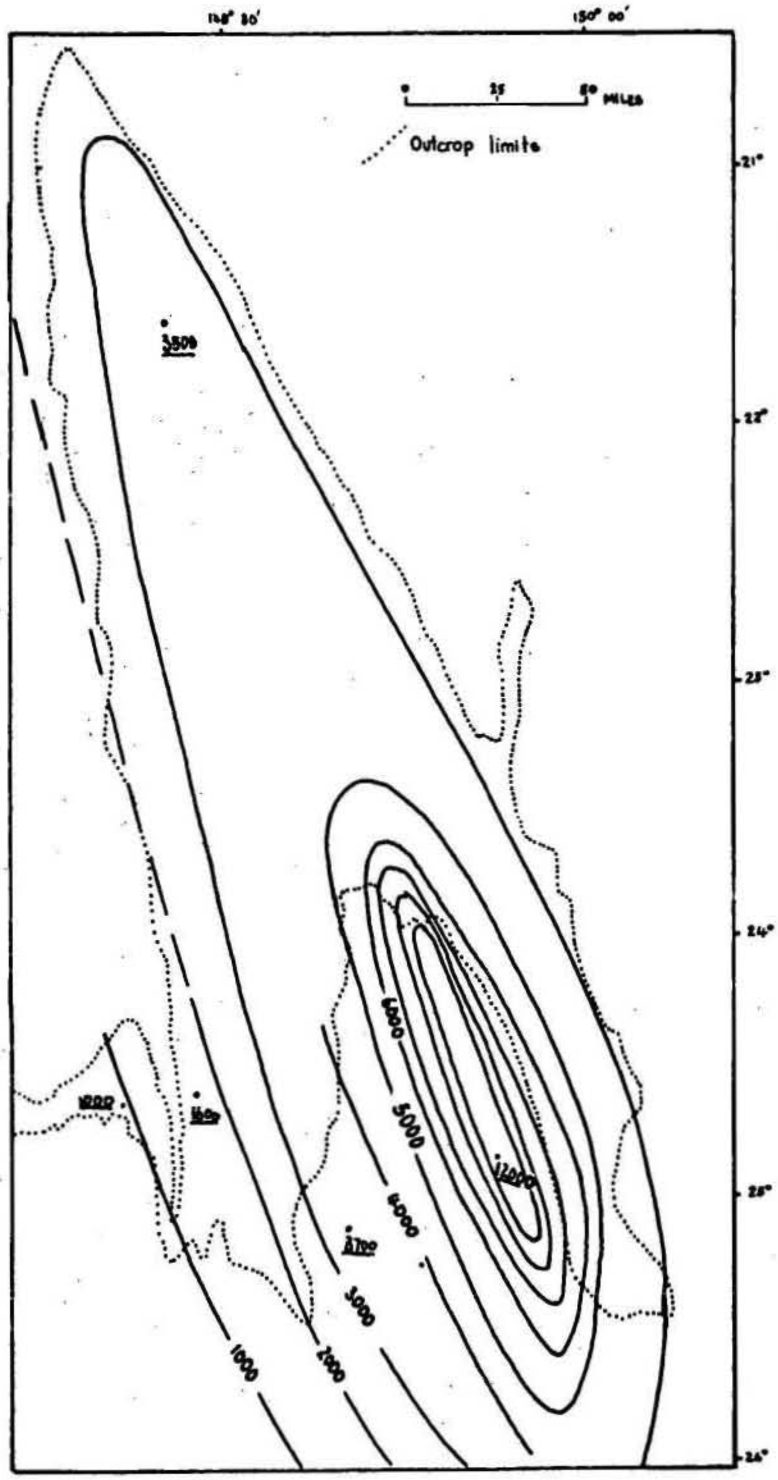

Fig. 21 Inferred thickness of sequence deposited during PHASE IV

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To accompany Record 1968/55.

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environments. River gradients were presumably minimal, and the plain was drained by sluggish streams which seldom cut down into previously deposited sediment. There is no evidence of marine incursion. Despite the relationship existing between tectonic setting, physiographic domain and coal formation, there can be little doubt that climatic conditions were also eminently suitable for the production, accumulation, and preservation of vast quantities of vegetable material. Presumably this required relatively humid conditions, but there are no indications as to temperature. Growth rings, so well preserved in the fossil logs of the sequence, presumably indicate marked seasonal changes, and the presence of tree ferns indicates a high annual rainfall. These conditions suggest a warm temperate to tropical, humid climate.

It appears likely that the conditions so suitable for the formation of peat changed swiftly towards the close of the Permian, and the basin became well drained by swiftly flowing streams relatively unaccompanied by associated lakes and swamps of any significance. Vulcanism ceased, and most of the subsidence was again in the Taroom Trough, east of the more stable western shelf and adjacent to highlands in the east. The highlands probably received a high seasonal rainfall and the red lateritic soils developed were washed westwards and deposited in the basin. The possibility exists that the highlands caused a rain-shadow, and deprived the basin of the amount of precipitation it had formerly received. At the beginning of this last phase (Fig. 21) uplift in the south-west part of the basin resulted in the spread of fine sand and silt derived from a plutonic, volcanic and sedimentary provenance northwards as far as Blackwater. Similar material, if anything a little coarser was swept southwards from the extreme northern part of the basin, and both these sequences were eventually transgressed by the red lateritic material derived from the east.

Economic Geology

COAL

Coal bearing sequences appear at more than one stratigraphic level in the Upper Permian succession. There are seams at the top of the Blenheim Subgroup on the western margins of the basin within equivalents of the German Creek Coal Measures, associated with the Crocker Formation and the Canangarra Sandstone Member. There are also indications of coal in the lower part of the Hail Creek Beds in the northern part of the basin. But by far the most widespread and important coal measures lie near the top of the Upper Permian succession just under the Rewan Formation. In the south-east part of the basin these are known as the Baralaba Coal Measures; in the central areas, Rangal Coal Measures; and in the northern area Elphinstone Coal Measures. The uppermost measures are being actively exploited at Moura, Baralaba, Bluff and Blackwater, but old mines and test shafts are scattered from one end of the basin to the other.

The Baralaba Coal Measures can be traced through Moura and Kianga to a position south of Cracow where they disappear under the Jurassic sequence. The structure of the Baralaba field is complicated, the beds being broken by south-west dipping reverse faults. Intensity of deformation decreases southwards as one moves away from the Dawson Tectonic Zone, and near Cracow the structure is relatively simple, the beds dipping regionally at about 13^{o} to the west-south-west. Mining operations commenced at Baralaba in 1921 and outcrop farther south in Kianga Creek (Reid, 1945) led to exploration and discovery of soft coking coal at Kianga in 1958. Hard coking coal was subsequently found at Moura, a few miles north of Kianga, and 1961 saw the commencement of a large scale, mainly open-cut, mining operation. Exploration has continued farther south and there are reasonable chances for the exploitation of non-coking coal.

In the central part of the basin, the Rangal Coal Measures have been found both east and west of Bluff. East of Bluff the coal measures are tightly folded and lie within the Dawson Tectonic Zone. Some of the earliest reports of outcropping coal were recorded in this part of the basin, and small mines have operated since early this century. West of Bluff, the coal measures dip regionally towards the east, striking south towards the Rolleston - Reid's Dome area and north towards the Elphinstone area. The recent discovery of near surface coking coal near Blackwater has led to a large open-cut mining operation. The extension of the Rangal Coal Measures southwards towards Rolleston is covered by basalt and Cainozoic alluvium, and has been little explored. Outcrops of coal equivalent to the Rangal Coal Measures are well known in Consuelo Creek and near Early Storms Homestead, but seem to be of little economic interest.

The Rangal Coal Measures extend north-north-west from Blackwater, but they are covered by alluvium. This area has been subjected to recent intensive drilling by companies in search of coking coal.

The Elphinstone Coal Measures are preserved in a synclinorium at the northern end of the basin. Areas of possible economic interest lie east, west, and north of the outcropping Triassic rocks which occupy a central, axial, position in the synclinorium. West of the central axis the coal measures are gently folded and faulted and surface exposures are rare. East of the axial zone, the coal measures are also gently folded and faulted as well as intruded by dykes and small stocks. As a result of private and government drilling programmes, large reserves of open-cut non-coking coal were proved in this area, but development of this area waned because of the lack of demand for this type of coal (Hawthorne, 1968).

The Elphinstone Coal Measures were drilled north of the Redcliffe Tableland in the extreme northern portion of the basin, but there have been no further developments. There is no reason why seams of good thickness should not be found in this area, but intrusions may be common and structure unsuitable for open-cut methods.

Further exploration for coal, particularly coking coal, will no doubt be concentrated on the Rangal Coal Measures and their equivalents. Some consideration should be given to the German Creek Coal Measures although distance from the Dawson Tectonic Zone may be a disadvantage; rank could increase northwards with the general increase in intensity of deformation and intrusion. This report has suggested the possibility of coal seams near the base of the Hail Creek Formation on the eastern margin of the basin and future prospecting especially south of the Bundarra Granodiorite could be rewarding.

It has long been recognized that there is a direct relationship between distance from the Dawson Tectonic Zone and the amount of volatile material (and hence rank) in the coals of the basin. A regular decrease in volatile constituents southwards from Baralaba to Moura and Kianga has been demonstrated by Wakeling (1968). The western margin of the tectonic zone is relatively well defined in the central and south-eastern parts of the basin, but its northern extension poses some problems through lack of outcrop and possibly because the zone fades northwards. The western margin is regarded generally as passing west of the Carborough Range along a thrust fault associated with the Kerlong Range (e.g. Malone 1964). It is possible, however, that it should be regarded as swinging farther east, passing close to Mount Travers (Fig. 1). This would have a direct bearing on exploration programmes. For example, the Elphinstone Coal Measures which have been extensively tested near Lake Elphinstone could be tested farther east, north of Fort Cooper Homestead (Fig. 10) in the hope that the rank or coking qualities change eastwards from the Lake Elphinstone. The fact that the Elphinstone Coal Measures are present in this area has not been previously noted.

PETROLEUM

There has been only minor success in the search for petroleum in the Bowen Basin, and there is no production at present. Drilling has so far been mainly confined to the southern part of the western shelf area, which includes the Denison Trough and Comet Ridge, although there have been two wildcats drilled in the south-east part of the area under discussion (UKA Burunga 1, and UKA Cockatoo Creek 1). Only three of nearly thirty wells drilled through Upper Permian rocks have encountered significant quantities of gas and none has encountered oil.

There is no lack of organic material preserved within the Upper Permian succession, and it is not unlikely that the lower parts of the sequence were potential source rocks. In particular, fine grained sediments such as those of the Barfield Formation formed away from the shallow water western shelf areas during phase I of the deposition history as described above, would appear to have been formed in a reducing environment capable of preserving a quantity of fine organic material. Similar condition may have existed for short periods on the western shelf areas during deposition of parts of the Peawaddy and Maria Formations.

If one were to judge from mineralogical composition of Upper Permian sandstone beds, reservoir potential of this sequence is not particularly good. The most common feature of sands in the sequence is the high proportion of volcanic rock fragments and associated carbonate cement. This certainly applies to the whole sequence in the south-east part of the basin and to most of the sequence in the northern half. Only in the stable shelf areas such as the Denison Trough and south of Clermont does not find quartz rich sands within the sequence. These lack cement at the surface but little is known of their subsurface fabric and mineralogical composition.

The present structural disposition of the Upper Permian sequence considerably reduces the possibility of finding petroleum in or near the Tectonic 'Zone', or in the northern part of the basin where post-Permian intrusion is common also. It has long been recognized that the most prospective areas are in and around the Denison Trough and possibly in the southern part of the basin where the sequence is covered by sediments of the Surat Basin. Petroleum prospects in the Denison Trough and environs have been discussed by Power (1967).

Equivalents of the Peawaddy Formation lying east of the Comet Ridge were probably in a position to received up-dip migration of petroleum in the early Upper Permian from sediments such as the Barfield Formation. Unfortunately the sequence east of the Comet Ridge is covered by a thick sequence of Mesozoic sediments, and the only drilling in this area has shown that this part of the sequence lacks porosity.

The dominance of a volcanic provenance reduces the chances of finding Upper Permian reservoirs in the south-eastern part of the basin, even though the sequence contains potential source rocks. The prospects for the accumulation of petroleum are much greater in the overlying Mesozoic rocks.

BENTONITE

Good quality bentonite comparable with Wyoming bentonite has been reported from the Black Alley Shale in the south-west part of the basin (Thompson and Duff, 1965), and its areal distribution and outcrop characteristics have been described. No further studies of this deposit were made during the present survey, but the occurrence has been investigated since that time by various private companies. As the MacMillan Formation of the Blackwater area is clearly equivalent to the Black Alley Formation, it is also worthy of some prospecting. Thin beds of a light green swelling clay were observed in the unit north of Cooroorah Homestead, and bentonite was recorded in the MacMillan Formation in AAO Sunlight No. 1 (Mines Administration, 1966). On the eastern side of the basin, some of the rocks forming the Mount Steel and Wiseman Formations are certainly of volcanic origin, but the admixture of terrigenous material may have been too great to permit a concentration of betonitic clay. Nevertheless these units could be investigated further.

It is perhaps surprising that despite the widespread vulcanism associated with the formation of the Fort Cooper Coal Measures, Burngrove Formation and Kia Ora Formations, no bentonite has been reported from these units. Clay beds presumed to be altered ash fall deposits have been observed in the 'Upper Bandanna' Formation (Thompson and Duff, 1965), and in the Burngrove and Kia Ora Formations, but they contain a high proportion of sandy material and appear to have a low swelling index. The fact that these units were formed in a continental environment leads one to suspect that the formation of sodium bentonite in this part of the succession is unlikely.

CONCLUSIONS

Conclusions relating to environment of deposition and provenance of each unit in the Upper Permian and lowermost Lower Triassic succession have been presented throughout the text and used in the synthesis of a possible depositional history. It is suggested that the Upper Permian marine regression took place during the deposition of the Mount Steel Formation and that marine conditions lasted longer in the southern part of the basin than in the north.

Conclusions have been made regarding the stratigraphic nomenclature of the sequence in various areas. In the northern part of the basin, the Rewan Formation can be split out of the old 'Upper Bowen' Coal Measures. The remaining sequence contains the more precisely defined Elphinstone and Fort Cooper Coal Measures and the newly defined Hail Creek Beds. The most satisfactory stratigraphic nomenclature to be applied to the sequence in the south-eastern, part of the basin is that of Mines Administration (1959) with the replacement of Isla Formation by Rewan Formation. It is concluded that the Mount Steel Formation is equivalent to the Wiseman Formation, and the Acacia to at least part of the Flat Top Formation. The Baralaba Coal Measures is regarded as part of the Kia Ora Formation, and the term 'Kia Ora' is not restricted to any particular conglomerate horizon. Use of the term 'Bandanna' Formation in the south-west part of the basin instead of 'Upper Bandanna' might best be discontinued. If a formal name is required for this unit by future workers an entirely new name should be proposed. The Brumby Sandstone, a name used for a thin unit within the Rewan Formation at Arcadia, is synonymous with Malta Grit, but not with 'Lower Rewan'.

Although the stratigraphic nomenclature of each area studied can be revised satisfactorily, no scheme for a basin-wide nomenclature is recommended except in the case of the Rewan Formation which can be recognized throughout the basin and name as such. It is thought proper that coal measures immediately beneath the Rewan Formation in each area should have different names of local significance such as Rangal and Baralaba even though in a regional sense they are equivalent. The Blenheim Formation can be correlated with sequences at German Creek and farther south, and this term could be extended down the western side of the basin without too much difficulty. An equivalent litho-stratigraphic interval in the south-east part of the basin cannot be recognized with any certainty.

Included in conclusions regarding the sequence in the south-west part of the basin are: 1) the slight angular unconformity beneath the Brumby Sandstone (Member) is within the Rewan Formation in the Arcadia area, and not at the base of the unit; 2) the sequence below the Brumby Sandstone at Arcadia is probably absent from the succession in the Reid's Dome area; 3) equivalents of the Fairhill Formation of the Blackwater area if present in the succession at Reid's Dome are very thin, and as yet undetected; 4) the Black Alley Shale is equivalent to the MacMillan Formation.

A system of nomenclature of arenites necessitating only the broadest of genetic interpretation, has been introduced and applied to sandstone of varying mineralogical composition.

It is suggested that more attention should be given to exploration for coking and non-coking coal in the northern part of the basin, despite the possibility of the deleterious effects of intrusions and complex structure. The Hail Creek Beds could be examined more closely and the Elphinstone Coal Measures prospected north of Fort Cooper Homestead. The western margin of the tectonic zone, apparently so critical in the control of coal rank, may swing farther to the east than normally supposed, and if so, areas south of the Bundarra Granodiorite are prospective.

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APPENDIX 1

MICROMETRIC ANALYSIS OF SAMPLES FROM THE UPPER PERMIAN AND LOWER TRIASSIC SEQUENCE

Abbreviations

Grainsize

vf	very fine
f	fine
m	medium
c	coarse
vc	very coarse

Sorting

p	poorly sorted
m	moderately sorted
w	well sorted

Minor constituents and lithic fragments

P	present
C	common
A	abundant

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NUMBER		GENERAL LOCATION	STRATIGRAPHIC SIGNIFICANCE		FABRIC		GENERAL MINERALOGICAL COMPOSITION												LITHIC FRAG.				MINOR CONSTITUENTS												QUARTZ: LITHIC FRAG., FELD RATIO			NOTES
							FRAMEWORK					MATRIX			CEMENT																						
FIELD	REGISTERED 6501–				GRAIN SIZE	SORTING	QUARTZ	LITHIC FRAGMENTS	FELDSPAR	CARBONATE	OTHERS	NOT IDENTIFIED	CLAY	CHLORITE	SILICA	CARBONATE	IRON	OTHERS	VOLCANIC	SEDIMENTARY	PLUTONIC	METAMORPHIC	MUSCOVITE	BIOTITE	CHLORITE	KAOLINITE	ILLITE	HAEMATITE	Fe OXIDE	EPIDOTE	ZIRCON	TOURMALINE	HORNBLENDE	APATITE	QUARTZ	LITHICS	FELDSPAR	
P3/19	4319	Lake Elphinstone	3500ft		m	m	56.7	15.7	10.0		1.3	4.3	11.9							P		P		P		P				C								
P3/18	4318	" "	2900ft		f	m	29.1	20.2	16.3		2.9	8.4		17.2	2.0			3.9	P	P		P			P					C								Some silica cement; clay possibly chlorite
P3/17	4317	" "	2500ft		f	m	32.5	24.9	14.4		6.3	5.0	14.4		1.3		1.0		P			P			C			P	P	A								Some grains replaced by iron oxides
P3/16	4316	" "	2100ft	above base	vf	vp	27	14	11		7		41										P	C	A					C		P		P				Fragments difficult to distinguish from matrix
A74	0174	" "	1700ft	of Rewan	vf	p	25.9	11.5	8.6		2.2	0.4		43.7		3.4	4.3		?			?	P	P	P		P			A	P	P		P				Chloritic clay possibly derived from biotite
A77	0177	" "	1300ft	Formation	f	p	30.0	8.7	6.8		10.6	4.8		32.8			6.2		C	P					A				C		P							Chloritic (chamositic) clay oolitic in part some haematite
P3/14	4314	" "	700ft		m	m	40.4	13.6	17.6		2.9	7.0		18.5					P	P	P	C	P	P	P	P	P											Clay matrix replaced by haematite. some haematitic pellets
Q5/7	5507	" "	<100ft	close to base	m	w	13.2	39.4	4.6		12.3		11.9			18.6			P	C		P			P			C	P	P								Others mainly FeOxide. Abundant haematite pellets
A67	0167	" "	<100ft	of Rewan	c	w	27.0	41.0	5.2			3.3	11.9		12.1				C	P			P		P													Rock fragments replaced by haematite. Many grains rimmed
A69	0169	" "	<100ft	Formation	c	m	14.1	42.8	1.2		15.9	19.9	4.8			1.2			C	C	P	P	P	A	P	P	P	P	P									Iron oxide replacing clay matrix
676		Blenheim	1800ft		f	p	35.0	27.4	8.2			9.1	5.1	14.4	0.2	0.6							P	C		P				C	P	P						Chloritic matrix formed from biotite
1409		"	1500ft		m	m	27.2	27.6	5.4			11.2	8.1	12.3		8.2			P	C	P			?	C	C	?		P					P				Chloritic matrix formed from biotite
1405		"	400ft	above base of Rewan	m	m	50.6	21.8	10.6			6.8	5.8	3.4		1.0			P			P		P	P	P	?			C			P					
1403		"	200ft	Formation			14.2	30.4	3.2	51.8					0.4				P	P					P									P				Carbonate may be partly secondary
294e		"	Near base of Rewan Formation		m	m	17.2	42.4	0.4			14.0	12.0	5.6	0.8	7.6			P						P		?				P							Colourless clay mineral
294a		"	Near base of Rewan Formation		m	m	13.8	40.8	0.2	32.8	3.6	0.8		8.0						P					P									P				Colourless clay mineral
R4/4	2404	Arcadia	750ft		f	m	9.1	53.0	2.8	10.0	0.3	13.2		1.9			9.7						P		P													Haematitic cement
R4/3	2403	"	450ft	above Brumby Sandstone	vf	m	6.6	22.4	15.6	50.3	5.0								C	P					P													Very fresh feldspar. Carbonate sparry
R4/1	2401	"	200ft		f	m	18.1	20.9	4.3		38.0	2.1	7.9				8.7		P	P		P	P			P		P		P								Haematite in cement
R5/2	2502	"	Brumby Sandstone		cgl		34.2	41.8	2.9			6.7				6.0	8.3		P	P	C	P						C			P							Carbonate clasts. Haematitic cement
R5/1	2501	"	Brumby Sandstone		vc	m	13.3	47.8	2.9	23.8			2.4				9.8		P	C	P					P		C		P	P							Haematite replacing cement
R5/5	2505	"	100ft	below Brumby	c	m	22.3	32.9	4.4				10.9			22.8	6.7		P	P			P			C				P				P				Haematite replacing cement
R5/4	2504	"	150ft	Sandstone	m	m	9.1	15.9	4.8	31.5	2.5	7.5	16.2					10.5	P	P	P	P		P	P			P	P									

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NUMBER				FABRIC		GENERAL MINERALOGICAL COMPOSITION												LITHIC FRAG.				MINOR CONSTITUENTS													QUARTZ: LITHIC FRAG. FELD RATIO			
						FRAMEWORK					MATRIX			CEMENT																							
FIELD	REGISTERED 6501–	GENERAL LOCATION	STRATIGRAPHIC SIGNIFICANCE	GRAIN SIZE	SORTING	QUARTZ	LITHIC FRAGMENTS	FELDSPAR	CARBONATE	OTHERS	NOT IDENTIFIED	CLAY	CHLORITE	SILICA	CARBONATE	IRON	OTHERS	VOLCANIC	SEDIMENTARY	PLUTONIC	METAMORPHIC	MUSCOVITE	BIOTITE	CHLORITE	KAOLINITE	ILLITE	HAEMATITE	Fe OXIDE	EPIDOTE	ZIRCON	TOURMALINE	HORNBLENDE	APATITE	PYROXENE	QUARTZ	LITHICS	FELDSPAR	NOTES
A8	0108	S.E. Ried Dome	Basal part of Rewan	c	w	14.4	53.3	9.5		2.0						20.8		P	P	P	P			P					P	P								A little derived chlorite
B41	0241	" " "	Basal part of Rewan Fm poss. equiv. to Brumby Ss	c	w	6.0	42.1	1.2	42.7	7.7						0.3		P	P	P	P			P														
B33	0233	" " "		m	m	2.6	45.8	2.1	46.7	2.8								P	P								P	P										Some ironstone pellets or pebbles
B42	0242	" " "	Just under Brumby equiv.	m	p	4.0	37.1	3.8		0.4		54.7						P	P	P	P		P				VC											Haematite with vague oolitic structure
B45	0245	" " "	Base of Rewan Fm	c	w	4.6	63.5	0.7		1.8							29.4	C	P	P					C													Kaolinitic cement
N6/1	3601	" " "		vc	p	23.6	34.4	5.5							25.4		11.1	P	P	P	P		P				P											Oolitic structure in cement
Q4/2	5402	7m N Fort Cooper Hs	1500ft above base of Hail Creek Beds	c	w	2	66	3							19	10		C	P	P								C										Limonitic cement
Q4/1	5401	" " "	1350ft	c	m	1	55	7	2						30	5		C																				Rather weathered
Q6/9	5609	1m SW Exmoor	800ft	f	m	12	38	11	1		4				10	24		C	C			P	P	P				P		P				P				
Q6/7	5607	¾m SW Exmoor	500ft	f-m	p	20	25	13			1		18		19	4		P	C			P		P				P										
Q6/6	5606	" " "	50ft	m	m	18	24	23			4		21		10			P			P		C	P														
Q6/5	5605	½m " "	25ft	f	p	66	5	8	1		14	2	3			1		P	P	P	P		P	P		P				P	P							
P7/1	4701	7m N Fort Cooper Hs	3400ft	c	p		58	17				16	5		4			C	P																			
P3/6	4306	Mt. Gotthardt	3000ft	m	m	5	75	5			5				10			A	P		P			P			P	P										
P3/5	4305	" "	2500ft	c	m	15	75	5				5						A	P		P																	
P3/4	4304	" "	2000ft above base of Hail Creek Beds	m	m	15	75	5	1				4					C	P		P			C			P	P										
Q4/2	5402	7m NE Fort Cooper Hs	1500ft	c	w	2	66	3							19	10		C	P	P								C										Limonitic cement
Q4/1	5401	" " "	1350ft	c	m	1	55	7	2						30	5		C																				
P4/3	4403	" " "	200ft	m	p	15	42	15	1	4	10	13						P			P	C			P			P		P								
P4/2	4402	" " "	50ft	m	p	12	40	21		5	14	6			2			P	P		P	C			P			P		P								

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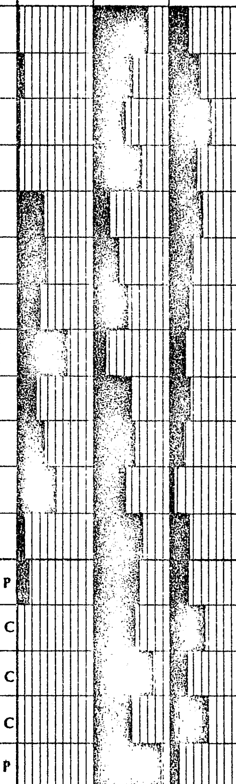
NUMBER		GENERAL LOCATION	STRATIGRAPHIC SIGNIFICANCE	FABRIC		GENERAL MINERALOGICAL COMPOSITION												LITHIC FRAG.				MINOR CONSTITUENTS													NOTES
						FRAMEWORK					MATRIX			CEMENT																					
FIELD	REGISTERED			GRAIN SIZE	SORTING	QUARTZ	LITHIC FRAGMENTS	FELDSPAR	MICA	OTHERS	NOT IDENTIFIED	CLAY	CHLORITE	SILICA	CARBONATE	IRON	OTHERS	VOLCANIC	SEDIMENTARY	PLUTONIC	METAMORPHIC	MUSCOVITE	BIOTITE	CHLORITE	KAOLINITE	ILLITE	HAEMATITE	Fe OXIDE	EPIDOTE	ZIRCON	TOURMALINE	HORNBLENDE	APATITE	OTHERS	
A55	0155	Nebo Area	Elphinstone Coal Measures	m	p	1	42	16		4					7		30						P		A										*Kaolinitic cement*
A56	0156	" "	" "	m	m	6	36	27	2		5				3		21	C	P		P	P		A									P		*Chloritic cement*
Q5/5	5505	" "	1200ft above base of Fort Cooper	m	m	2	29	38							1		30	C	P		P												P		*Chloritic cement*
Q5/1	5501	" "	300ft Coal Measures	c	p	1	51	28							5		15	C	P					P									P		*Stilpnomelane cement*
U8/1	6801	8	Near Top	m	p	19	11	22	2	1	36		2		7			P			P	P	P	P							P		P		
U8/3	6803	8	Near Top	f	p	25	22	19	2	2		23	6		1			P			P	P	P	P									P		
B69	0269	6	Near Top	f	m	20	32	18	1			18			11			P	P		P		P	P									P		
N8/1	3801	2 miles north	about 100 feet below top of Fairhill	f	m	38	9	10	1		12	20	1	3		6			P		P	P		P			P	C							
B68	0268	7 of Cooroorah	about middle Formation	m	m	12	23	13				8	2		28	14		P		P	P						C	C							*Brown limonitic replacement*
Q1/3	5103	4 Homestead	Near Top	m	m	10	20	7				1	2	1	48	11		P	P		P						C	C							
B67	0267	7	Towards Base	m	m	23	19	3	1	1		11			42			C			P														
Q1/2	5102	4	About middle	c	m	5	35	14				4	2		22	18		C	P	P				P				C							
R1/3	2103		100ft	m	w	8	30	12	1	7					42								C						C					P	
R1/2	2102	1 to 2 miles	200ft Below top	m	p		34	29		1		21					15							C					P	C	P			C	*Chloritic cement*
M4/2	1402	SE of Gyranda	700ft of Gyranda	c	m		50	14		2					34									P										C	
M4/1	1401	Homestead	700ft Formation	m	m		33	35		1	4	4					23							C					P	P				C	*Chloritic cement*
M3/1	1301		1400ft	m	w		55	7	1						37									P										P	

QUARTZ: LITHIC FRAGMENTS: FELD RATIO



NUMBER		GENERAL LOCATION	STRATIGRAPHIC SIGNIFICANCE	FABRIC		GENERAL MINERALOGICAL COMPOSITION: FRAMEWORK					MATRIX			CEMENT		
FIELD	REGISTERED			GRAIN SIZE	SORTING	QUARTZ	LITHIC FRAGMENTS	FELDSPAR	MICA	OTHERS	NOT IDENTIFIED	CLAY	CHLORITE	SILICA	CARBONATE	IRON
292C		Blenheim Area	Top of Blenheim Fm	m	m	46.5	18.9	8.2	2.9		12.2	6.5		4.8		
293a		" "	100ft	vf	m	45.2	11.8	4.3	3.8	2.5	29.4	0.2				2.7
B4		" "	100ft	f	p	44.8	9.8	8.2	1.4	1.4	18.2	5.6	2.8		6.2	1.4
Q6/2	5602	Exmoor	200ft	m	m	74.9	0.8	0.6			7.8	8.9				
Q6/1	5601	"	300ft below top	m	p	67.5	2.0	2.0	1.0			23.5				
B3		Blenheim	700ft of Blenheim Fm	vf	p	34.8	6.8	6.4	1.8	1.2	36.6	7.0	0.2		5.2	
B2		"	700ft	f	p	42.6	12.3	3.8			16.6	3.2	0.1	16.2	5.2	
Q6/11	5611	Exmoor	1400ft	f	p	54	7	12	2	2	9		14			
Q6/10	5610	"	1600ft	f	p	42	21	6			3		4		24	
R8/2	2802	Mt.MacMillan	Near base of Carnangarra Ss	c	w	63.6	7.2	6.1	0.3			20.3				2.8
C7	0307	4m NNW Carnangarra	Middle type section - Carnangarra Ss	c	w	66	7	14			1	4			8	
B64	0264	6½m N Cooroorah	Base of Cooroorah Ss	m	m	74.2	8.1	10.4	0.2		1.2	5.9				
R8/1	2801	Mt. MacMillan	at top of Macmillan Member	f	m	18.4	10.6	11.1	0.5	2.0		15.3			7.9	34.2
U9/5	6905	7m NNW Cooroorah	near base of MacMillan Member	f	p	20	15	15					18		30	
U9/6	6906	"	near base of MacMillan Member	vf	p	15	13	16		1	2	18	1		34	
R7/3	2703	Mt. Crocker - Blackwater	265ft above base	m	m	77.1	4.4	4.9	1.6			12.0				
R7/1	2701	"	115ft Mt.Crocker	m	m	77.8	1.5	1.8	0.6			18.3				

FIELD	LITHIC FRAG.: VOLCANIC	SEDIMENTARY	PLUTONIC	METAMORPHIC	MINOR CONSTITUENTS: MUSCOVITE	BIOTITE	CHLORITE	KAOLINITE	ILLITE	HAEMATITE	Fe OXIDE	EPIDOTE	ZIRCON	TOURMALINE	HORNBLENDE	APATITE	PYROXENE	QUARTZ: LITHIC FRAGMENTS: FELD RATIO — QUARTZ	LITHICS	FELDSPAR	NOTES
292C	?				P	P	P						P								
293a					C	C							P	P		P					
B4	P				P	P							P	P		P					
Q6/2				P	P	P							P	P							
Q6/1		?			P	P								P							
B3					P	P							P	P		P					
B2	P		P		P	P	P						P	P		P					
Q6/11			P	P							P		P	P							Brown chloritic matrix - ? altered biotite
Q6/10														P							
R8/2				P	P								C				P				Clay possibly authigenic
C7				P	P		P														Authigenic feldspar
B64		P		P									P								Authigenic feldspar
R8/1	?	P			P						P		P	P							Plagioclase common
U9/5	P			P												P					
U9/6	P			P												C					
R7/3				P		C								C	C						
R7/1				P		C								C	C						

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