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VOLUME 99 1966 COMPLETE

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Dr. W. R. Browne

Journal and Proceedings, Royal Society of New South Wales, Vol. 99, pp. 1-4, 1966.

By the publication of this volume of its Journal the Council of the Royal Society of New South Wales pays tribute to the long and outstanding service given to Australian science by

WILLIAM ROWAN BROWNE, D.Sc., F.A.A.

Dr. Browne joined the Society in 1913, served on its Council for many years and was its President in 1932 and Honorary Secretary in 1934 and 1935. He has contributed twenty-three papers to the ''Journal'', many of which are of such importance in the development of Australian geological thought that they are still frequently referred to. Especially is this true of his paper ''Notes on bathyliths and some of their implications'' (1931).

For his distinguished contributions to geology to that time, Dr. Browne was awarded the Clarke Medal by the Society in 1942 and was invited to deliver the Clarke Memorial Lecture for 1949. Seven years later the then Council had the pleasure of awarding him the Society's Medal in recognition of his scientific contributions and services to the Society.

''W.R.B.'s'' speech has a pleasant burr which is very slight but sufficient to reveal his Irish origin. For he was born, the son of James Browne, at Lislea, Co. 'Derry, on December 11, 1884. After a period at the Academical Institute, Coleraine, he came to Australia for health reasons and took up appointment as tutor to country families in the New England and Goulburn districts. The years 1907-1909 were spent at Sydney University and he graduated Bachelor of Science with first-class honours in Mathematics and Geology and the University Medal in Geology.

In February 1910 W. R. Browne was appointed First Assistant to G. F. Dodwell at Adelaide Observatory and experienced some of the trials of astronomical work of the day. He was a member of the team of astronomers organized by Baracchi to observe the total eclipse of the sun May 10 1910 from Bruny Island. For him the experience was memorable if unsuccessful, for the expedition was a failure due to cloud and rain. Dodwell left him to return with the equipment, but when Browne got it to the ship he was dismayed to find that, contrary to arrangement, Dodwell had not reserved or paid for his passage. Having only five shillings upon him he negotiated his passage intending to telegraph from Melbourne to Dodwell for money. His minuscule financial resources were to be depleted further, however. King Edward VII had died a few days previously and he had to purchase a black tie for 1/6 reducing his funds to 3/6, with which he reached Melbourne! Eventually he obtained his passage money from Dodwell and was able to proceed to Adelaide.

Dr. Browne was observer in Adelaide in February, 1911 during the interstate redetermination of the longitude of the Todd-Smalley obelisk, on the northern bank of the Murray River, near the 141st meridian, for purposes of evidence in connection with the South Australia/Victoria boundary dispute.

Later in 1911 he accepted Professor T. W. E. David's invitation to join the staff of the Geology Department of Sydney University as a Junior Demonstrator. He was in Adelaide again in 1912 on secondment to the University Geology Department as a temporary lecturer in mineralogy and petrology while Mawson was in the Antarctic. From 1913 to 1923 he was Lecturer, from 1923 to 1939 Assistant Professor, and from 1939 to 1950 Reader in the Department of Geology, University of Sydney. He also lectured in Economic Geography in the Faculty of Economics of that University in 1924-1926 and 1929.

In 1922 the University of Sydney conferred upon him the degree of Doctor of Science, with University Medal, for his work on the geology of the Broken Hill district.

To Dr. Browne fell the onerous and yet compelling task of editing and preparing for publication the voluminous manuscript on the geology of Australia which the late Sir Edgeworth David had accumulated. The University relieved him of normal duties between 1935 and 1939 to enable him to carry out this work, and the book would have gone to press in 1939 had not World War II intervened. After the War Dr. Browne carried through extensive revision of the work, collating the assistance of many colleagues, and in 1947 flew to England to arrange publication with Messrs. Edward Arnold & Co. "The Geology of the Commonwealth of Australia, by the late Sir T. W. Edgeworth David, edited and much supplemented by W. R. Browne" finally appeared in print in 1950.

Dr. Browne has given significant service to science in general, not only by his work in and for the Royal Society of New South Wales but also as President of the Linnean Society of New South Wales on two occasions (1928, 1944), and as a member of the Council, and in recent years as Honorary Secretary of that Society. He had a long and fruitful association with the National Research Council during its existence and was President of Section C of A.N.Z.A.A.S. in 1949. He was elected a Fellow of the Australian Academy of Science in 1954, and Honorary Life Member of the Geological Society of Australia in 1957.

To Dr. Browne we owe a great debt of gratitude for his foresight and leadership in engendering scientific interest in the Kosciusko State Park and countering much of the tendency of commercial and engineering activities to despoil the Park. He is still contributing to our knowledge and understanding of the glacial features and general geomorphology of the Snowy Mountains, and is a staunch advocate of the creation and preservation of a Primitive Area in the summit region.

Retirement from Sydney University in no way marked a reduction in Dr. Browne's scientific activity. He was for several years consultant to the Sydney Water Board for the Warragamba Dam project and consultant to other organizations. He has maintained active personal association with Sydney University by acting as examiner for the former third-year course in the History and Philosophy of Science and in sorting Professor David's papers for the University archives.

To Dr. Browne, affectionately known by generations of students as "Buster", widely honoured for his research publications, and now the doyen of Australian geologists, the Royal Society of New South Wales respectfully dedicates this volume of invited contributions.

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A.A.D.

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Granitic Intrusions and Regional Metamorphic Rocks of Permian Age from the Wongwibinda District, North-eastern New South Wales

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Abstract—A gneissose granitic intrusion in the vicinity of Wongwibinda is surrounded by regional metamorphic rocks, including migmatites and sillimanite, and garnet-bearing schists derived from geosynclinal Permian sediments. Although the area has been much disturbed by later faulting and by emplacement of massive granitic batholiths, the complete progression from virtually unmetamorphosed sediments through partly-recrystallized sediments and low-grade schists to high-grade schists is exposed. The Permian age of both the massive and the gneissic granitic intrusions and also of the regional metamorphism has been confirmed by potassium-argon measurements.

"We now turn our attention to New England, to some extent a geological *terra incognita*, a land as yet of many stratigraphical mysteries, and an area in which orogenic forces continued to be active long after other parts of the State had attained comparative equilibrium."

W. R. Browne (1929, p. xxx)

Among Dr. Browne's many contributions to the understanding of New South Wales geology are his pioneering accounts of the metamorphic terrains at Cooma and Broken Hill (1914, 1922). The following article describes a new occurrence of regional metamorphic rocks from north-eastern New South Wales, differing considerably in geological age from those in the above two areas. The association of these rocks with a synchronous batholith and their significance in the Permian history of the New England area touch upon other problems investigated in the past by Dr. Browne, adding greatly to the pleasure that accompanies the honour of contributing to this volume of appreciation.

Introduction

Situated about forty miles north-east of Armidale (Figure 1), the *Wongwibinda Complex* consists of a north-westerly trending belt of schists, migmatites and gneissose granitic intrusions some fifteen miles long and up to seven miles wide. It is closely associated with one of the major structural elements of the New England region, the *Wongwibinda Fault* (see accompanying geological map). East of this fault lie outcrops of *Dyamberin Beds*,[1] a group of unmetamorphosed Permian sediments, and immediately to its west occurs the *Abroi Gneiss*, a foliated granitic intrusion. A *Zone of Migmatites* is developed at the western margin of the gneiss. This passes into the main belt of *Rampsbeck Schists*, which grade westwards through a *Zone of Transitional Schists* into the Permian *Lyndhurst Beds*, a relatively unmetamorphosed sequence of greywackes and slates.

The Wongwibinda Fault is cut obliquely by a second fault, the *Fishington Fault*, and this in turn is displaced by a third, the *Glen Bluff Fault*. The latter disrupts the *Tobermory Adamellite*, a mildly foliated intrusive having many mineralogical features in common with the Abroi Gneiss.

Both to its north and its south the Wongwibinda Complex is truncated by younger granitic batholiths. In the north the *Kookabookra Adamellite* and the *Mornington Diorite* lie across the Wongwibinda Fault, but each has been disrupted by it during later phases of movement. The *Wards Mistake Adamellite* cuts the Glen Bluff Fault and the Kookabookra Adamellite. In the south the *Round Mountain Adamellite* crosses the Wongwibinda Fault, intruding both Dyamberin Beds and Abroi Gneiss.

Residuals of Tertiary *Doughboy Basalts* are scattered throughout the area.

Until recently the Wongwibinda district has received little attention from geologists.

[1] Several new formational names are proposed in this paper. Because suitable topographical features are scarce, duplication of names already used in other States has been unavoidable. Field studies are now being extended over the whole New England area, and it is intended that the nomenclature used in the present paper should not prejudice revision according to the requirements of the Code for Stratigraphic Nomenclature when these studies are completed.

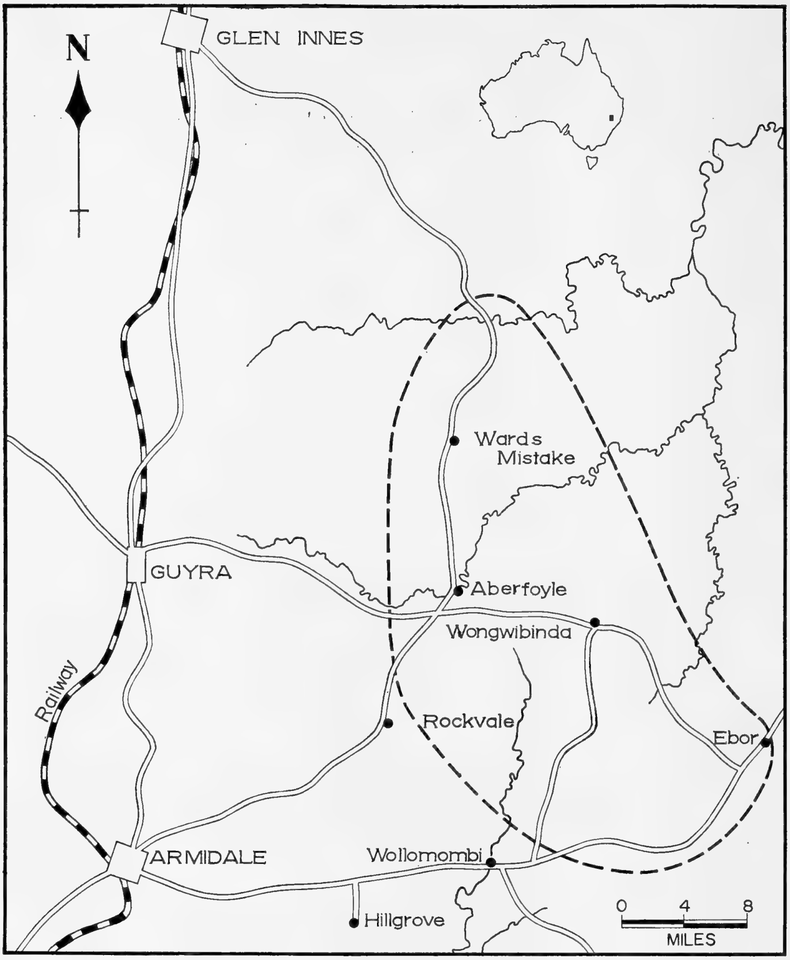


Fig. 1

Locality map showing the area studied. The small inset in the upper right shows the position of the map on the Australian continent

The area to its south, occupied by granitic rocks of the Tobermory type and by sediments similar to the Lyndhurst Beds, was mapped by Andrews (1900), Raggatt (1938*a*), and Voisey (1942). To the west lie massive granitic rocks belonging to the New England Batholith, overlain by Tertiary basalts. The rugged country north-east of Wongwibinda has not yet been geologically surveyed.

Structural Geology

Foliation Structures in the Wongwibinda Complex

A pronounced swing in the attitude of foliation structures characterizes the southern portion of the Wongwibinda Complex. The near-vertical axial plane cleavage of slaty argillaceous units within the intensely folded Lyndhurst Beds maintains a constant east-west strike throughout the mapped area. This continues to the south-west at least as far as Rockvale. In the Zone of Transitional Schists, it passes into the penetrative schistosity of sheared greywackes and pelitic phyllites, still striking in the east-west direction. The schistosity of the thoroughly-recrystallized Rampsbeck Schists is at first conformable with that in the adjacent Transitional Schists, but as metamorphic grade increases towards the centre of the Complex, this east-west attitude swings gradually towards the north and then, having changed through an angle of about 120°, the regional schistosity becomes conformable with the north-westerly primary foliation of the Abroi Gneiss.

Except in the shear zone of the Glen Bluff Fault, and where irregular contortions in the Zone of Migmatites reflect a partly-solid, partly-liquid state during deformation and metamorphism, the regional foliation structure is continuous throughout the Complex from Lyndhurst Beds to Abroi Gneiss. The general pattern is shown on the geological map and on Figure 2. There is little in the way of puckering or superimposed foliations.

No detailed analysis of linear structures has been attempted, although bedding-cleavage and bedding-schistosity lineations in the Lyndhurst Beds, Transitional Schists and low-grade Rampsbeck Schists (plunging very steeply towards a direction just north of east) differ from mineral lineations in migmatite veins and the Abroi Gneiss (plunging steeply to the north-west) in a manner suggesting that these have been rotated through the same angle and about the same axis as have the foliations (see Figure 2). Regardless of whether the schistosities of the recrystallized rocks represent reactivation of the slaty cleavage in ancestral Lyndhurst Beds, or whether the two structures were synchronously developed under different tectonic conditions, the regional metamorphism in the Wongwibinda Complex was clearly associated with rotational deformation increasing in intensity towards the Abroi Gneiss.

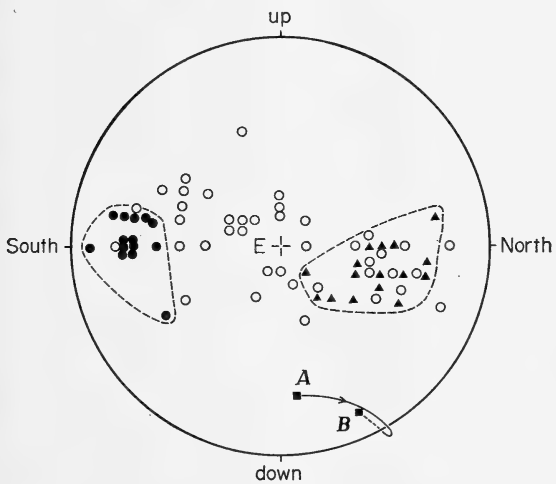


Fig. 2

Equal-area projection (on the eastern hemisphere) of regional foliation structures in the region south of the Fishington Fault, excluding the Aberfoyle district. Solid circles denote cleavage and schistosity in the Lyndhurst Beds and the Zone of Transitional Schists, and solid triangles represent the primary gneissic foliation of the Abroi Gneiss. The pronounced swing in regional foliation structures between these two extremes is shown by the open circles, representing schistosities in the low-grade and high-grade Rampsbeck Schists. A and B denote the typical lineation directions in the Lyndhurst Beds and the Abroi Gneiss respectively, and differ from one another as though rotated about a vertical axis through the same angle as the regional foliations. B plots in the western hemisphere. Note that the orientation of the projection is nonconventional

Similar but less systematic foliation patterns exist in the Aberfoyle and Riverview-Wards Mistake areas. Irregularities in these regions correlate with petrographic evidence of thermal metamorphism by later granitic intrusions.

Wongwibinda Fault

Major activity on the Wongwibinda Fault was confined to the Permian period. The fault has been traced for almost fifty miles, its continuation northwards from Kookabookra to the Red Range (east of Glen Innes) being marked by a prominent lineament on aerial photographs. Excellent exposures occur in many of the streams crossing the fault, one of the more accessible outcropping about a hundred yards downstream from the bridge over Kangaroo Creek on the Guyra-Ebor road. South of Wongwibinda, the fault plane dips steeply to the west at angles between 75° and 80°, but its inclination gradually changes northwards, shallowing to 35° west within the Kookabookra Adamellite.

The outcrop pattern and primary gneissosity of the Abroi Gneiss indicate emplacement into a tectonically active zone paralleling the Wongwibinda Fault more or less at the time the schists in the Wongwibinda Complex were metamorphosed. The curved pattern of regional foliation structures in the Complex (visualized as a gigantic drag), and the steeply-dipping primary lineation of the Abroi Gneiss suggest that this tectonically active belt behaved as a transcurrent fault zone, the western block moving south in sinistral fashion. Since later movements on the fault have prevented the eastern half of the Wongwibinda Complex from cropping out, no estimate can be made of the total displacement on this zone during what might be regarded as the initial phase of movement on the Wongwibinda Fault. As a basis for comparison, the known lateral displacement of a granite batholith for nineteen miles along the Demon Fault (Shaw, 1955), a parallel structure about fifteen miles east of the Wongwibinda Fault, deserves mention.

The present aspect of the Wongwibinda Fault arose largely during a second phase of movement that followed consolidation of the Abroi Gneiss. Cataclastic effects due to this movement first appear in the gneiss about five hundred yards from the fault. They increase in intensity until a mylonite is produced at the plane of rupture (see Plate IV). Here, mylonites formed from the Abroi Gneiss merge into similar mylonites derived from Dyamberin Beds. East of the fault the Dyamberin sediments are shattered and sheared for several hundred yards.

The cataclastic foliation in sheared Abroi Gneiss is generally parallel to its primary gneissosity, but at places, e.g. near Riverview, the two are inclined at angles up to 30°. There is usually a steeply-pitching linear structure on cataclastic foliation surfaces, defined by intersection of anastomose elements of the shear planes, by elongation of residual fragments and grains, and in thin section by alignment of fibrous bundles of cataclastically deformed quartz (see Plates IVB, C). Macroscopic rodding with similar attitudes occurs in certain Dyamberin sediments close to the fault. The elongate rather than rotational character of these structures is taken to indicate a near-vertical movement on the fault during the second phase. The contrast between the unmetamorphosed sediments east of the fault and the metamorphic rocks to its west, and the highly compressional nature of the mylonite zone suggest a thrust movement with the western block rising. The amount of movement cannot be assessed, though this must have been considerable in view of the intensity of cataclasis and the likely vertical profile of the Wongwibinda Complex.

Movement continued on the Wongwibinda Fault either continuously or by stages until the Round Mountain Adamellite was emplaced. The southern margin of the Kookabookra Adamellite, which cuts directly across the Wongwibinda Complex in the north of the mapped area, is disturbed by the Wongwibinda Fault and also by a small subsidiary fault branching north-westwards from the main zone near Mornington. The amount of displacement of its contact and the less severe nature of its shear zone at the Wongwibinda Fault compared to that in the Abroi Gneiss indicate that the Kookabookra Adamellite was emplaced after completion of the second phase of movement (thrusting of the Abroi Gneiss over Dyamberin Beds). There is some suggestion in thin sections that mylonitic rocks (due to the second phase) in the fault zone near Riverview, have suffered thermal reconstitution, but this may have been caused by the Mornington Diorite rather than the Kookabookra Adamellite. Steeply pitching lineations in sheared Kookabookra Adamellite near the fault zone indicate a vertical movement, while the greater extent of adamellite west of the fault suggests a reverse or overthrust displacement during the third phase, with the western block rising.

The Mornington Diorite shows localized shearing and a relatively small overthrust displacement where cut by the Wongwibinda Fault. Comparison with the effects of the fault on the Kookabookra Adamellite dates the diorite as a younger intrusion and also defines a fourth phase of movement (post-diorite).

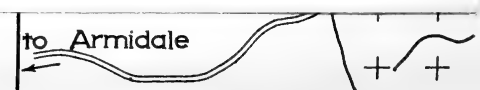
No evidence has been found of shearing or cataclastic deformation in the Round Mountain Adamellite, which was emplaced across the Wongwibinda Fault after cessation of major reverse movements. However east of Fishington and in the Doughboy Range, Tertiary basalts have been faulted against Dyamberin Beds and the Round Mountain Adamellite during a late-stage normal movement. The abrupt eastern margin of a small basalt residual capping Round Mountain suggests that post-basalt movement on the fault extended well into the Round Mountain Adamellite, probably along one of the major joints.

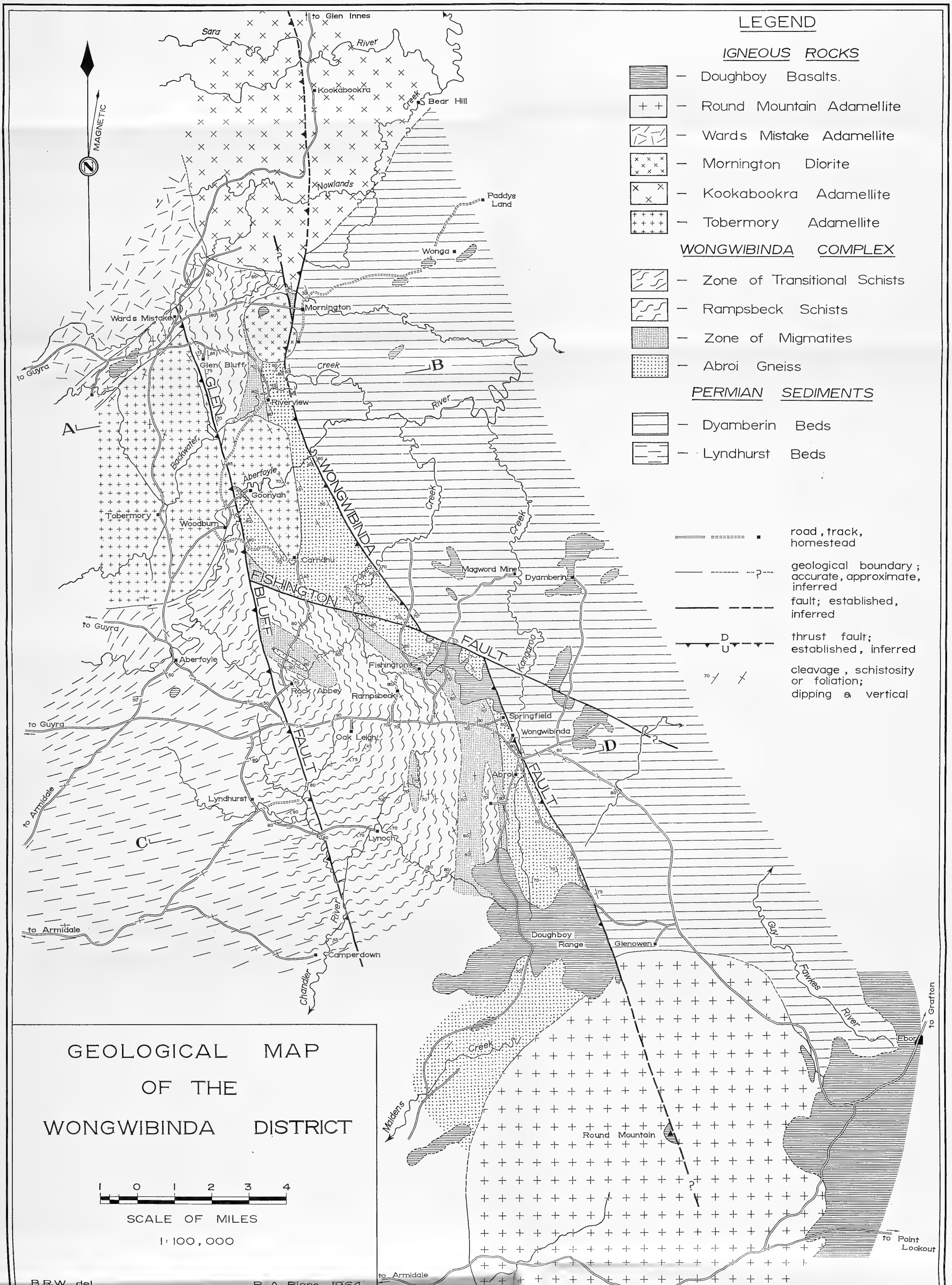
The different base levels of basalt residuals either side of the fault show the western block to have fallen between three hundred and five hundred feet relative to the eastern block during the fifth phase of movement (post-basalt) on the Wongwibinda Fault. Since the mylonites in the main fault zone show no sign of late-stage brecciation, the movement apparently occurred slightly to one side, possibly in shattered Dyamberin Beds.

Incised meanders in Copes Creek, Backwater Creek, and the Aberfoyle River where they cross the Wongwibinda Fault attest the former existence of a westerly-facing scarp such as would have been produced during the post-basalt movement. This has since been virtually removed by erosion. Indeed, the physiographic situation is now reversed, for the Wongwibinda Fault marks the approximate western limit of deep gorges cut through the readily-disintegrated Dyamberin Beds.

B.R.W. del.

R. A. Binns 1964





LEGEND
IGNEOUS ROCKS
— Doughboy Basalts.
— Round Mountain Adamellite
— Wards Mistake Adamellite
— Mornington Diorite
— Kookabookra Adamellite
— Tobermory Adamellite
WONGWIBINDA COMPLEX
— Zone of Transitional Schists
— Rampsbeck Schists
— Zone of Migmatites
— Abroi Gneiss
PERMIAN SEDIMENTS
— Dyamberin Beds
— Lyndhurst Beds
road, track, homestead
geological boundary; accurate, approximate, inferred
fault; established, inferred
thrust fault; established, inferred
D
U
cleavage, schistosity or foliation; dipping & vertical
MAGNETIC
N
to Glen Innes
Sara
River
Kookabookra
Creek
Bear Hill
Nowlands
Paddys Land
Wonga
Mornington
Wards Mistake
to Guyra
Glen Bluff
Creek
B
Riverview
River
GLEN
A
Backwater
Aberfoyle
Goonyah
WONGWIBINDA
Creek
Creek
Tobermory
Woodburn
Carrandu
Magword Mine
Dyamberin
FISHINGTON
BLUFF
to Guyra
Copes
FAULT
Kangaroo
Aberfoyle
Fishington
Rock Abbey
Rampsbeck
Springfield
to Guyra
Oak Leigh
Wongwibinda
D
FAULT
Abroi
to Armidale
Lyndhurst
FAULT
C
Lynoch
to Armidale
River
Doughboy Range
Glenowen
Guy
Camperdown
Fawkes
Chandler
River
to Grafton
Ebor
Creek
Maidens
Round Mountain
to Point Lookout
to Armidale
GEOLOGICAL MAP OF THE WONGWIBINDA DISTRICT
1 0 1 2 3 4
SCALE OF MILES
1:100,000
B.R.W. del.
R. A. Binns 1964

Fishington Fault

The vertically-dipping Fishington Fault is marked by a narrow zone of sheared and contorted Dyamberin Beds and Abroi Gneiss, and by faulted Tertiary basalts near Fishington and east of Wongwibinda. Since it displaces the Wongwibinda Fault but is itself cut by the Glen Bluff Fault, its main activity was confined to a relatively short period during the Permian.

No clear picture of the direction of movement is provided by structures in the fault zone. The displacement of the outcrop trace of the Wongwibinda Fault shown on the geological map can be explained either by a vertical upthrust movement of 17,000 feet (north block rising) or by a sinistral transcurrent movement of 10,000 feet. An irregular mass of shattered mylonitic rocks north of Fishington where the faults meet suggests that alternating movements occurred at some stage on the two structures.

Post-basalt movement of between a hundred and two hundred feet occurred on the fault in the vicinity of Fishington, the southern block falling relative to the northern. East of the Wongwibinda Fault this late-stage movement appears to have been smaller in magnitude and partly transcurrent in sense.

The continuation of the Fishington Fault west of the Glen Bluff Fault has not been located. A marked lineament on aerial photographs occurs near Tobermory, and there is an embayment in the contact of the Tobermory Adamellite at Woodburn, but exposures in this area are not sufficiently good to establish the existence of a fault.

Glen Bluff Fault

The youngest major structure in the Wongwibinda area, the Glen Bluff Fault, cuts the Fishington Fault but is truncated in the north by the Wards Mistake Adamellite. It displaces the Tobermory Adamellite at Glen Bluff, and near Woodburn cuts off the Abroi Gneiss and a small mass of migmatites. South of Rock Abbey its continuation is marked by distortions and fracturing in Rampsbeck Schists and Transitional Schists. The Chandler River follows the fault for a short distance near Camperdown.

At its northern and southern extremities within the mapped area the Glen Bluff Fault

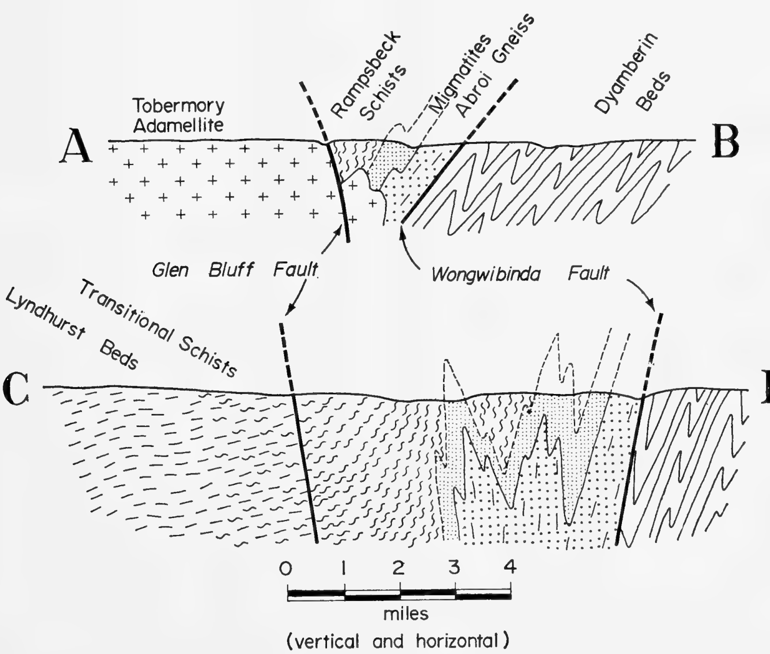


Fig. 3

Schematic cross-sections through the Wongwibinda area. Symbols correspond (except for the Dyamberin Beds) with those used in the accompanying geological map, on which the section lines A-B and C-D are shown dips steeply to the east, but in the centre it is almost vertical. Extensive cataclastic shearing has occurred in adjacent granitic rocks. Lineations in sheared rocks pitch down the dip of their cataclastic foliation, suggesting a near-vertical direction of movement. The nature of the shear zone indicates that the Glen Bluff Fault is a compressive structure, but despite its overall easterly dip, the manner in which the Tobermory Adamellite has been displaced shows that the western block rose (see Figure 3).

No evidence has been found of Tertiary movement on the Glen Bluff Fault.

Notes on the Various Formations

Dyamberin Beds

This sequence of quartz-bearing greywackes, "cherts" and argillaceous silts and shales outcropping east of the Wongwibinda Fault is strongly folded about north-westerly striking axes. Shelly fossils referred to the genera *Aviculopecten*, *Spirifer*, *Dielasma*, *Pleurotomaria* and *Conularia* by Voisey (1950*a*) occur in exposures in Kangaroo Creek north-west of Dyamberin, indicating a Permian age.

Individual greywacke units are thick and massive, with occasional large-scale size grading. Their main detrital constituents are angular grains of quartz and plagioclase and fragments of argillaceous siltstone. Many of the quartz grains are bipyramidal in shape with marginal embayments reminiscent of volcanic phenocrysts. Others are broken fragments with razor-sharp edges. Plagioclase grains, including both albite and calcic oligoclase,[2] are also very angular, some being almost perfect cleavage fragments. Potassium feldspar (microperthitic orthoclase) and acid volcanic rock fragments form a significant constituent of many greywackes. Fragments of intermediate volcanic rocks are comparatively scarce. Texturally, the various kinds of rock fragment resemble those described below from pebbly greywackes and conglomerates.

Sorting of the greywackes ranges from very poor to moderate, the coarsest detritus being typically between 0·5 and 1 mm in size. The matrix consists largely of finely comminuted quartz and feldspar, with a little fine-grained micaceous material and sparsely-scattered granules of recrystallized epidote.

The poorly-bedded light greenish or greyish "cherts", tough and of siliceous appearance in hand specimen, are merely finer-grained equivalents of the greywackes, containing silt-sized fragments of quartz and feldspar as their largest constituents. The argillaceous siltstones and shales are usually well laminated. They consist of very fine-grained quartz and feldspar with abundant micaceous and graphitic material.

Pebbly or conglomeratic horizons with gradational relationships towards greywacke occur within the Dyamberin Beds. These contain, dispersed through a greywacke matrix, moderately well-rounded and well-sorted pebbles (2 mm to 5 cm in size) of acid volcanic rocks and of siltstones and shales identical to those found elsewhere in the sequence. The acid volcanic fragments include flow-banded and spherulitic types, and porphyritic varieties with phenocrysts of quartz and feldspar. Their glassy material is devitrified and appears chert-like when viewed in thin section under crossed nicols. Occasional intermediate volcanic rock fragments also occur, the common type being composed largely of pilotaxitic plagioclase laths (andesine showing marginal replacement by albite) with interstitial opaque oxide granules.

Thermally metamorphosed Dyamberin Beds occur at the contact of the Round Mountain Adamellite. Greywackes yield blastopsammitic biotite hornfelses, containing relic detrital grains of quartz and plagioclase. Scattered decussate clusters of biotite in these probably represent metamorphosed argillaceous fragments from the greywackes. The cherts form fine-grained quartz-feldspar-biotite hornfelses. Pelitic hornfelses include spotted cordierite-bearing types. Contact-altered Dyamberin Beds also occur near the Kookabookra Adamellite.

Near the Wongwibinda and Fishington Faults the Dyamberin Beds have suffered intense dislocational metamorphism. In the greywackes much of the deformation is accommodated by the matrix but where shearing is well advanced, quartz grains are granulated and stretched, feldspars smashed, and siltstone fragments extremely attenuated. Mylonites formed from Dyamberin greywackes resemble those formed from the Abroi Gneiss, but lack residuals of potassium feldspar and biotite.

[2] All plagioclase compositions quoted throughout this paper are based on refractive index measurements referred to the determinative curves of Chayes (1952).

Lyndhurst Beds

The sequence of intensely folded, highly indurated sediments west of the Glen Bluff Fault includes quartz-bearing greywackes, silty greywackes and slaty argillaceous rocks. No fossils have been recovered from outcrops in the area of the accompanying geological map, but fragmentary remains, including valves of the Permian lamellibranch *Myonia*, occur in rocks equivalent to the Lyndhurst Beds at Rockvale, just to the south-west.

Quartz and plagioclase, together with a little potassium feldspar, are the main detrital constituents of the greywackes. Rock fragments including siltstone, shale and acid volcanic rocks, though significant, are less abundant than mineral grains. Intermediate volcanic rock fragments are rare. Sorting is very poor, with the maximum grainsize of the coarsest greywackes being about 0·5 mm.

The quartz grains are very angular, but few possess bipyramidal habits. Most show strain extinction; this, however, is a result of mild shearing suffered by the Lyndhurst Beds rather than a feature acquired from their source rocks. Angular plagioclase grains are mostly of calcic oligoclase composition (observed range An_{18}-An_{40}). The potassium feldspars are a triclinic variety with vein perthitic structure. The acid volcanic fragments are cherty in appearance; flow structures have been destroyed during devitrification, but many retain phenocrysts of quartz and feldspar.

A mild form of thermal metamorphism has reconstituted the argillaceous fraction of greywacke matrices to tiny flakes of biotite and white mica (typically 0·02 mm across). The minute angular particles of detrital quartz and feldspar are unaffected. The white mica flakes tend to be vaguely aligned, but biotite occurs in small decussate clusters rimming the larger detrital grains (Plate IA).

Silty greywackes are petrographically similar to their coarse equivalents in all respects except maximum grainsize. Argillaceous members of the Lyndhurst Beds resemble the matrix of the greywackes, containing fine detrital quartz and feldspar particles with aligned flakes of recrystallized mica and graphite.

Lamination is poorly developed but graded bedding occurs from greywacke through silty greywackes to slaty argillite.

Thoroughly-reconstituted psammitic and pelitic hornfelses formed from Lyndhurst Beds occur in the vicinity of Aberfoyle and in the narrow strip of sediments separating the Wards Mistake Adamellite from the Tobermory Adamellite.

Apart from degree of induration, the Lyndhurst Beds differ from the Dyamberin Beds mainly by their higher proportion of silty and argillaceous rocks, by their lack of pebbly horizons, and also by the slightly finer overall grainsize, the higher percentage of argillaceous matrix, and the scarcity of bipyramidal quartz grains in greywackes. The provenance of both formations was clearly very similar—an acid volcanic terrain (mainly dacitic) containing some intermediate volcanic material. Both were laid down in an unstable environment from turbidity current media. The petrological features of greywackes, the laminated structures of argillaceous rocks, and the occasional conglomeratic units in the Dyamberin Beds suggest that these were deposited closer to their source area and possibly under shallower conditions than were the Lyndhurst Beds.

Zone of Transitional Schists

Sheared greywackes and pelitic phyllites occupying a zone transitional between the Lyndhurst Beds and the Rampsbeck Schists outcrop well in the Upper Chandler River area east of Lyndhurst. North of Rock Abbey and in the vicinity of Camperdown these partly-recrystallized rocks are obscured by the thermal aureoles of later granitic intrusions.

The sheared greywackes retain their larger detrital grains of quartz and feldspar but edges and angular projections on these recrystallize into granular aggregates and are incorporated into the schistose matrix. Quartz grains show severe undulose extinction and partial granulation at an early stage of shearing. Detrital plagioclase is commonly clouded by tiny biotite and opaque inclusions, whereas its recrystallized equivalent is quite clear. Both are typically of calcic oligoclase composition (observed range An_{18}-An_{35}). Potassium feldspar grains break down to small flakes of muscovite. Siltstone and acid volcanic fragments recrystallize to fine biotite schist and cherty aggregates respectively, tending to lose their individuality by becoming incorporated into the sheared matrix. The matrix is completely reconstituted to fine granoblastic quartz and plagioclase, interleaved with aligned flakes of brown biotite

(0·05 to 0·1 mm across), a little white mica, and scattered graphite scales (Plate IB).

Argillaceous phyllites in the Zone of Transitional Schists consist of granoblastic quartz and plagioclase with abundant well-aligned flakes of brown biotite (typically 0·03 mm in size). Small flakes of white mica and scales of graphite accompany the biotite in some specimens. Occasional larger detrital grains may be preserved in silty phyllites.

The amount of detrital material retained in sheared greywackes decreases across the Zone of Transitional Schists towards the Rampsbeck Schists, but this progression is disrupted by the Glen Bluff Fault, which marks the western extent of thoroughly-recrystallized rocks.

Rampsbeck Schists

Although no isograds have been mapped, the Rampsbeck Schists may be divided on a textural-mineralogical basis into a low-grade zone adjacent to the Zone of Transitional Schists and a high-grade zone near the Zone of Migmatites.

Low-grade schists outcrop well east of the Glen Bluff Fault in the vicinity of Lynoch. Detrital material in the pelitic and psammitic schists is entirely reconstituted, so that derivatives of greywackes and argillaceous rocks can be recognized only by their relative proportions of biotite and felsic minerals (Plates IC, IIA). Some outcrops retain bedding structures (usually transposed into the schistosity) and even grading from dark pelitic schists to light psammitic schist.

The assemblage biotite-muscovite-plagioclase-quartz is characteristic of both pelitic and psammitic schists in the low-grade zone. Micas occur as aligned flakes 0·06 mm to 0·1 mm in size, with pale greenish muscovite greatly subordinate to brown or reddish-brown biotite. The granoblastic felsic constituents are typically about 0·06 mm in grainsize. Untwinned plagioclase is limited to a calcic oligoclase composition (observed range An_{25}-An_{30}). Small flakes of graphite, granules of opaque oxide and prisms of apatite form ubiquitous accessories. Certain low-grade schists contain transgressive poikiloblasts of colourless muscovite, apparently a late-stage metasomatic product.

Lensoid calcareous nodules, up to six inches across, occur sporadically throughout the low-grade schists, usually only in the axial regions of small fold structures. These segregations are mineralogically zoned from calcite-bearing cores to the assemblage of the surrounding schists. The following progression is typical:

1. diopside-calcite-grossular-quartz (core)
2. diopside-clinozoisite-grossular-quartz
3. diopside-clinozoisite-plagioclase-quartz
4. diopside - tremolite - clinozoisite - plagioclase-quartz
5. hornblende (bluish-green) - clinozoisite (epidote)-plagioclase-quartz
6. biotite-clinozoisite-plagioclase-quartz
7. biotite - muscovite - plagioclase - quartz (surrounding schist).

The plagioclase increases in calcium content to An_{85} in the central zones of the nodules. Typical refractive indices of minerals in the innermost zones include grossular, $n = 1{\cdot}743$, and clinozoisite, $\beta = 1{\cdot}705$. Sphene is a constant accessory.

High-grade Rampsbeck Schists, characterized by greatly increased grainsize and occurrence of the minerals orthoclase, almandine, cordierite and sillimanite, extend up to two miles from migmatitic rocks. Garnet has been found only near the main mass of Abroi Gneiss. The following are the principal mineral assemblages (brackets denote those minerals that may or may not be present).

Pelitic Schists

1. biotite-(sillimanite)-plagioclase-(orthoclase)-quartz
2. biotite-cordierite-sillimanite-plagioclase-orthoclase-quartz
3. biotite-(cordierite)-almandine-(sillimanite)-plagioclase-(orthoclase)-quartz

Semipelitic and Psammitic Schists

4. biotite-plagioclase-(orthoclase)-quartz
5. biotite-almandine-plagioclase-orthoclase-quartz.

Deep red-brown or orange-brown biotite occurs as flakes 0·1 mm to 0·5 mm across. In pelitic schists containing cordierite or sillimanite, alignment of biotite flakes is not so marked as in other varieties of pelitic and psammitic schist. Pink almandine garnet forms scattered anhedral poikiloblasts up to 4 mm across sieved with quartz grains (Plates ID, IID). Data listed in Table 1 indicate significant pyrope and spessartine components in the pelitic garnets. Cordierite is rarely found unaltered, usually being replaced by a

TABLE 1
Data for Wongwibinda Garnets

Rock type	Specimen No.†	Properties Refractive index n($\pm 0\cdot 002$)	Cell dimension a($\pm 0\cdot 002$)	MnO (wt. %)	Mol per cent end members* Almandine	Spessartine	Pyrope	Grossular
Rampsbeck Schists								
pelitic schist ..	12738	1·807	11·536	4·64	72	11	14	3
pelitic schist ..	9824	1·807	11·542	n.d.	—	—	—	—
leucocratic vein ..	12578	1·807	11·540	4·90	71	12	13	4
Zone of Migmatites								
pelitic schist ..	12615	1·807	11·547	8·70	62	20	12	3
pelitic schist ..	12616	1·805	11·551	10·27	60	24	13	3
Abroi Gneiss (garnetiferous) ..	12682	1·814	11·551	5·82	75	14	7	4
Albite pegmatite dyke near Lynoch (garnetiferous) ..	12739	1·817	11·550	10·12	71	24	4	1

*Mol per cent end members calculated using diagrams similar to those of Winchell (1958), with MnO instead of S.G. as the third variable.

†Specimen numbers apply to collections at the University of New England. Localities for specimens listed in tables are given in Appendix.

pale green-brown isotropic substance or by aggregates of greenish muscovite and pale green-brown biotite retaining pleochroic haloes (Plate IIB). It occurred originally as elongate poikiloblasts 0·5 mm to 2 mm in size containing inclusions of quartz, plagioclase and green-brown biotite. The latter contrast with the red-brown biotites found elsewhere in the schists. The refractive index of an unaltered cordierite relic ($\beta = 1\cdot 554$) indicates a variety with an Fe/Mg ratio of approximately unity.

Sillimanite occurs in curious felted or stellate aggregates at the junctions of felsic grains, especially at the margins of orthoclase (Plate IIIA). The tiny needles constituting the aggregates are typically 0·02 mm long and about a micron across. Their identity has been confirmed by the straight extinction and refractive index ($\gamma = 1\cdot 680 \pm \cdot 004$) of needles released by etching thin sections with hydrofluoric acid. Sillimanite does not occur as fibrolitic growths on biotite.

By contrast with that in low-grade schists, the plagioclase of high-grade pelitic and psammitic schists (calcic oligoclase, An_{20}-An_{28}) is well twinned on the albite law. Potassium feldspar is untwinned and has been identified as monoclinic orthoclase by X-ray diffraction study (see Figure 4). The felsic constituents of high-grade schists range from 0·2 to 0·5 mm in size, quartz commonly being a little smaller than the feldspars. Accessory minerals include apatite, ilmenite, graphite and tourmaline.

Although muscovite does not appear to have crystallized during the high-grade regional metamorphism of Rampsbeck Schists, certain specimens contain large transgressive crystals of this mineral sieved with grains of quartz and feldspar. As with similar muscovites in low-grade schists, a late-stage metasomatic origin appears likely.

Zoned calcareous nodules are also sparsely scattered throughout the high-grade schists. Except that amphiboles have not been detected in them, they resemble their equivalents in the low-grade Rampsbeck Schists.

Many high-grade schists are crossed by narrow leucocratic veins containing quartz, plagioclase (calcic oligoclase) and orthoclase, with scattered grains of tourmaline and almandine garnet. In places these are ptygmatically folded or boudinaged. The garnet crystals (1 cm across) in an exceptionally wide vein (twelve inches wide) are almost identical in composition to those in adjacent pelitic schists (Table 1). Apart from abundance, these veins resemble the secretionary veins described below from the Zone of Migmatites.

A belt of pegmatite veins of uncertain affinity crosses the Rampsbeck Schists from Rock Abbey towards Lynoch. Individual veins range up to several hundred yards in length and ten feet in width, and are composed of quartz-orthoclase-albite pegmatite with variable grainsize and showing abundant cataclastic phenomena. Crystals of blue-green tourmaline and almandine-spessartine garnet (Table 1) up to several inches in size are scattered through them. Cordierite-bearing hornfelses occur beside the veins, and schistose rocks at the margins of the belt containing post-tectonic poikiloblasts of muscovite, orthoclase and cordierite suggest that these pegmatites were emplaced after the main regional metamorphism of the Complex.

Localized post-crystallization deformation of Rampsbeck Schists in various parts of the Wongwibinda Complex has caused granulation of quartz, cross-hatched twinning in orthoclase, and replacement of potassium feldspar by muscovite or mymekite.

Rampsbeck Schists lying between the Glen Bluff and Wongwibinda Faults east of Wards Mistake have suffered thermal reconstitution in the aureoles of the Kookabookra Adamellite and the Mornington Diorite. Thoroughly-recrystallized biotite-cordierite hornfelses and quartzo-feldspathic hornfelses produced from Rampsbeck Schists occur right at the adamellite contact.

Zone of Migmatites

About one mile from the Abroi Gneiss, the Rampsbeck Schists grade into a zone characterized by heterogeneous vein rocks and small granitic intrusions. Two small migmatite masses occur in addition to the zone outcropping along the western margin of the main Abroi Gneiss, one crossing the Little Chandler River about one and a half miles north-east of Lynoch and the other lying just north of Rock Abbey. A small intrusion of Abroi Gneiss lies at the centre of the Rock Abbey mass. Excellent exposures of migmatites occur in Backwater Creek west of Riverview, and in the Little Chandler River north-east of Lynoch. The latter provide the best material for microscopic examination since at Riverview there has been later contact metamorphism.

Metasedimentary rocks in the Zone of Migmatites resemble the high-grade Rampsbeck Schists. Mineral assemblages listed for high-grade schists all occur in the migmatite zone. The compositional range of plagioclase (An_{20}-An_{27}) is similarly restricted, but sillimanite garnet and altered cordierite tend to be more abundant than in unveined schists (Plate IIC). The grainsize of migmatite zone schists is slightly coarser on the whole (0·2 to 1·0 mm) than that of the Rampsbeck Schists.

Certain schists from this zone contain garnet as clusters of small euhedral grains (0·1 mm across) rather than as scattered ragged porphyroblasts. Data presented in Table 1 (specimens 12615, 12616) reveal such garnets to be enriched in manganese. Their unusual habit recalls relationships between size and composition of almandine-spessartine garnets described by Chinner (1960).

Many pelitic and psammitic schists from heavily-veined outcrops contain abundant ovoid orthoclase grains, sieved with tiny quartz and biotite inclusions and slightly larger in size than the accompanying quartz and plagioclase (see Plate IIC). This orthoclase is too abundant to have been produced isochemically by breakdown of muscovite and biotite, and introduction of potassic material from the adjacent veins appears likely. Felted sillimanite aggregates commonly surround such grains, indicating that the introduction took place during high-grade recrystallization. Large transgressive muscovite flakes also occur, appearing to have formed during another metasomatic interlude.

Thin felsic bands, varying in abundance from the occasional vein to intimate penetrations involving roughly equal proportions of schists and vein material (Plate IIIC), cross most outcrops of metasedimentary schist in the Zone of Migmatites. Mineralogically, they are closely related to the enclosing schist, being composed of quartz, unzoned plagioclase (calcic oligoclase), orthoclase and a little biotite. Where the enclosing schists lack orthoclase, so do the veins, and where the schists contain almandine garnet, scattered porphyroblasts of this mineral also occur in the felsic bands. The grainsize of the veins (typically 0·5 to 2 mm) is slightly coarser than that of the schists.

Usually these veins follow the foliation of the schists, but transgressive, crenulated and ptygmatic types also occur. The close structural and mineralogical relationship between veins and enclosing schist suggest that the former have been produced by some kind of secretionary process. The total absence of orthoclase in some veins (despite the abundance of potassium in the biotites of the contiguous schist), and the occasional presence of garnet favour metamorphic differentiation rather than partial fusion as the responsible mechanism.

A second vein type, of intrusive leucocratic adamellite, varies considerably in field habit. In the Little Chandler River migmatite mass, schists with closely-spaced veinlets of the secretionary type are penetrated by an irregular array of transgressive leucocratic veins between six inches and two feet wide (Plate IIIC and D). Thinner offshoots from these follow the crenulated foliation of the invaded schist. West of Riverview, vein material of similar lithology is more abundant, forming a kind of stockwork surrounding isolated angular blocks of finely-veined schist. The blocks are commonly rotated relative to one another. In the Rock Abbey migmatite mass, leucocratic adamellite is more abundant still, occurring as more or less massive bodies several hundred yards across in which schistose rocks are represented only by scattered, partly-digested inclusions.

The leucocratic adamellite in these occurrences is coarse grained (0·5 to 5 mm) and consists of quartz, practically unzoned plagioclase (An_{23}-An_{27}) and perthitic orthoclase. The mode of a typical specimen is listed in Table 2. The orthoclase contains tiny exsolved blocks and rods of albite. Narrow rims of similar albite (0·05 mm wide) occur around oligoclase inclusions in orthoclase and at the junctions with adjacent plagioclase grains. Myrmekitic structures are also developed at the margins of orthoclase grains. Scattered flakes of muscovite and red-brown biotite (almost uniaxial with $\beta\gamma$ typically 1·652) make up about 5 per cent of the rock. Pink almandine garnet is a rare constituent. Accessories include apatite, tourmaline and ilmenite.

Many outcrops show a different intrusive rock cutting these leucocratic adamellite veins. This contains a higher proportion of biotite (about 10 per cent) and occurs as veins and sill-like bodies from one foot to thirty feet wide. Although the rock is foliated and lineated, the sheet-like intrusions do not show the complex folding characteristic of the two earlier types of vein. Small schistose biotite-rock xenoliths with diffuse margins are abundant.

The mode of a typical specimen of the third vein type from the Little Chandler River mass is presented in Table 2. Red-brown biotite ($\beta\gamma$ 1·652 to 1·656) occurs as large flakes 1 mm across and also as a host of smaller flakes spread out in streaks defining a distinct lineation in the rock. The larger flakes are generally slightly bent. Plagioclase (An_{21} to An_{27}, and showing normal zoning over a range of 3 to 4% An) and quartz form anhedral grains from 0·5 to 1 mm in size. Perthitic orthoclase occurs as slightly larger anhedral individuals (3-5 mm in size) enclosing smaller euhedral grains of plagioclase and biotite. Narrow albite rims surround the plagioclase inclusions and also occur at some boundaries between orthoclase and adjacent plagioclase. Myrmekitic growths in orthoclase are relatively abundant. Despite the bent habit of the larger biotites, indications of shearing in the felsic constituents are rare.

TABLE 2

Micrometric Analyses of Rocks from the Zone of Migmatites

	Leucocratic vein	Biotite-rich vein	Small intrusion
Specimen No.	12656	12655	12620
Quartz	42·2	35·8	32·2
Plagioclase	25·4	26·0	33·5
K-feldspar	21·0	21·2	9·0
Myrmekite	5·3	3·7	3·6
Muscovite	1·3	1·3	2·2
Biotite	4·7	11·7	18·3
Ilmenite	—	0·1	0·6
Sphene	0·1	—	0·2
Apatite	—	0·2	0·4
Composition of plagioclase (mol % An)			
Core	25	27	23
Rim		23	
Refractive index of biotite			
$\beta\gamma$ ($\pm$0·002)	1·651	1·652	1·652

Some specimens of the third type of vein contain scattered anhedral grains of almandine garnet. In such rocks orthoclase is less abundant and the plagioclase slightly more calcic (An_{30}) than usual. Apatite and ilmenite are accessory constituents in both garnetiferous and non-garnetiferous varieties.

Finally, in the main migmatite zone south of the Fishington Fault, there occur larger granitic intrusions ranging in size from lenses fifty yards across and several hundred yards long to ovoid bodies almost half a mile across. The two largest masses lie west of Springfield and just north of the Doughboy Range respectively. Field relationships to the third vein type have not been determined. The gneissic rock composing the larger intrusions is similar to that in the smaller veins and sills, differing mainly by a further increase in biotite content (10 to 20 per cent). It also resembles Abroi Gneiss but is slightly finer grained, contains more muscovite, and has less conspicuously zoned plagioclases. Schistose biotite-rich xenoliths are again common.

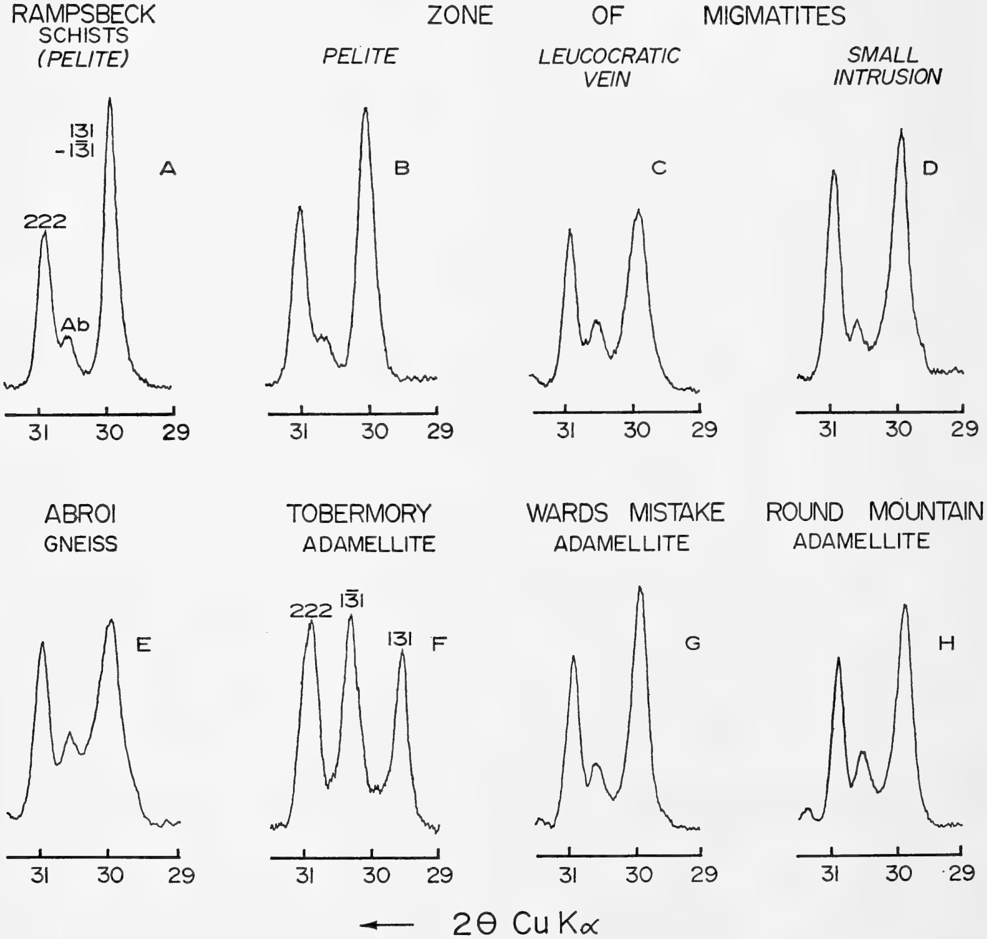


Fig. 4

Diffractometer traces in the region of the 131-1$\bar{3}$1 peaks of potassium feldspars from various rocks in the Wongwibinda area. Only that from the Tobermory Adamellite (F) is distinctly triclinic, but the 131-1$\bar{3}$1 peaks of the shadowy-twinned orthoclase from the Abroi Gneiss (E) and the intrusive rocks from the Zone of Migmatites (C, D) are broadened and depressed relative to the 222 peaks. The small peaks at 2θ approximately 30·6° are due partly to unmixed albite and partly to plagioclase impurities in the samples. Specimen numbers: A, 12581; B, 12615; C, 12617; D, 12620; E, 12679; F, 12693; G, 12715; H, 12718

The mode of a typical specimen from the Springfield intrusion is given in Table 2. The compositional range of the plagioclase (An_{23} to An_{27}) and refractive indices of the red-brown biotite ($\beta\gamma$ 1·652 to 1·654) in this and other specimens emphasize the similarity between the larger intrusions and the third type of vein.

Certain migmatite zone rocks, including metasedimentary schists and all vein types, show microscopic evidence of post-crystallization deformation in the form of strain and granulation of quartz and bending of biotite. Many orthoclases in these deformed rocks display shadowy cross-hatched twin patterns, especially at grain edges. Although the 131-1$\bar{3}$1 peak on X-ray diffractometer patterns of these is slightly broadened and depressed relative to the 222 peak, it is not split (Figure 4, leucocratic vein), so the triclinicity of the deformed orthoclase is very small. Microscopic evidence in specimens from the Little Chandler River outcrops supports field evidence of repeated deformation during emplacement of three types of vein. Where crenulated leucocratic veins of the second type are intruded by unfolded sills of the third type, specimens of the former show extensive granulation of quartz and incipient twinning of orthoclase whereas the latter lack such features.

Migmatite zone schists near Riverview are distinctly polymetamorphic in appearance, cordierite having altered to aggregates of muscovite and biotite, almandine to biotite and chlorite, and sillimanite to fine muscovite aggregates. The large quartz and feldspar grains in vein rocks are altered to fine granoblastic aggregates. In some specimens large biotite grains are replaced by decussate patches of smaller flakes. It has not proved possible in this area to distinguish between the contact effects of the Kookabookra Adamellite, the Mornington Diorite and the Tobermory Adamellite.

Abroi Gneiss

Apart from a small lens at the centre of the Rock Abbey migmatite mass, the Abroi Gneiss forms a single elongate intrusion parallel to the Wongwibinda Fault. Its characteristic foliation is due to alignment of individual flakes and small clusters of biotite rather than to alternation of dark and light bands. Such alignment is commonly better in one direction, defining a vague lineation in addition to the foliation. Foliations follow the elongation of the intrusion and dip steeply to the south-west. Contacts between the Abroi Gneiss and the Zone of Migmatites are abrupt. The gneiss outcrops as large flat rock platforms rather than as tors, aiding its distinction from other granitic rocks in the field.

Xenoliths of biotite-rich schist, siliceous schist (some showing sedimentary banding) and also recognizable fragments from the Zone of Migmatites are abundant in the gneiss. Most are aligned in the foliation, the smaller ones tending to be smeared out and partly digested. Some large angular inclusions lie across the foliation, which either swirls around them or continues without change of orientation right up to the xenolith margins. The foliation of certain smaller transverse xenoliths is crenulated by a kind of false cleavage parallel to the foliation in the enclosing gneiss. The foliation of the Abroi Gneiss thus appears to be mainly a primary igneous flow structure, which has been emphasized in places by continued movement after the stage of crystallization when the magma could transmit stress to enclosed rock fragments.

The modes of four typical specimens of Abroi Gneiss, including one from the small lens at Rock Abbey, illustrate its uniformity in composition (Table 3). Mineralogically, the gneiss has granodioritic affinities, but its high biotite content would introduce much potassium feldspar into the norm.

The Abroi Gneiss has suffered considerable cataclastic deformation. It is completely free from dislocational effects only in some outcrops south of the Doughboy Range and in the upper reaches of Kangaroo Creek south of Abroi. Here it contains large flakes of biotite (1 to 2 mm across), clustered and aligned in such a fashion as to introduce both lineation and foliation into the rock. The deep red-brown biotite contains many pleochroic haloes and is an almost uniaxial variety with $\beta\gamma$ refractive index ranging from 1·652 to 1·657. Plagioclase is the most abundant constituent, occurring as subhedral grains (about 1 mm in size) with an oscillatory-normal, subhedral to euhedral zoning pattern. Many grains contain a small core of andesine (An_{35}) but the greater part of most lies in the compositional range An_{20}-An_{27}. The plagioclase is well twinned on the albite law, with occasional combined Carlsbad and pericline twins. Orthoclase occurs both as smaller anhedral grains similar in size to plagioclase and as

Table 3

Micrometric Analyses of Abroi Gneiss

	Main Mass			Rock Abbey Mass	Garnetiferous Gneiss
Specimen No.	12679	12681	12686	12685	12682
Quartz	32·4	32·9	29·4	33·7	38·7
Plagioclase	39·5	39·2	35·2	33·4	39·5
K-feldspar	8·5	12·7	12·0	11·7	trace
Myrmekite	4·0	1·7	6·1	5·4	—
Biotite	14·7	12·1	15·4	14·9	19·0
Muscovite	—	0·6	0·8	—	—
Garnet	—	—	—	—	1·9
Ilmenite	0·4	0·3	0·7	0·4	0·7
Sphene	0·2	0·2	0·3	0·4	0·1
Apatite	0·3	0·3	0·1	0·1	0·1
Composition of plagioclase (mol % An)	25	20	23	25	27
Refractive index of biotite $\beta\gamma$ ($\pm$0·002)	1·652	1·654	1·654	1·657	1·657

subhedral phenocrysts 5 mm to 1 cm long. It contains tiny blocks and rods of exsolved albite. Subhedral to euhedral grains of calcic oligoclase (many with narrow discontinuous albite rims) and biotite are included within the larger phenocrysts. Quartz forms large anhedral grains from 1 mm to 1 cm in size, often "cementing" the subhedral grains of plagioclase and orthoclase. It usually shows mildly undulose extinction and contains an abundance of whisker-like rutile inclusions. Accessory constituents include prisms of apatite and scattered granules of ilmenite and sphene.

Two kinds of deformational effect occur in the Abroi Gneiss. The first is shown to a greater or lesser extent in almost all specimens studied, and is considered to have resulted from continued flow of the gneiss after completion of crystallization. The large biotites are mildly bent or kinked and frayed at their edges, clusters of smaller flakes shredded from the larger accentuating both the foliation and the lineation. Quartz becomes severely strained and breaks up into finer granular aggregates composed of equant anhedra about 0·2 mm across. Plagioclase grains are broken or curiously bent. Orthoclase shows shadowy cross-hatched twinning, in places restricted to grain corners and the vicinity of inclusions but elsewhere extending across the whole grain, depending on the intensity of the deformation. As in vein rocks from the Zone of Migmatites, the 131-1$\bar{3}$1 diffractometer peaks of such orthoclases are not separated, although they may be broadened and slightly depressed relative to the 222 reflections (Figure 4). Cauliflower-like myrmekite growths up to 0·3 mm long extend into orthoclase grains from their margins (Plate IIIB). The abundance of these varies directly with the amount of post-crystallization deformation (of the first type) shown by other constituents of the rocks. The myrmekite usually occurs at marginal portions of orthoclase grains next to plagioclase. The host feldspar of the structure, an oligoclase with refractive indices overlapping those of the intergrown quartz, is often continuous with the plagioclase from which it grows. Myrmekite does not grow on plagioclase inclusions within orthoclase.

Scattered flakes of secondary muscovite form an accessory constituent in certain deformed gneisses. Other minor alteration phenomena include chloritization of biotite, rimming of ilmenite by sphene, and rare replacement of plagioclase by epidote or calcite.

The second kind of dislocational metamorphism suffered by the Abroi Gneiss is associated with movement on major fault structures, particularly on the Wongwibinda Fault. Effects are first visible at a distance of about five hundred yards from the Wongwibinda Fault, and increase gradually in intensity to the stage where a mylonite is produced at the fault plane. Quartz is the first mineral to suffer, becoming severely strained then stretched and broken up into fibrous bundles composed of extremely elongate individuals

(Plate IVB, C). Biotite is severely bent or kinked, and shredded into many small flakes accompanied by tiny granules of sphene. Plagioclase and orthoclase grains at first behave as resistant blocks around which the shear planes swirl or flow.

Closer to the fault the shearing is more penetrative. Plagioclase grains become bent and broken, their twin composition planes curving through angles up to 45° (*cf.* Plate IVB). Pieces are broken from the edges and corners and incorporated into the finer-grained sheared material, leaving isolated plagioclase ''augen'' (Plate IVC). The potassium feldspar, which in the advanced stages is a thoroughly-twinned microcline, is crushed into fine unaltered particles. Myrmekite is completely obliterated by the shearing. A mortar structure is developed in the ultimate mylonite, with residuals of plagioclase, microcline and biotite scattered through a fine-grained matrix of stretched quartz, feldspar, biotite, muscovite and sphene (*cf.* Plate IVD). In some specimens the biotite alters to pale green chlorite. The feldspars are rarely sericitized, plagioclase retaining an oligoclase composition to the most advanced stage of deformation.

Near its contact with migmatites north of Fishington, the Abroi Gneiss contains pink almandine garnet, both as small subhedra 0·2 mm in size and as larger ragged poikilitic grains up to 1·5 mm across. Data in Table 1 indicate a substantial spessartine component (14 per cent) and very little pyrope in this garnet. Orthoclase is scarce or lacking. Plagioclase (An_{27}) is mildly zoned in a normal pattern. The biotite is a deep red-brown variety with refractive index $\beta\gamma$ 1·657. The felsic constituents are about 1 mm in size and the biotite, in places accompanied by a little muscovite, occurs as aligned flakes 1 to 1·5 mm across. The mode of an orthoclase-free specimen is included in Table 3.

Scattered grains of garnet have also been observed in the Abroi Gneiss near Goonyah homestead.

The common xenolith types in the Abroi Gneiss are schistose assemblages of biotite, oligoclase, quartz and ilmenite, with or without muscovite. Usually, their mica flakes are not bent and their oligoclase lacks zoning. Margins of the biotite-rich xenoliths are usually quite diffuse. Siliceous xenoliths are less distinctly foliated and have sharper margins. A single basic patch, apparently a xenolith, has been observed near the Fishington Fault in Copes Creek. This consists of a fine-granoblastic aggregate of pale green hornblende and andesine (An_{35}), with accessory apatite and ilmenite.

Tobermory Adamellite

This subcircular batholithic intrusion invades Lyndhurst Beds in the vicinity of Aberfoyle and Wards Mistake. It is disrupted by the Glen Bluff Fault, east of which it intrudes the Wongwibinda Complex, transgressing Rampsbeck Schists, the Zone of Migmatites and the Abroi Gneiss. No exposure of the junction between Tobermory Adamellite and Abroi Gneiss has been found, but an abrupt change in outcrop pattern from large tors to flat rock platforms suggests a sharp contact between the two.

The adamellite contains abundant large flakes of biotite, aligned so as to define a poor foliation which parallels the contact in marginal portions of the intrusion but strikes regularly north-south in its interior. Marginal variants of the adamellite are slightly finer-grained than those at the centre of the intrusion near Tobermory. South-east of Goonyah the adamellite is quite massive.

Xenoliths are abundant, the chief varieties being schistose or hornfelsic biotite-rich and siliceous types, some with sedimentary banding. Larger xenoliths (3 to 9 inches) are sharply bounded and angular in outline, and tend not to be oriented in any particular direction. Smaller xenoliths have diffuse margins and are mostly aligned in the foliation, the occasional transgressive types showing mild crenulation.

The modes of three specimens, one from the margin near Aberfoyle, one from the centre near Tobermory, and one from east of the Glen Bluff Fault, are presented in Table 4. Other specimens confirm a tendency for the coarser-grained rocks at the centre of the intrusion to contain slightly less potassium feldspar than the marginal varieties. The central types are mineralogically granodiorites rather than adamellites.

The Tobermory Adamellite shows much evidence of cataclasis in thin section. The biotite, a deep red-brown variety similar to that in the Abroi Gneiss ($\beta\gamma$ ranging from 1·650 to 1·656), occurs as flakes varying in size from 1 mm in the marginal variants and in the adamellite east of the Glen Bluff Fault to 3 mm in the coarser-grained varieties near Tobermory. They are commonly bent, but

TABLE 4

Micrometric Analyses of Tobermory Adamellite

	Western portion		Eastern portion
	Centre	Margin	
Specimen No.	12693	12697	12698
Quartz	28·2	31·2	31·2
Plagioclase	37·4	34·6	31·2
K-feldspar	14·8	17·6	19·4
Myrmekite	0·4	1·1	1·9
Biotite	18·8	14·4	15·4
Muscovite	0·1	—	—
Ilmenite	0·2	0·8	0·6
Sphene	—	0·2	0·3
Apatite	0·1	0·1	tr
Composition of plagioclase (mol. % An)			
Core	34	30	34
Rim	23	27	20
Refractive index of biotite			
$\beta\gamma$ ($\pm 0{\cdot}002$)	1·656	1·650	1·650

have suffered no shredding of the kind seen in the Abroi Gneiss. Plagioclase forms subrectangular grains ranging in size from 1 mm in the finer adamellites to 2 mm in the coarser types. It is more distinctly zoned than that in the Abroi Gneiss, usually following an oscillatory-normal euhedral pattern with cores of andesine (An_{34}-An_{40}) zoned outwards to calcic oligoclase (An_{20}-An_{27}). Twinning on the albite law, accompanied by pericline and occasionally by Carlsbad twinning, is well developed. Cataclastic effects shown by plagioclase include bending of twin composition planes and fracturing. In places, the broken grains are drawn apart and the fractures healed with relatively undeformed quartz.

Potassium feldspar occurs as anhedral grains slightly larger than the plagioclases. Except in certain specimens from the very margin, it shows microcline twinning. X-ray diffractometer patterns (Figure 4) reveal it to be a distinctly triclinic variety close to maximum microcline ($\triangle = 0{\cdot}89$).[3] Veinlets and comb-like marginal intergrowths of albite are characteristic features of this microcline. These may have formed by exsolution from their host, but in some specimens their abundance and habit suggest a replacement origin. Myrmekite is rare in the Tobermory Adamellite, being restricted to occasional narrow selvages (0·02 mm wide) between potassium feldspar and plagioclase grains.

Quartz occurs as large anhedral grains from 1 to 2 mm in size, distinctly bluish in hand specimen and containing many tiny needles of rutile. Most show severe undulose extinction and some have recrystallized to finer-grained aggregates of elongate or equant individuals. In certain specimens large unrecrystallized quartz grains surround bent biotites and bent or fractured plagioclase grains, indicating that some cataclasis occurred before crystallization of the magma was complete.

Accessory minerals in the adamellite include scattered granules of ilmenite and sphene, and prisms of apatite. Small flakes of muscovite are rare.

The schistose and hornfelsic xenoliths in the adamellite are composed of red-brown biotite, oligoclase, quartz, ilmenite and occasional muscovite. Those with a more digested appearance commonly contain large grains of plagioclase or microcline and poikilitic flakes of biotite, similar to those in the enclosing adamellite.

Close to the Glen Bluff Fault the Tobermory Adamellite has suffered dislocational metamorphism. Shredding of large biotites and cataclastic breakdown of felsic constituents are the main results.

The principal mineralogical features by which the Tobermory Adamellite differs from the otherwise similar Abroi Gneiss are its preservation of large pale blue quartz grains, the scarcity of myrmekite, the triclinicity

[3] $\triangle = 12{\cdot}5\ (d_{131}\text{-}d_{1\bar{3}1})$, after Goldsmith and Laves' 1954.

and exsolution structures of its potassium feldspar, and the nature and compositional range of zoning in its plagioclases.

Kookabookra Adamellite

The transgressive Kookabookra Adamellite marks the northern boundary of the Wongwibinda Complex. Its southern contact is displaced by the Wongwibinda Fault, which continues through the intrusion as a prominent shear zone. In the west it is cut by the Wards Mistake Adamellite. It continues to the north well beyond the mapped area.

The Kookabookra Adamellite is readily distinguishable in the field by its abundant biotite and its mildly-foliated porphyritic texture. Evidence of mild cataclasis occurs in most thin sections. Small biotite-rich xenoliths are common.

The mode of a representative specimen is listed in Table 5. Although this may be somewhat inaccurate because of the porphyritic texture, the high biotite and potassium feldspar contents and relatively low quartz are noteworthy.

Biotite is a deep brown variety whose colour and refractive indices ($\beta\gamma = 1{\cdot}657$-$1{\cdot}662$) differ from those of biotite in the Abroi Gneiss and the Tobermory Adamellite. It occurs as slightly bent flakes 1 to 2 mm in size. Patchy alteration to chlorite may accompany cataclastic deformation. In places the larger biotite flakes are surrounded by smaller flakes of similar biotite and granules of sphene.

Plagioclase occurs as anhedral or subhedral grains 1·5 to 3 mm in size, irregularly zoned in an oscillatory-normal pattern from andesine (An_{34}-An_{38}) to calcic oligoclase (An_{23}-An_{27}). Twinning is particularly well developed and in some specimens the twin composition planes are faulted or bent. Potassium feldspar occurs both as subhedral phenocrysts 1 to 2 cm across, and as smaller anhedral grains comparable in size with the plagioclase. In unsheared specimens it is perthitic orthoclase, but with increased cataclastic deformation shadowy cross-hatched twinning and eventually distinctly triclinic microcline twinning becomes characteristic.

Quartz, faintly bluish in hand specimen, forms anhedral grains up to 5 mm in size. These show strain extinction and localized cataclastic recrystallization to finer granular aggregates. Accessory constituents include opaque minerals, apatite and tourmaline. Some specimens contain a small proportion of pale green hornblende.

Structural evidence discussed above indicates that the Kookabookra Adamellite was emplaced during activity on the Wongwibinda Fault. Cataclastic effects are widespread in the intrusion, reflecting its crystallization under somewhat stressed conditions. Near the Wongwibinda Fault postcrystallization deformation becomes more

Table 5

Micrometric Analyses of Later Granitic Intrusions

	Kookabookra Adamellite	Wards Mistake Adamellite	Round Mountain Adamellite white	Round Mountain Adamellite pink
Specimen No.	12709	12715	12718	12720
Quartz	24·2	25·5	30·9	37·0
Plagioclase	32·8	27·6	35·6	25·4
K-feldspar	27·0	40·3	31·7	37·0
Biotite	15·3	5·1	1·7	0·5
Hornblende	—	1·3	—	—
Opaque	0·4	0·2	0·1	0·1
Apatite	0·2	—	tr	—
Sphene	0·1	—	—	—
Composition of plagioclase (mol. % An)				
Core	32	34	25	20
Rim	25	20	12	4
Refractive index of biotite				
$\beta\gamma$ ($\pm 0{\cdot}002$)	1·657	1·676	1·666	—

severe, rocks of mylonitic aspect occurring at the actual fault plane.

Although there is no direct evidence for the relative ages of the Tobermory Adamellite and the Kookabookra Adamellite, the more intense cataclastic deformation suffered by the former and its mineralogical similarities to Abroi Gneiss indicate it to be older than the latter.

Mornington Diorite

A detailed study of this interesting intrusion will be reported separately. The common rock type is a quartz diorite containing deep red-brown biotite, pale green hornblende and abundant orthopyroxene with a little clinopyroxene and orthoclase. The plagioclase is sodic andesine (An_{30}-An_{35}) and occurs as zoned lath-shaped subhedra.

Basic variants are free of hornblende and contain plentiful orthopyroxene and clinopyroxene. Their plagioclases are zoned from sodic labradorite to calcic andesine. Veins of adamellite crossing the intrusion appear to be associated genetically with the diorite. They do not extend from nearby adamellite batholiths.

At the Wongwibinda Fault the dioritic rocks are crushed and altered, their pyroxine being replaced by fibrous amphibole aggregates, their biotite and plagioclase grains bent and broken, and their quartz strained and granulated. Similar alteration occurs in numerous smaller shear zones cutting the intrusion.

Dykes of altered diorite ten to twenty feet thick occur in the Dyamberin Beds near the Magword antimony mine and in the Abroi Gneiss between Fishington and Carndhu. These may be related to the Mornington Diorite.

Wards Mistake Adamellite

Large tors of massive, coarse-grained adamellite in the vicinity of Wards Mistake mark the latest intrusion in the northern part of the mapped area, which cuts directly across the Glen Bluff Fault and embays the Kookabookra Adamellite.

The mafic constituents of the Wards Mistake Adamellite include very deep brown biotite ($\beta\gamma = 1{\cdot}668$-$1{\cdot}676$) and moderately deep green hornblende. These tend to occur in clotted aggregates that probably represent thoroughly digested xenoliths. In places the hornblende contains small cores of clinopyroxene. Perthitic orthoclase is abundant in grains from 3 mm to 5 mm in size and as slightly larger phenocrysts. Laths of plagioclase (3 to 5 mm in size) are irregularly zoned in an oscillatory normal pattern from cores of andesine (An_{46}-An_{34}) to rims of oligoclase (An_{23}-An_{20}). Quartz forms large unstrained anhedral grains filling the space between feldspar laths. Characteristic accessories include allanite and pyrite.

The mode of a typical specimen is given in Table 5.

Round Mountain Adamellite

The roughly circular batholith cutting across the Wongwibinda Fault at the southern end of the Wongwibinda Complex is marked by its scarcity of mafic minerals and the almost complete absence of xenoliths. Three main lithological variants have been recognized. These are intimately associated, field evidence suggesting an intrusive sequence from relatively basic to particularly acid types.

A white leucocratic adamellite (average grainsize 2 mm) is the main phase in the south-western part of the intrusion. The mode of a typical specimen is given in Table 5. Plagioclase is strongly zoned without break and only rare oscillation from cores of calcic oligoclase to rims of sodic oligoclase (An_{25}-An_{12}). Orthoclase contains fine perthitic veins of untwinned albite. The sparsely scattered flakes of biotite ($\beta\gamma = 1{\cdot}666$) are pleochroic from straw to almost opaque.

Coarser-grained pink leuco-adamellite (average grainsize 5 mm) is most abundant in the northern and eastern sectors of the batholith. The mode quoted in Table 5 shows it to contain more quartz and less biotite than the white adamellite, which it invades in several outcrops along the Armidale-Ebor road. Plagioclase is again intensely zoned in a normal pattern from cores of oligoclase (An_{20}) to rims of almost pure albite ($\beta = 1{\cdot}534$). Extinction angle and refractive index measurements confirm the absence of any compositional break in the zoning. At the temperatures of crystallization there appears to have been no miscibility gap ("peristerite gap") between albite and oligoclase. Orthoclase in the pink adamellite contains abundant exsolved veinlets and patches of twinned albite. The rare biotite is also a very deep brown variety.

In the northern portion of the intrusion the pink adamellite is intruded by large dykes several hundred feet wide composed of a miarolitic albite-bearing granite virtually devoid of biotite. The texture of this phase is variable, its grainsize ranging from 0·5 to 3 mm. Graphic intergrowths occur between quartz and albite or quartz and orthoclase. The large albite grains are only slightly zoned (β = 1·534-1·535). Orthoclase displays extensive exsolution of albite after the manner of that in the pink adamellite. The rare deep brown biotite occurs as very thin flakes.

Doughboy Basalts

The residuals of basalt outcropping throughout the Wongwibinda district form portion of the extensive Tertiary volcanic province of New England. Apart from the Ebor-Point Lookout occurrence, of which the western margin is shown on the accompanying geological map, the thickest sequences in the area studied occur in the Doughboy Range (about 500 feet) and just north of Dyamberin (300 feet). Since much basalt has clearly been lost through faulting and erosion, the former extent of Tertiary volcanic rocks in the Wongwibinda area is uncertain. Some suggestion that an almost continuous series of flows once linked the thick lava sequences to the west at Guyra with those to the east in the Ebor-Point Lookout district is provided by the basalt capping (about 100 feet thick) on Round Mountain (5,280 feet, the highest point in New England), some thousand feet above the general level at which basalts occur.

Although most flows near Wongwibinda now form topographical prominences, their basal surfaces are by no means horizontal and many occupy former valleys. Poorly consolidated, horizontally stratified sandy sediments underlie those basalts north of Springfield. The relatively steep sides of the basalt-filled valleys (commonly 15° to 20°) and the varied topographical levels at which basalt remnants are now found indicate that the basalts were poured over an area of mature physiography and relief between five hundred and a thousand feet. All occurrences of basalt in the area are distinctly terraced, the individual flows varying from twenty to fifty feet in thickness.

Most flows are composed of porphyritic olivine basalt, containing euhedral or anhedral olivine phenocrysts in a groundmass of plagioclase laths, interstitial or ophitic diopsidic clinopyroxene, and skeletal opaque oxide. Analcime and alkali feldspar occur in the groundmass of certain specimens from the Doughboy Range.

The olivine phenocrysts in several specimens show marginal zoning, and many have undulose extinction suggestive of xenocrystal origin (*cf.* Wilshire and Binns, 1961). Scattered xenocrysts of spongy clinopyroxene and of orthopyroxene with reaction coronas of granular olivine occur in some basalts from the Fishington-Springfield area. Peridotite xenoliths containing olivine, chrome diopside, enstatite and picotite are abundant in analcime-bearing ankaramitic basalts at Round Mountain, where the host rocks also contain xenocrysts of the various constituents of the xenoliths, each showing its characteristic reaction relationship towards the enclosing basalt (specimens 12729, 12730).

A porphyritic hawaiite occurs near the base of the Ebor-Point Lookout basalt pile in the mapped area. This contains subhedral phenocrysts of zoned labradorite set in a groundmass composed of andesine laths, a little intergranular olivine and pale green augite, and intersertal chlorophaeite and alkali feldspar (specimen 12731). A similar hawaiite at the base of a series of flows at Ebor Falls has been chemically analysed (Wilkinson, 1965).

The great majority of basaltic rocks in the Wongwibinda area are members of the alkali olivine basalt lineage. However a small basalt residual with possible tholeiitic affinity overlies the Mornington Diorite. This contains embayed subhedral olivine phenocrysts in a groundmass composed of plagioclase laths (An_{50}), small olivine granules and dark grey intersertal glass containing fine fern-like growths of an opaque mineral (specimen 12723). Pyroxene is altogether lacking. Similar basalts near Inverell, N.S.W., have been chemically identified as tholeiites (Wilkinson, 1965).

Potassium-Argon Age Determinations

The limited fossil evidence available shows that at least portions of the Lyndhurst Beds are of Permian age. Since these are the ancestral sediments from which the Rampsbeck Schists were formed, the main period of regional metamorphism in the Wongwibinda Complex necessarily took place during the Permian period or later. To date the metamorphism more precisely, potassium-argon age determinations have been performed on biotites from seven carefully selected speci-

TABLE 6

Potassium-Argon Ages of Wongwibinda Rocks
(From Binns and Richards, 1965)

Rock	Specimen No.	Age ($\times 10^6$ years)*
Abroi Gneiss	12679	208
Abroi Gneiss (garnetiferous)	12682	252
Zone of Migmatites (biotite-rich vein)	12617	253
Rampsbeck Schists (garnetiferous psammitic schist) ..	12605	250
Tobermory Adamellite	12693	259
Wards Mistake Adamellite	12715	244
Round Mountain Adamellite..	12718	224

*Relative accuracy $\pm 2\%$
For details and localities of specimens see Appendix.

mens, including four rocks belonging to the Wongwibinda Complex and one from each of the Tobermory Adamellite, the Wards Mistake Adamellite and the Round Mountain Adamellite. A summary of the results (from Binns and Richards, 1965) is given in Table 6.

The excellent consistency of the ages obtained for the psammitic schist, the migmatite vein and the garnetiferous Abroi Gneiss indicate that the biotites in these have suffered no loss of radiogenic argon since their formation. Their average age, about 250 million years, dates the closing stages of the regional metamorphism in the Wongwibinda Complex. The specimen of Abroi Gneiss from Kangaroo Creek, although the best obtainable, was clearly not ideal for age determination, and its anomalous 208 million year age may be discounted as being due to loss of argon during weathering or alteration.

The dates obtained for the Wards Mistake Adamellite and the Round Mountain Adamellites compare favourably with age determinations previously reported for massive granitic rocks in the New England Batholith (Evernden and Richards, 1962; Cooper, Richards and Webb, 1963) and provide a younger limit to age of the regional metamorphism in agreement with the dates obtained on rocks from the Wongwibinda Complex itself.

The 259 million year result for the Tobermory Adamellite is slightly older than the dates obtained on Wongwibinda Complex rocks, in apparent contradiction to field relationships near Riverview where the Tobermory Adamellite intrudes the Zone of Migmatites and the Abroi Gneiss. The exact time interval spanned by the regional metamorphism in the Wongwibinda Complex cannot be determined by the potassium argon method. The 250 million year dates would represent the final stages in this metamorphism, and it is not impossible for the greater part of the metamorphism to have occurred *before* emplacement of the Tobermory Adamellite. If so, the adamellite was not affected by the later phases of metamorphism to such an extent that all its radiogenic argon was expelled.

The alternative hypothesis (*cf.* Binns and Richards, 1964), that the Tobermory Adamellite is an older intrusion which suffered only partial loss of radiogenic argon during the regional metamorphism and emplacement of the Abroi Gneiss, is not supported by field evidence in the Riverview-Carndhu area.

A summary of the geological history of the Wongwibinda area compiled from field, structural and petrological studies and from potassium-argon age determinations is presented in Table 7.

Petrological Discussion

NATURE OF THE METAMORPHISM IN THE WONGWIBINDA COMPLEX

The major period of recrystallization in the Wongwibinda Complex has so far been referred to as a regional metamorphism. However the very close relationship between distribution of the Abroi Gneiss and zoning of the metamorphic rocks suggests an aureole association, and the question whether contact metamorphism during forceful intrusion might not be a more accurate description must be considered.

From an extensive survey of descriptions available at the time, Grout (1933) estimated that schistose aureoles outnumber hornfels zones around granitic intrusions by almost two to one. Little modification of this appraisal seems necessary in the light of sub-

TABLE 7

Summary of the Geological History of the Wongwibinda Area

Time (m.y.)	Period	Event	
		Erosion Minor movement on Wongwibinda and Fishington Faults	
	TERTIARY	Outflow of basalts	
	CRETACEOUS JURASSIC TRIASSIC	↑ Uplift and erosion	
225	————	↓	Emplacement of Round Mountain Adamellite
244			Emplacement of Wards Mistake Adamellite
		↕ Movement on the Glen Bluff Fault	
		↑ Movement on the Fishington Fault	
		↓	Emplacement of Mornington Diorite
	PERMIAN	Second and later periods of movement on the Wongwibinda Fault	Emplacement of Kookabookra Adamellite
250			
		Deformation and regional metamorphism in the Wongwibinda Complex associated with first period of movement on the Wongwibinda Fault, and emplacement of the Abroi Gneiss	Emplacement of Tobermory Adamellite
		Folding of Lyndhurst Beds	
		Deposition of Lyndhurst Beds (and Dyamberin Beds?)	
275	———— CARBONIFEROUS		

sequent studies. A recent account of contact metamorphic zones surrounding diversified intrusions in Donegal, Ireland (Pitcher and Read, 1963), emphasizes the importance of manner of emplacement and consequent structural effects upon country rocks in determining both the fabric and the mineralogy of the metamorphosed rocks. About the permissively-emplaced (cauldron subsidence) Barnesmore Granite is developed a massive hornfels zone barely several yards wide; the Famad Granodiorite (introduced by "reactive emplacement") has sharp contacts and a more extensive massive hornfels zone characterized by "vigorous metamorphic and metasomatic static recrystallization"; and surrounding the forcefully-injected Main Donegal Granite there is a zone some 1 to $1\frac{1}{2}$ miles wide of schistose rocks containing, *inter alia*, staurolite, kyanite, andalusite and almandine garnet. Field relationships of this kind, strongly supported by experimental studies of metamorphic minerals and systems, tend to weaken the mineralogical contrasts between contact and regional metamorphic rocks implied in the facies classification proposed by Fyfe, Turner and Verhoogen (1958) and other systematic schemes.

By comparison with described contact zones, however, the areal extent of the Wongwibinda metamorphism classifies it as regional, although set against regional metamorphic terrains such as the Archaeozoic Willyama Complex at Broken Hill, N.S.W. (Browne, 1922; Binns, 1964) it is a diminutive example of its class. More important is the fact that, as evidenced by the sequence of intrusion and deformation in the Zone of Migmatites, the Abroi Gneiss at its present level was not directly responsible for the thermal gradient reflected by the metamorphic zonation in the Wongwibinda Complex, even though it occupies the focal position and was probably part of the intrusive cycle that did provide the supply of heat. If a particular physical variable is to be singled out as dominating the Wongwibinda metamorphism, then this is clearly deformative stress. As shown by the regional foliation pattern in the schists and the gneissose character of the intrusive rocks, the Complex lies in a zone of uncommonly severe deformation, interpreted above as arising during the early stages of movement along a zone that later became the Wongwibinda Fault.

In both scale and metamorphic style, the Wongwibinda Complex resembles the Cooma Complex in southern New South Wales (Browne, 1914; Joplin, 1942). Due to faulting and intrusion by later granitic masses the exposed metamorphic belt is less complete at Wongwibinda, and as a consequence of the kind of sedimentary rocks involved in the metamorphism, the mineralogical zonation is less spectacular. At Wongwibinda the intrusive or arteritic character of much of the venation in the Zone of Migmatites is more evident than is perhaps the case at Cooma (*cf.* Joplin, 1964).

The absence of basic intercalations or aluminous lithologies that might provide distinctive minerals such as andalusite, kyanite or staurolite in the outer zones hinders accurate determination of metamorphic grades in the Wongwibinda Complex. Conditions equivalent at least to the higher-grade subdivisions of the amphibolite facies (following Turner, 1948) are indicated by the abundant cordierite, almandine, sillimanite and orthoclase in metasedimentary schists and the diopside, grossular and clinozoisite of calcareous nodules in the Zone of Migmatites and the higher-grade portions of the Rampsbeck Schists. From what is known of pyroxene hornfels facies and granulite facies assemblages elsewhere, and from the mineralogy (hornblende-andesine) of a basic xenolith in the Abroi Gneiss, the highest grade attained in the Wongwibinda Complex is unlikely to have exceeded the amphibolite facies. The altered habit of cordierite in these rocks might be taken to suggest an earlier phase that has become unstable during the high-grade regional metamorphism. However cordierite is not foreign to regional metamorphic rocks (*cf.* Binns, 1964) and is apparently very susceptible to retrograde alteration. The shape and size of the pseudomorphous aggregates in Wongwibinda rocks, and their occurrence along with garnet in coarse-grained rocks where other constituents indicate thorough recrystallization, show that cordierite was truly a stable phase at the peak of the metamorphism.

Under high amphibolite facies conditions, the manganese contents of garnets in Wongwibinda metamorphic rocks (5-10 wt. % MnO), when plotted on the pyralspite variation diagram of Miyashiro (1953), suggest a comparatively low-pressure kind of regional metamorphism. In the absence of chemical data for the host rocks or the coexisting biotites, too much significance cannot be attached to this observation. The lack of basic and aluminous rocks in the Wongwibinda Complex is particularly unfortunate since it precludes exact classification according to the concept of metamorphic facies series (Miyashiro, 1961) or in terms of the hornblende hornfels facies of contact metamorphism and almandine amphibolite facies of regional metamorphism into which Turner (Fyfe, Turner and Verhoogen, 1958) has subdivided Eskola's (1939) more embracive amphibolite facies.

The mineralogy of calcareous nodules (diopside, grossular, clinozoisite, hornblende, calcic plagioclase) and the stability of calcic oligoclase in psammitic and pelitic schists show that metamorphism in the lower-grade portion of the Rampsbeck Schists also took place under amphibolite facies conditions. The presence of muscovite instead of orthoclase points to a lower-grade subdivision of the facies. In the Zone of Transitional Schists, recrystallization of detrital plagioclase to clear calcic plagioclase rather than to albite and epidote once again suggests amphibolite facies metamorphism.

There is no outer zone of lower-grade greenschist facies rocks at the edge of the Wongwibinda Complex, an unusual situation requiring explanation. The mild recrystallization of argillaceous rocks and the matrix of greywackes, characteristic of the Lyndhurst Beds, is a widespread feature of the belt of sedimentary rocks extending southwards from Tobermory through Rockvale towards Hillgrove. This area is marked also by mildly gneissic, biotite-rich intrusions similar to the Tobermory Adamellite (*cf.* Voisey, 1959, Figure 1), whose thermal influence apparently extended well beyond their thoroughly-recrystallized hornfels aureoles. Petrographical similarities and potassium-argon dates suggest close magmatic and temporal relationships between these intrusions and the Abroi Gneiss. Field studies currently being undertaken in the area south of the Wongwibinda Complex indicate that the Abroi Gneiss becomes less gneissic southwards and merges into one such intrusion outcropping in the Rockvale-Wollomombi area. The schists and migmatites of the Complex contract to a relatively narrow contact aureole around the intrusion. These relationships accord with the hypothesis that the Wongwibinda Complex owes its unique character to a tectonically active belt following the course of the Wongwibinda Fault, outside which metamorphism associated with contemporaneous granitic intrusions was more or less static. The widespread heating of the Tobermory-Lyndhurst-Hillgrove sediments by biotite-rich intrusive rocks while deformation and recrystallization were proceeding in the Wongwibinda Complex explains the absence of a low-grade greenschist facies zone fringing the Complex. This may not necessarily have been the case in those parts of the regional metamorphic belt no longer exposed to view.

The rapidity with which recrystallization was accomplished is a remarkable feature of the Wongwibinda Complex. The involved depositional, tectonic and intrusive history established by field studies and by isotope dating leaves only a short span of time, perhaps ten to fifteen million years, for the regional metamorphism in the Complex to have taken place. This may explain the unusually fine-grained fabrics of the Wongwibinda schists compared with products of similar grade in other regional metamorphic terrains.

Another exceptional feature of the Complex is the shallow crustal level at which it formed. At least some, if not all, of the sedimentary rocks from which the Rampsbeck Schists are derived were of Permian age, yet they were folded, then deformed and recrystallized by mid-Permian time. Even if Lower Permian geosynclinal sedimentation took place under the most violently unstable circumstances, it is difficult to conceive more than about five thousand feet of cover to the Complex at the time of its formation. Under such conditions it may appear strange for metamorphic rocks bearing mineralogical and textural evidence of reasonably high pressures to have developed, but the short duration of the regional metamorphism implies a relatively high strain rate during deformation and recrystallization, and the rocks were probably able to withstand a substantial "tectonic overpressure". Metamorphic situations where geological estimates can be made of the depth of burial are rare. It is most regrettable that manganese contents of Wongwibinda garnets preclude estimation of total pressure during metamorphism according to the method of Yoder and Chinner (1960).

Intrusive Rocks

Chemical studies of intrusive rocks from the Wongwibinda area currently in progress are expected to shed much light on problems associated with their genesis. The salient features arising from field and microscopic investigations will be discussed here.

An intrusive sequence has been established in the Zone of Migmatites, commencing with leucocratic adamellite veins and continuing through a series of biotite-enriched sills, dykes and small intrusions. The abundance of schistose xenoliths with diffuse margins in the later members of the sequence point to increasing assimilation of metasedimentary material by an initially siliceous, ferromagnesian-free magma.

The Abroi Gneiss, whose magmatic character is amply displayed by the subhedral habit and zone patterns of its plagioclase, by its overall uniformity in composition and by the sharpness of its contact with country rocks, can be regarded as the last intrusion in the sequence. Its close mineralogical and spatial relationship to the veins in the migmatite zone, particularly well illustrated by the small lens of gneiss at the centre of the Rock Abbey migmatite mass, suggests that the veins represent precursors advancing ahead of a much larger body of magma during its upward movement towards the level where it eventually solidified under stressed conditions to form the Abroi Gneiss. The lens of gneiss at Rock Abbey possibly represents the very top of a much larger intrusion, or an apophysis from the main mass to the east. Further erosion might be expected to reveal a similar body of gneiss associated with the Little Chandler River migmatites.

Abundant biotite-rich inclusions, many clearly of sedimentary derivation and most with very diffuse margins, attest the contaminated nature of the gneiss magma. The similar Tobermory Adamellite also contains abundant biotite-rich xenoliths of apparent sedimentary ancestry. This intrusion and the Abroi Gneiss belong to a group of mineralogically similar, variously-foliated granitic intrusions outcropping extensively in the area between Tobermory and Tia (south-east of Walcha), including those at Rockvale and Hillgrove. Although the age relationships of the different members of this group have not yet been elucidated, it appears that during mid-Permian times a magma of quite constant composition was available for intrusion in a large area east of Armidale. A preliminary examination suggests this magma could be obtained by contaminating a siliceous low-melting liquid similar in composition to the leucocratic adamellite found in the Zone of Migmatites at Wongwibinda with the common sedimentary rocks of the area, *viz.* quartz-bearing greywacke and slate. This hypothesis is being tested by further chemical and petrological studies.

The garnetiferous marginal variant of Abroi Gneiss near Fishington is a rare rock type in New South Wales. It differs substantially in texture from the metamorphic Potosi-Footwall Gneiss at Broken Hill (*cf.* Binns, 1964, Figure 13B), containing larger biotite flakes and subhedral, normally-zoned oligoclases that contrast with the equant-granoblastic, unzoned or reverse-zoned andesines of the Broken Hill gneisses. The garnets in the latter are richer in calcium but poorer in magnesium and manganese (Stillwell, 1952) than their equivalents in the Fishington gneiss (Table 1).

The distinctly lower magnesium content of the garnets in the Abroi Gneiss at Fishington compared to that of metamorphic almandines from the nearby schists, together with their habit and relatively uniform distribution throughout the rock suggest that they are primary precipitates from the magma rather than xenocrystal residuals derived from assimilated inclusions of country rock. The high refractive index of the biotite and scarcity of orthoclase indicate enrichment of the magma in iron and depletion in potassium. Although markedly iron-rich xenoliths or unusually iron-rich lithologies in the adjacent schists have not been observed, the unique composition of the Abroi Gneiss in this locality can probably be attributed to contamination.

The Wards Mistake Adamellite is quite distinct modally and mineralogically from the Abroi Gneiss and the Tobermory Adamellite. It belongs to a group of massive hornblendic adamellites prominent in the late Permian New England Batholith (Wilkinson *et al.*, 1965). These rocks are characterized by hornblende-rich dioritic xenoliths or microxenoliths, and much evidence is accumulating to suggest an origin by contamination of acid low-melting liquid with quartz-mica diorite (Wilkinson, Vernon and Shaw, 1964; see also Wilkinson in this volume). The occurrence of an isolated intrusion of diorite at Mornington is particularly significant in this context.

If contamination of acid low-melting liquid is indeed an essential process in the generation of both the Abroi-Tobermory and the Wards Mistake-New England Batholith magmas, then during the intrusive history of the Wongwibinda area there was apparently a change, possibly connected with the nature of tectonic activity, from assimilation of sedimentary material to assimilation of dioritic rocks. The Kookabookra Adamellite, characterized by high biotite content but by quartz and orthoclase in amounts comparable to the Wards Mistake Adamellite perhaps links the two contrasted magma types. It was certainly emplaced at the appropriate time in the intrusive sequence.

The leucocratic Round Mountain Adamellite, practically devoid of xenoliths, bears witness to the existence of large quantities of acid liquid comparable to the low-temperature partial melting fraction of Tuttle and Bowen (1958). Similar rocks occur elsewhere in the New England Batholith, especially at Tingha (Carne, 1911), Torrington (Lawrence and Markham, 1963), and the New South Wales-Queensland border (where Evernden and Richards (1962) obtained a potassium argon age of 225 million years, identical within the limits of experimental accuracy with the Round Mountain Adamellite). Most of these leucocratic intrusions, in common with the Round Mountain Adamellite, are associated with tin mineralization.

The Abroi Gneiss as a Batholith

If account is taken of those parts covered with basalt or removed by faulting or later igneous intrusion, the Abroi Gneiss qualifies in size as a batholith (more than forty square miles outcrop area, *cf.* Daly, 1914). According to the classification of Billings (1928), elaborated and summarized by Browne (1931), it has most of the characters of a synchronous batholith, including elongate conformable habit, association with regional metamorphic rocks and migmatites, primary foliation and lineation, abundance of aligned xenoliths, and localized garnetiferous modifications.

The form and environment of the Abroi Gneiss deserve discussion in terms of two classificatory schemes proposed subsequently to that of Billings.

The concept of a Granite Series (Read, 1948, 1949) stresses the tectonic setting of an intrusion as an important criterion of classification and deals equally with the question of generation and evolution of granitic magma (or migma). The division of intrusive masses into two or more extreme groups is broken down into a series in space and time and so far as classification goes, "each granite is a unit to be discussed by itself, to be related to its setting and to be interpreted on its intrinsic evidence" (Read, 1957, p. xix). In the Wongwibinda area and its environs, where the same or closely related magma emplaced into contrasted tectonic environments has given rise to intrusions as varied as the Abroi Gneiss, the Tobermory Adamellite and the Rockvale Adamellite, the advisability of taking into account separately the structural setting of individual intrusions is particularly well illustrated.

Buddington (1959) has classified granitic intrusions as epizonal, mesozonal and catazonal on the basis of character of the invaded country rocks according to the depth-zone concept, restricting his attention in the main to magmatic granites (essentially "intrusive granites" and "plutons"; the two later- and higher-members of Read's Granite Series). Although the hazards involved in correlating structural and metamorphic intensity with crustal level were recognized and discussed in some detail, Buddington reviewed the internal and external characteristics of numerous intrusions representative of the three categories, characteristics which permit classification according to the zonal scheme of a newly surveyed batholith from observable field and petrographic relationships. Under this scheme the Abroi Gneiss is a catazonal intrusion. However its shallow level of emplacement and the fact that, in the country surrounding the Wongwibinda Complex, intrusions ranging from the catazonal Abroi Gneiss through the mesozonal Tobermory Adamellite and the mesozonal-epizonal Wards Mistake Adamellite to the distinctly epizonal adamellite porphyrites (Wilkinson, Vernon and Shaw, 1964) were emplaced under roughly the same sedimentary cover and during a very restricted span of geological time (20 to 30 million years), detract from the usefulness of such a classification. If *overall* structural style and metamorphic grade are used as the principal criteria, then the New England district of New South Wales is probably best classified as transitional epizone-mesozone. However, where tectonic conditions vary laterally in such an extreme manner as at Wongwibinda, the epizonal-mesozonal-catazonal concept of classification becomes very difficult to apply.

The simple two-fold classification into synchronous and subsequent batholiths of Billings is not quite flexible enough to cover the variety of intrusions occurring in the Wongwibinda district and elsewhere. For definitely magmatic batholiths (as the majority of New South Wales granitic rocks appear to be), an adaptation delineating the phase of tectonic activity during which emplacement occurred (after Eskola, 1932) provides a more practical descriptive classification. Much can usually be discerned in this respect from the macroscopic and microscopic structures of an intrusion and its metamorphosed country rocks. In Eskola's terminology, the Abroi Gneiss would be a synkinematic batholith (just post-dating, however, the peak of deformational activity) and the Tobermory Adamellite a late kinematic intrusion, whereas the Wards Mistake and Round Mountain Adamellites would be classed as post-kinematic. Classification of the Kookabookra Adamellite in such terms needs to take into account the complicated structural history of the area.

Polymorphism of Potassium Feldspar

Due to the failure so far to synthesize either microcline or orthoclase, phase relationships of the potassium feldspar polymorphs remain a major problem of mineralogy. Heating experiments on natural feldspars, crystal structure determinations, and petrological studies such as those by Heier (1957, 1961) have provided much evidence on this question, some of it conflicting (*cf.* the review by MacKenzie and Smith, 1961). A complete series of feldspars between monoclinic orthoclase and "maximum microcline" (i.e. that having the greatest triclinicity known) has been established, in which microcline is customarily regarded as the lower-temperature, more ordered form. Laves (1950) concluded that twinned microclines necessarily invert from monoclinic potassium feldspars.

Alling (1921, p. 209) has emphasized the importance of deformative stress in promoting inversion from monoclinic to triclinic symmetry. There is much collaborative evidence to support this contention at Wongwibinda. In both the Abroi Gneiss and the Kookabookra Adamellite, potassium feldspar first crystallized as monoclinic orthoclase. Where there is evidence, such as bending of biotite flakes or granulation of quartz, to indicate deformation during or after the late stages of crystallization, patchy cross-hatched twinning appears in the orthoclase grains. Although the triclinicity thus induced cannot be detected on X-ray diffractometer patterns, such twinning must represent the onset of inversion. Where severe cataclastic deformation has taken place near major fault zones, the potassium feldspar becomes a distinctly twinned microcline. Similar relationships are shown by the potassium feldspars of schists and vein rocks in the higher-grade metamorphic zones of the Wongwibinda Complex. Furthermore, the detrital volcanically-derived orthoclase in greywackes from the Dyamberin Beds invert to microcline in sheared greywackes near the Wongwibinda Fault.

By contrast the perthitic potassium feldspars in the unstressed (post-kinematic) Wards Mistake Adamellite and the Round Mountain Adamellite are quite monoclinic, both optically and on the basis of X-ray study.

The potassium feldspar in some less gneissic marginal variants of the Tobermory Adamellite are not distinctly twinned, suggesting that the near-maximum microcline characteristic of the interior parts of the intrusion crystallized initially as orthoclase. Here again there are abundant textural indications of cataclasis, both during and after crystallization. The contrast between the thoroughly triclinic feldspar in this intrusion and its faintly-twinned equivalents in the Abroi Gneiss suggests that the exact time relationships between crystallization and deformation (and perhaps by implication the temperature relationships) influence the triclinicity value assumed by the resultant potassium feldspar.

The Origin of Myrmekite

The theory that myrmekitic intergrowths between quartz and sodic plagioclase are connected with exsolution of albite from potassium feldspar (Schwantke, 1909; Spencer, 1945) has been revived in two recent papers. Phillips (1964) follows Schwantke in attributing the intergrown quartz to exsolution of a hypothetical substance $Ca(AlSi_3O_8)_2$ from potassium feldspar, whereas Shelley (1964), deriving it by recrystallization of granulated quartz adjacent to the potassium feldspar, suggests a possible explanation for the frequent association of myrmekite with cataclastic structures.

At Wongwibinda, myrmekite is an abundant constituent of the Abroi Gneiss. It occurs also in certain vein rocks from the Zone of Migmatites, and in some orthoclase-bearing high-grade schists. In all three environments a direct abundance relationship exists between myrmekite and cataclasis. The lobate myrmekite is usually situated at the boundary between primary plagioclase and orthoclase, and projects into orthoclase in a clearly replacive manner (see Plate IIIB). The host material is oligoclase of similar composition (approximately An_{20}) to the outer zones of accompanying primary plagioclase. Quartz is a relatively abundant component of the intergrowths.

Two factors suggest that, although they might explain myrmekite formation in other petrological environments, the mechanisms of Phillips and Shelley cannot be applied to the intergrowths in Wongwibinda rocks. First, exsolved albite occurs abundantly throughout the orthoclase. Narrow rims of albite ($\beta = 1{\cdot}533$) surround large inclusions of plagioclase and in places separate the orthoclase from adjacent plagioclase. These are structurally continuous with the plagioclase but a distinct compositional break is indicated by abruptly reversed extinction angles. Small blocks or platelets of twinned or untwinned albite are also scattered through the orthoclase, as are tiny rods of optically unidentifiable material showing more distinct Becke lines than albite (probably a more calcic plagioclase). Such forms of albite have long been recognized as arising by exsolution from a formerly homogeneous alkali feldspar.

Secondly, myrmekite is only observed growing in from the margin of potassium feldspar grains, generally where there is adjacent plagioclase. It does not form on plagioclase inclusions completely enclosed by potassium feldspar. If the myrmekite were an exsolved structure, there seems to be no reason why it should favour marginal plagioclase rather than included plagioclase as a place to grow, especially when other forms of exsolved albite occur both in the marginal and interior portions of the potassium feldspar.

By ruling out an exsolution origin for the Wongwibinda myrmekites, these two factors support the classical theory of Sederholm (1916), namely that myrmekite originates from replacement of potassium feldspar by lime-bearing plagioclase, with release of quartz according to the following reactions:

$$2KAlSi_3O_8 + CaO \rightarrow CaAl_2Si_2O_8 + 4SiO_2 + K_2O$$

$$2KAlSi_3O_8 + Na_2O \rightarrow 2NaAlSi_3O_8 + K_2O$$

Although deformation clearly influences abundance of myrmekite, it is not apparent how this is accomplished. Possibly the intergranular or late-stage magmatic fluids attack the margins of potassium feldspar where there may be some kind of localized dislocation. Alternatively, deformation may enhance growth of myrmekite by remobilizing already-crystallized plagioclase (*cf.* Riecke's principle).

Replacement of orthoclase by myrmekite according to the equations quoted above releases potash. Some of this would be fixed in accessory muscovite, although there is usually not sufficient muscovite present to take up all the potassium released (see Table 3). Evidence of potassium metasomatism provided by the abundant orthoclase of certain migmatite zone schists, the scattered transgressive muscovite flakes in high- and low-grade schists of the Wongwibinda Complex, and the alteration of cordierite to micaceous aggregates, suggests that much of the potash released during formation of myrmekite has been expelled from the Abroi Gneiss and the migmatite veins into adjacent country rocks.

The Permian History of New England

Sedimentation

The implications of batholithic intrusions led Browne (1931) to postulate extensive Permo-Carboniferous sedimentation over the New England area. Both Permian and Carboniferous sedimentary rocks have since been discovered (Voisey, 1950*a*, 1958, 1959; Crook, 1958), but no detailed descriptions have been available prior to the present account. Two interesting facts emerge from the study of Permian sedimentary rocks at Wongwibinda.

First, these rocks were deposited under unstable geosynclinal conditions from turbidity current media. Potassium-argon measurements and fossil evidence indicate that the Lyndhurst Beds are partly early Permian, but it is not known how far back into geological time the exposed portions of the formation extend. Petrological similarities suggest correlation of the Lyndhurst Beds with the Dyamberin Beds, but until further palaeontological investigations are undertaken the latter cannot be placed with confidence into any particular subdivision of the Permian period. No *definite* younger Permian sedimentary rocks have been discovered in the area. In view of the age of diastrophism and igneous injection, none would be expected.

Secondly, there was a large contribution by acid and, to a lesser extent, intermediate volcanic activity to the detritus of which the Permian sediments at Wongwibinda are composed. No lavas or tuffs have been found either in the Lyndhurst Beds or the Dyamberin Beds.

No conclusion can be reached at the present stage concerning the lateral extent and the interval of time spanned by the Permian geosyncline in New England. Even its general trend is obscure, for quite contrasted regional strike directions exist to either side of the Wongwibinda Fault. Further studies of the Permian history and palaeogeography of the area east of the Great Serpentine Belt are now in progress.

A great contrast exists between the Permian geosynclinal sedimentation in the Wongwibinda area and the contemporaneous shelf sedimentation, both shallow water marine and terrestrial, in the Hunter Valley district some hundred and fifty miles to the south. Corresponding to this is an equally marked contrast between the severe Permian diastrophism at Wongwibinda and the comparatively mild folding in the Hunter Valley district.

Orogenesis

Although detailed structural and stratigraphic studies (Raggatt, 1938*b*; Osborne, 1950) have revealed mild warping during the early Permian, the major tectonic movements recognized in Permian rocks of the Hunter Valley region of central-eastern New South Wales are the modest folding and comparatively severe thrust faulting associated with the late Permian Hunter-Bowen Orogeny (Carey and Browne, 1938). Unconformities between Permian and Mesozoic rocks at Drake (Andrews, 1908; Voisey, 1936, 1939*a*) and in the coastal Manning-Macleay province (Voisey, 1939*b*, 1950*b*) indicate that tectonic activity during the Hunter-Bowen Orogeny extended into the New England region. Although few details were known about its effects, Voisey (1959) suggested that diastrophism commenced earlier in New England than in the Hunter Valley region to the south.

This is confirmed by the evidence from Wongwibinda, where geosynclinal deposition during the early Permian preceded a period of intense folding which, together with regional metamorphism along certain tectonically active belts and extensive intrusion by granitic rocks of the Tobermory-Abroi type, was accomplished by mid-Permian time (250 million years). A complex sequence of compressional faulting and intrusion by a variety of post-kinematic intrusions followed during the second half of the Permian period. With the exception of comparatively minor epeirogenic faulting and tilting, the area has remained relatively stable since the emplacement of the Round Mountain Adamellite at the close of the Permian.

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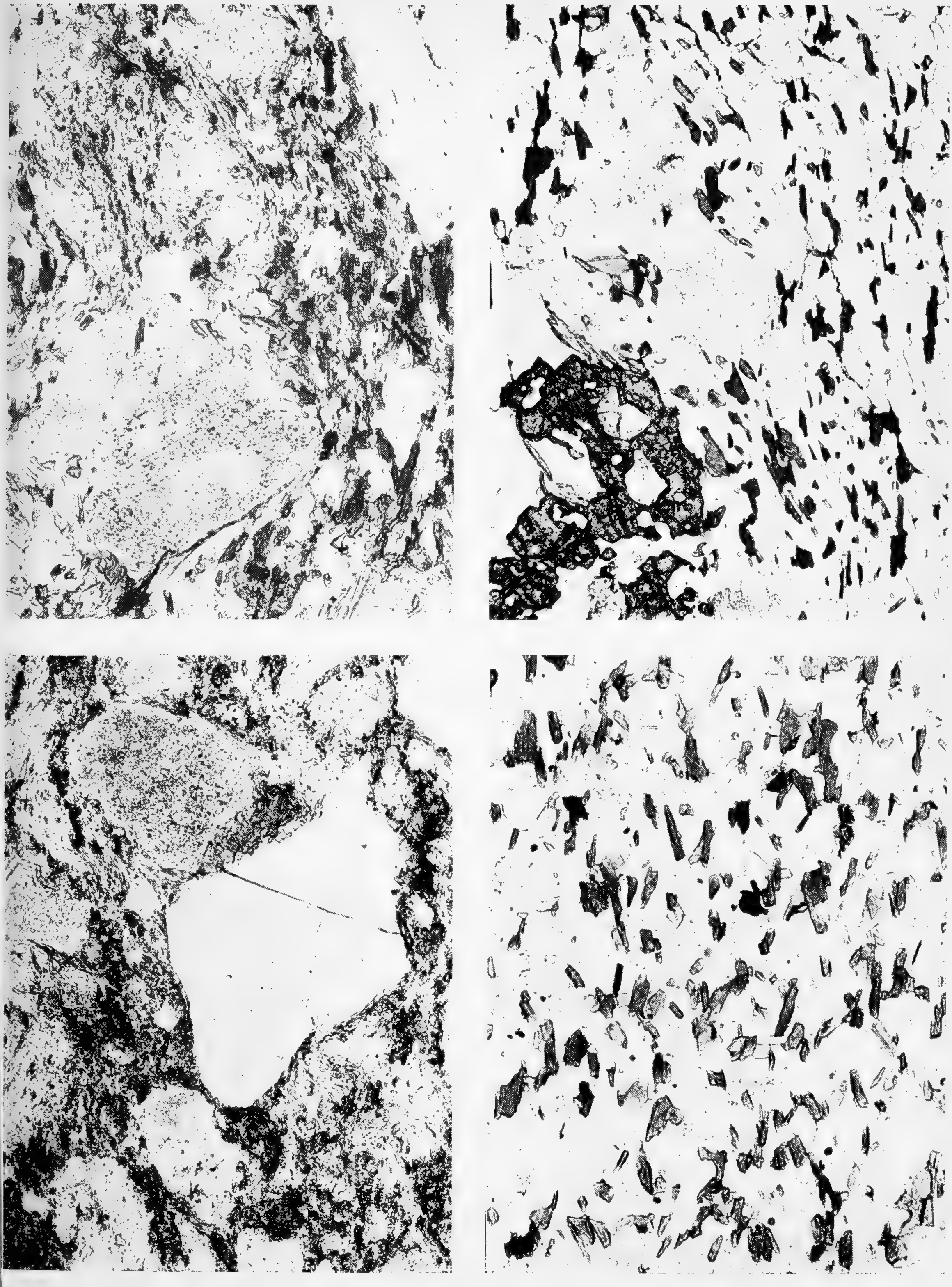

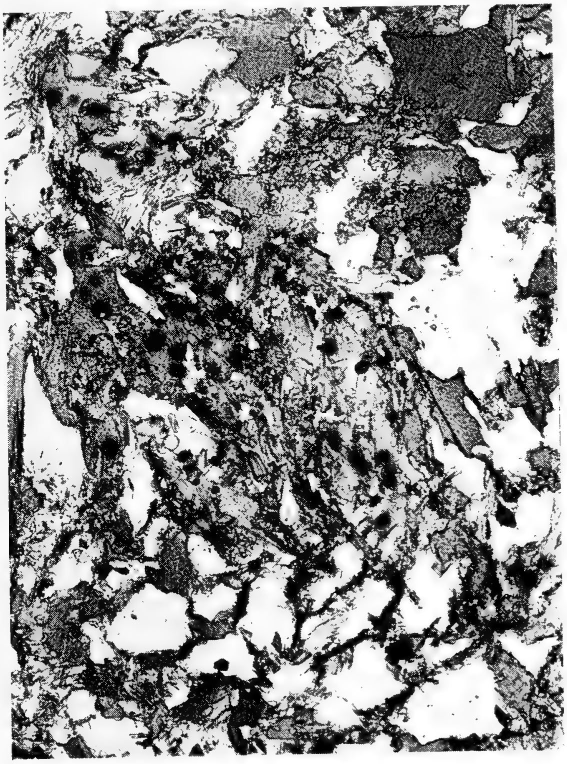

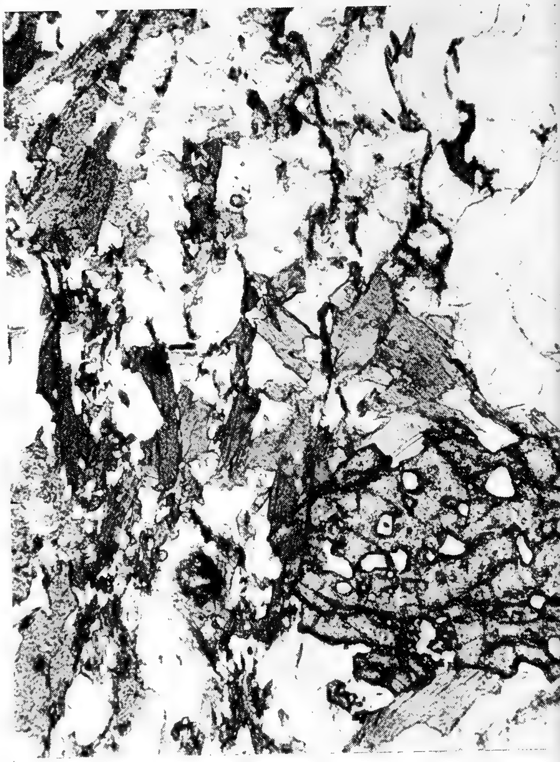

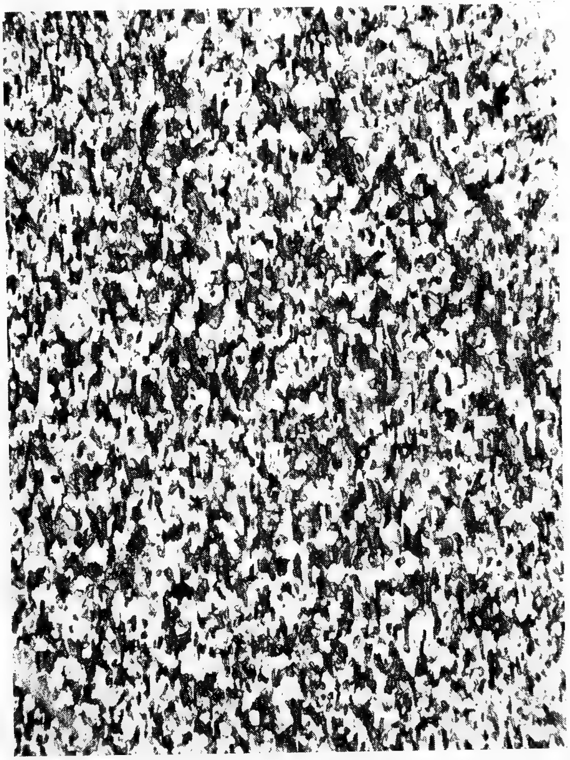

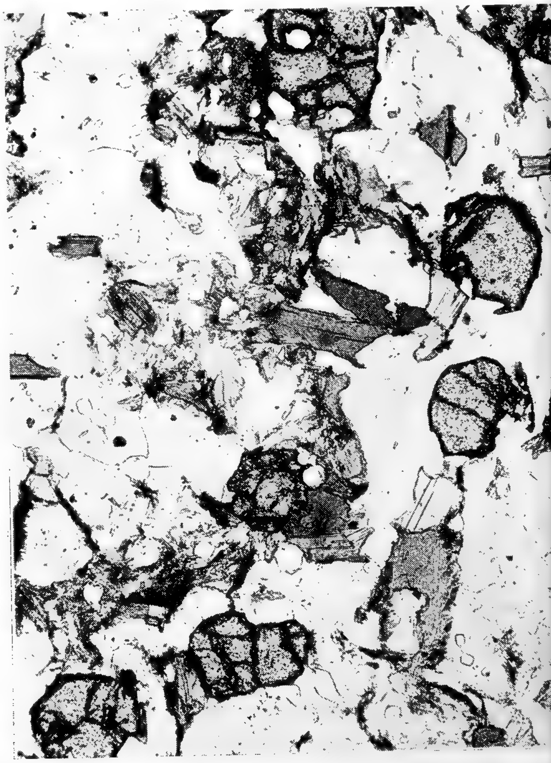

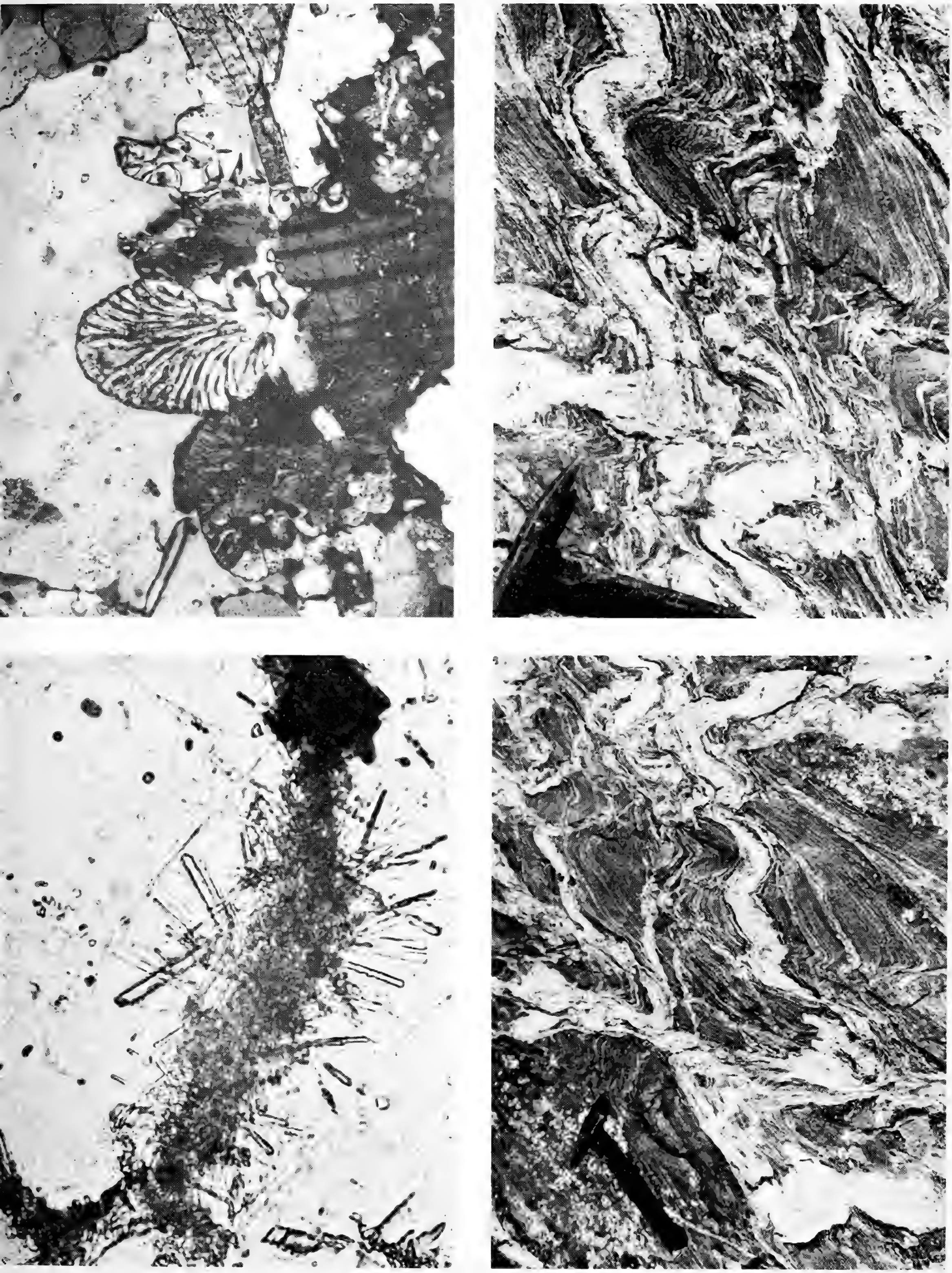

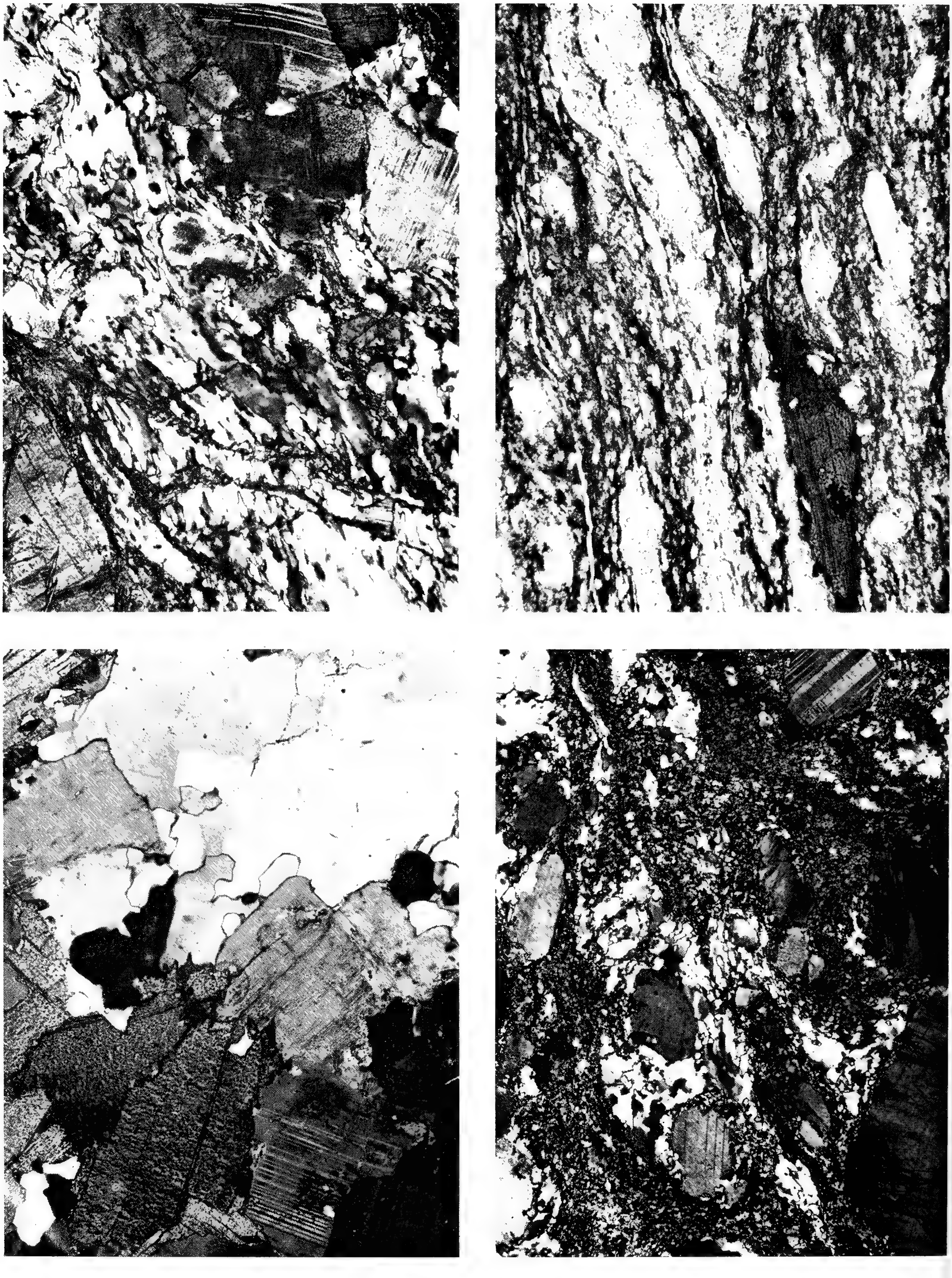

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Appendix

Locality information for specimens mentioned in the text, tables and plates

Bearings are quoted with respect to true north. Specimen numbers apply to the rock collections, Department of Geology, University of New England.

9824; *Rampsbeck Schists*, high-grade sillimanite-garnet-biotite pelitic schist, 0·9 miles south (bearing 160°) of Fishington. Table 1, Plate IID.

12542; *Lyndhurst Beds*, greywacke, 2·4 miles south-west (215°) of Lyndhurst. Plate IA.

12555; *Zone of Transitional Schists*, sheared greywacke, Chandler River, 1·0 miles south-east (125°) of Lyndhurst. Plate IB.

12566; *Rampsbeck Schists*, high-grade sillimanite-biotite-cordierite-garnet schist, beside track 1·0 mile south-east (150°) of Fishington. Plate IIIA.

12568; *Rampsbeck Schists,* low-grade psammitic schist, 0·6 miles west (260°) of Lynoch. Plate IC.

12570; *Rampsbeck Schists,* low-grade pelitic schist, same locality as 12568. Plate IIA.

12578; *Rampsbeck Schists,* vein of quartz-orthoclase-oligoclase-garnet pegmatite with garnets up to 5 mm across, traversing high-grade schists, drain beside Guyra-Ebor road, 250 yards east of Rampsbeck turn-off. Table 1.

12581; *Rampsbeck Schists,* high-grade biotite-garnet pelitic schist, same locality as 12578. Figure 4.

12587; *Rampsbeck Schists,* high-grade sillimanite biotite-cordierite pelitic schist, same locality as 12578. Plate IIB.

12596; *Rampsbeck Schists,* high-grade biotite-garnet psammitic schist, 0·2 miles north (330°) of Rampsbeck. Plate ID.

12605; *Rampsbeck Schists* (WC 39, Binns and Richards, 1965), collected with explosives from same outcrop as 12596. Table 6.

12615; *Zone of Migmatites,* sillimanite-garnet-biotite-cordierite pelitic schist, 200 yards north of Guyra-Ebor road, 0·7 miles east of Fishington turn-off. Table 1, Plate IIC, Figure 4.

12616; *Zone of Migmatites,* similar to 12615 and from same outcrop. Table 1.

12617; *Zone of Migmatites,* (WB 71, Binns and Richards, 1965), biotite-rich granitic vein in schists. Fresh specimen collected from outcrop broken and since partly covered by road-building operations. The biotites occur in two generations, the dated concentrate consisting mainly of the smaller flakes shredded from the larger. Beside Guyra-Ebor road, 0·4 miles west of Springfield turn-off. Table 6, Figure 4.

12620; *Zone of Migmatites,* biotite-rich gneiss from small intrusion, 200 yards north-west of Springfield turn-off from Guyra-Ebor road. Table 2, Figure 4.

12655; *Zone of Migmatites,* biotite-rich vein crossing schists and leucocratic veins, south of Little Chandler River, 1·4 miles north-east (45°) of Lynoch. Table 2.

12656; *Zone of Migmatites,* leucocratic vein crossing schists (see Plate IIID), same locality as 12655. Table 2.

12665; *Abroi Gneiss,* intensely sheared (50 yards from Wongwibinda Fault), bridge over Kangaroo Creek on Guyra-Ebor road. Plate IVB.

12668; *Abroi Gneiss,* intensely sheared (about 50 yards from Wongwibinda Fault, west of track, 2·2 miles south-east (145°) of Abroi. Plate IVC.

12669; *Abroi Gneiss,* beside track 1·2 miles south (190°) of Abroi. Plate 111B.

12679; *Abroi Gneiss* (WC 33, Binns and Richards, 1965), showing minor cataclasis. Slightly iron-stained specimen collected with explosives from near Kangaroo Creek, 2·9 miles south (175°) of Abroi. Tables 3 and 6, Figure 4.

12681; *Abroi Gneiss,* Copes Creek below Fishington Fault, 2·4 miles north-west (312°) of Fishington. Table 3.

12682; *Abroi Gneiss* (WC 38, Binns and Richards, 1965), garnetiferous marginal variant. Described in text and Table 3. Fresh specimen collected with explosives from small outcrop 0·7 miles north-west (325°) of Fishington. No cataclastic structures. Tables 3 and 6.

12685; *Abroi Gneiss,* from small lens at centre of Rock Abbey migmatite mass, 0·6 miles north (15°) of Rock Abbey. Table 3.

12686; *Abroi Gneiss,* beside track 0·4 miles west (270°) of Carndhu. Table 3.

12689; *Abroi Gneiss,* mylonite at Wongwibinda Fault, Backwater Creek, 0·6 miles north-east (65°) of Riverview. Plate IVD.

12693; *Tobermory Adamellite* (WB 123, Binns and Richards, 1965), freshly blasted tors at new road workings, Aberfoyle-Wards Mistake road, 0·6 miles north of Tobermory. Coarse grained central variety. Tables 4 and 6.

12697; *Tobermory Adamellite,* marginal variant near contact, 1·9 miles north-west (335°) of Aberfoyle. Table 4.

12698; *Tobermory Adamellite,* east of Glen Bluff Fault, 1·4 miles north (340°) of Carndhu. Table 4.

12709; *Kookabookra Adamellite,* near margin, beside track 2·0 miles north-east (35°) of Wards Mistake. Table 5.

12715; *Wards Mistake Adamellite* (WB 166, Binns and Richards, 1965), near margin, freshly blasted sample from new road cutting on Wards Mistake-Guyra road, 2·3 miles south-west (240°) of Wards Mistake. Tables 5 and 6.

12718; *Round Mountain Adamellite* (WC 3, Binns and Richards, 1965), white leucocratic adamellite from freshly blasted tors in new road workings at the 34 mile peg, Armidale-Grafton road (6·0 miles south-west (235°) of Round Mountain). Table 5.

12720; *Round Mountain Adamellite,* pink leuco-adamellite, cutting on Armidale-Grafton road, 4·0 miles south-east (155°) of Round Mountain. Table 5.

12723; *Doughboy Basalts,* probable tholeiitic basalt discussed in text, 1·0 mile west (270°) of Mornington.

12729, 12730; *Doughboy Basalts,* xenolithic and xenocrystic, discussed in text, from north-eastern side of basalt capping on Round Mountain.

12731; *Doughboy Basalts,* porphyritic hawaiite discussed in text, from base of basalt pile 3·2 miles east (100°) of Round Mountain.

12738; *Rampsbeck Schists,* high-grade biotite-garnet pelitic schist, same locality as 12578. Table 1.

12739; Albite pegmatite containing large crystals of tourmaline and garnet, from 0·3 miles north-east (50°) of Lynoch. Table 1.

Explanation of Plates

Plates are arranged thus: A, lower left; B, upper left; C, lower right; D, upper right.

Plate I

Progressive Metamorphism of Greywackes

A. Photomicrograph of greywacke 12542 from the Lyndhurst Beds, showing angular quartz (clear) and plagioclase (cloudy) grains but no rock fragments. The argillaceous portion of the matrix is partly recrystallized to fine aggregates of biotite. Ordinary light (O.L.), x 120.

B. Sheared greywacke 12555 from the Zone of Transitional Schists, showing relic detrital grains of plagioclase (cloudy) and quartz (clear, lower right) in a recrystallized schistose matrix of biotite and granoblastic quartz and plagioclase. O.L., x 120.

C. Thoroughly-recrystallized psammitic schist 12568 from lower grade portion of Rampsbeck Schists, containing biotite, quartz, plagioclase (showing mild relief) and accessory graphite and opaque oxide. O.L., x 120.

D. High-grade psammitic schist 12597, composed of aligned biotite with granoblastic quartz, orthoclase and plagioclase, and showing portion of a garnet porphyroblast. O.L., x 45 (note that magnification is different to A, B and C).

Plate II

Pelitic Rampsbeck Schists

A. Biotite-rich schist 12570, containing also a little muscovite, from the lower-grade zone and photographed at the same magnification as B, C and D to show increase in grainsize with grade. O.L., x 45.

B. Patch of altered cordierite, consisting of greenish biotite and pale green muscovite and retaining relic pleochroic haloes, in high-grade pelitic schist 12587. The biotite surrounding the patch (at edges of field of view) is red-brown in colour. Felted aggregates of sillimanite lie between orthoclase grains in lower left. O.L., x 45.

C. High-grade pelitic schist 12615 from the Zone of Migmatites, showing subhedral garnet grains, altered cordierite (just above centre and above garnet on right), sillimanite (upper left) and abundant sieved orthoclase. O.L., x 45.

D. High-grade pelitic schist 9824, Rampsbeck Schists, showing poikiloblastic garnet and moderately well aligned biotite. O.L., x 45.

Plate III

A. Typical sillimanite aggregate between two orthoclase grains in high-grade pelitic schist 12566, Rampsbeck Schists. O.L., x 600.

B. Myrmekite outgrowths from plagioclase (lower portion of field) replacing orthoclase (upper portion) in Abroi Gneiss 12669. Crossed nicols, x 120.

C. Field photograph of migmatites, Little Chandler River, showing branching transgressive veins of leucocratic adamellite (*cf.* 12656, Table 2), in places following crenulated foliation.

D. Close-up of another portion of the same outcrop, showing leucocratic adamellite veins and also the closely-spaced secretionary veinlets described in the text.

Plate IV

A. Abroi Gneiss 12679 comparatively free from cataclastic effects, containing clusters of aligned biotites (upper left), subhedral plagioclase (lower left) and quartz. No orthoclase is visible in the photograph. The large quartz grains at the lower right have recrystallized marginally to finer-grained mosaics. Crossed nicols, x 45.

B. Sheared Abroi Gneiss 12665, 50 yards from Wongwibinda Fault. The section has been cut parallel to the cataclastic lineation and shows the elongate individuals of quartz derived by deformation of originally large grains. A bent biotite lies in the upper left, and residuals of plagioclase with bent and broken twin planes occur in the lower right. Crossed nicols, x 45.

C. Sheared Abroi Gneiss 12668, similar to that illustrated in B but sectioned normal to the cataclastic lineation to reveal fibrous character of deformed quartz. At the lower left is a potassium feldspar residual showing shadowy microcline twinning. Crossed nicols, x 45.

D. Mylonite 12689 formed from Abroi Gneiss at the Wongwibinda Fault, showing augen-like residuals of plagioclase (right) and biotite (left). O.L., x 45.

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On Lamprophyres

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Abstract—It is argued that camptonites and analcime- and nepheline-monchiquites are differentiates of the alkali basalt magma, whilst minettes, vogesites, kersantites and spessartites, which commonly invade granites and other plutonic rocks, are differentiates of the potash-rich basaltic magma, shoshonite. The leucite monchiquite may also be related to the shoshonites.

Rare types of lamprophyre, such as alnöite and the leucite lamproites of Western Australia, are not discussed, but it is suggested that they may belong to an ultramafic magma-type.

I. Introduction

Many attempts have been made to classify the lamprophyres and they have posed an especially difficult problem to those who have written text-books for students. Harker (1895 and subsequent editions) gave them a separate chapter among the hypabyssal rocks; Hatch (1891) placed them in a special family of melanocrates in his hypabyssal group and in a later edition of this book by Hatch, Wells and Wells (1960) they are dealt with in a separate chapter; Williams, Turner and Gilbert (1958) described them with the Ultramafic Clan; and in the first edition of their text-book Turner and Verhoogen (1951) dealt with them in the same chapter as the pegmatites and nepheline syenites because all of these rocks contain high alkalies, carbon dioxide, water and phosphorus; but in the second edition of their book these authors (1960) place them with the potash-rich volcanic rocks, where, I believe, most of them rightly belong.

In writing a text-book on Australian igneous rocks, I was also confronted with the problem of the lamprophyres and came to the conclusion that the camptonites and most of the monchiquites should be included with the differentiates of the alkali basalt magma and that all the other common lamprophyres, as well as the leucite monchiquites, were related to a potash-rich basaltic magma and should be discussed with the differentiates of the shoshonite magma (Joplin, 1964, 1965).

Before attempting to justify this classification, it is pertinent to outline the characteristics of the lamprophyres, and to suggest the main reasons for the difficulties in classifying this seemingly anomalous rock group.

II. Characteristics of Lamprophyres

1. *Texture.* Some lamprophyres are aphyric, but most of them are porphyritic and all are panidiomorphic granular, that is to say, all minerals show idiomorphic outlines whether they occur in one or in two generations.

2. *Mineral Composition.* Some petrographers define lamprophyres as rocks containing only mafic phenocrysts, but actually many contain small phenocrysts of feldspar as well, and with an increase in the content of feldspar phenocrysts, they pass into porphyrites with which many lamprophyres are closely associated in the field. The mafic phenocrysts may be olivine, augite, hornblende or mica and in many lamprophyres several of these minerals occur together. The groundmass consists of a second generation of the mafic mineral or minerals and either potash feldspar or plagioclase (oligoclase to andesine), and undersaturated types contain feldspathoids with or without melilite. Opaque minerals are abundant, apatite is always present and may be very abundant in some types. Carbonates and other alteration products are ubiquitous in the minettes, vogesites, kersantites and spessartites, though not present in all camptonites and monchiquites. Mafic phenocrysts such as olivine and augite are commonly pseudomorphed by serpentine, carbonates or clay minerals, and though hornblende and mica are less commonly altered, they may be pseudomorphed by chlorite and a secondary amphibole with separation of sphene and iron ore granules. Hornblende and mica phenocrysts typically show resorption and marginal alteration.

Three common types of lamprophyre contain hornblende: two, vogesites and spessartites, common green hornblende; and camptonites, a brown oxyhornblende said to be barkevikite, but possibly kaersutite. Lime-rich pyroxene occurs in many lamprophyres, but in the camptonites and in many of the monchiquites it is also titaniferous. Monchiquites containing titanaugite commonly contain oxyhornblende, analcime and/or nepheline, but leucite monchiquites usually contain mica and rarely hornblende. The leucite monchiquites thus appear to show some relation to the minettes and the analcime and nepheline monchiquites to the camptonites.

3. *Chemical Composition.* Many authors state that the lamprophyres show a wide range of chemical composition, and this might be expected when the range of mineral composition is taken into account. Cross (1915) and Knopf (1936) have pointed out however that many of the common lamprophyres, such as minettes, vogesites, kersantites and spessartites, are almost chemically identical, and this is borne out by a recent set of averages based on a very large number of carefully selected analyses (Métais and Chayes, 1963).

Reference to Table 1 will show that, except for alkalies, minettes, vogesites, kersantites and spessartites have a very similar chemistry, and that they all show high potash, which is in excess of soda except in the spessartites. Camptonites and monchiquites on the other hand contain less silica, more magnesia, lime, iron and titania with soda in excess of potash.

Unfortunately these averages do not give BaO and SrO, probably because these oxides have been rarely estimated. An inspection of lamprophyre analyses in Washington (1917) and in Joplin (1963) suggests that BaO is high in the minettes, vogesites, kersantites and spessartites and ranges from about 0·06% to about 0·50%, whereas in the camptonites it is lower and ranges from about 0·04% to about 0·08%.

4. *Field Occurrence.* Von Gümbel first gave the name lamprophyre to certain dark, lustrous dyke rocks in Saxony, and most lamprophyres occur in dykes, though they have been described from sills, small laccoliths and as marginal phases of larger bodies.

There is no doubt that a close field association exists between camptonites, many monchiquites and fourchites and members of the alkali basalt series, such as alkali basalts, hawaiites, mugearites, nepheline basanites, nephelinites etc. and though dykes of camptonite and nepheline- or analcime-monochiquite are recorded among the rocks of other suites, and are in places associated with other types of lamprophyre, the association is probably accidental and the two suites usually have a different geological age.

Minettes, vogesites, kersantites and spessartites are commonly associated with granites, diorites, syenites and monzonites, which they cut as dykes. Dykes of aplite, pegmatite and porphyrite are also associated with these plutonic rocks and it was earlier suggested that the felsic dyke-rocks and the lamprophyres were complementary variants of the associated plutonic type. Because of their close field association and mineralogical resemblances to certain plutonic types, vogesites have been called syenite-lamprophyres and spessartites diorite-lamprophyres.

As indicated by the work of Pirsson (1905) and Cross (1906, 1915), lamprophyres appear to be especially abundant in the monzonitic

TABLE 1

Average Analyses of Lamprophyres

	Minette	Vogesite	Kersantite	Spessartite	Camptonite	Monchiquite
	Av. 64	Av. 30	Av. 95	Av. 45	Av. 78	Av. 61
SiO_2	51·17	51·13	51·80	52·37	44·67	40·68
Al_2O_3 ..	13·87	14·35	14·84	15·44	14·35	13·20
Fe_2O_3.. ..	3·27	3·63	3·03	3·27	4·50	4·87
FeO	4·16	4·74	5·32	5·35	7·19	6·47
MgO	6·91	6·84	6·29	6·27	7·02	9·17
CaO	6·58	7·05	6·24	7·36	9·45	11·02
Na_2O ..	2·12	3·00	2·98	3·30	2·99	3·06
K_2O	5·49	3·81	3·68	2·54	1·91	2·16
H_2O	2·42	2·62	2·56	2·36	3·12	3·52
CO_2	1·30	0·74	1·14	0·41	1·58	1·38
TiO_2	1·36	1·44	1·32	1·31	2·46	2·34

complexes where they are associated with shonkinites and potash-rich syenites. Many types of lamprophyre are also associated with the monzonitic complex of Mount Dromedary, New South Wales (Brown, 1930). In the Spanish Peaks region of Colorado, Knopf (1936) recorded numerous lamprophyres associated with microsyenodiorites, augite microsyenites, syenogabbros, trachydolerites and shonkinites—a suite which, I believe, belongs to the monzonite or shoshonite series.

Some of these dykes cut the monzonitic rocks and others radiate out from them, the latter occurrence suggesting a close tectonic relation.

In the Walhalla-Woods Point district of Victoria (Junner, 1920; Hills, 1952), a dyke-swarm consisting largely of lamprophyres, includes hornblende pyroxenites, diorites and diorite porphyrites, which contain orthoclase, and this series is also suggestive of a monzonitic type of magma.

In the Snowy Mountains region of New South Wales I (Joplin, 1958) described a number of co-linear intrusions consisting of pyroxenites, hornblende pyroxenites, monzonites, orthoclase-bearing diorites and lamprophyres and explained the presence of potash feldspar by hybridization with adjacent granite. I now believe that these rocks have differentiated from a monzonitic magma, and though some hybridization has certainly taken place, most of the potash feldspar has originated from the mafic magma.

5. *Tectonic Environment*. As noted above, camptonites and analcime- and nepheline-monchiquites occur with the alkali basalt suite, which is associated with a typically stable environment.

Granites and diorites, which are invaded by lamprophyres, occur characteristically in *subsequent* bathyliths (Browne, 1931), that is, in bathyliths associated with the late stages of diastrophism (Joplin, 1962). The lamprophyritic dyke-swarm at Walhalla-Woods Point is truncated by still later granites occurring as ring-dykes (Hills, 1959).

Recent dating by the potassium-argon method has shown that the monzonitic complex of Mount Dromedary is probably Cretaceous (Evernden and Richards, 1962), and this points to an almost stable environment for these intrusions, with which lamprophyres appear to be genetically related.

According to Knopf (1936) the intrusions from which the lamprophyre dykes radiate in the Spanish Peaks region took place during a late phase of the Laramide Revolution and in Montana and Wyoming the shoshonite complexes, with their accompanying lamprophyres were also late in the diastrophic cycle.

Thus, lamprophyres appear to be intruded during or after the late stages of the stabilization of the geosyncline.

III. Main Difficulties of Classification

Because all lamprophyres are very similar texturally, and most of them occur as dykes, there is good reason for placing them together in one group and the almost ubiquitous presence of carbonates and other alteration products also serves to link them.

On the other hand, the diversity of mineral composition and their apparent association with a number of different plutonic rocks suggest different parentages. Because dykes of lamprophyre and of aplite invade subsequent bathyliths so commonly, a genetic relation between granite, aplite and lamprophyre seems obvious, and when Bowen's theory of magmatic differentiation was applied to a granitic complex, the late appearance of these mafic dykes was puzzling, and was explained by complementary differentiation which give rise to diaschistic dykes—mafic and felsic. Tyrrell (1926) stated, ''minettes, vogesites, kersantites and spessartites occur as basic differentiates of granitic or granodioritic magmas, and are complementary to aplites and pegmatites''. Bowen (1928) suggested that lamprophyres and allied alkaline rocks may be produced by remelting earlier crystallized hornblende and biotite, and Eskola (1954) suggested that the crystallization of mafic minerals might be delayed in a mafic magma with a high concentration of carbon dioxide and that a late magmatic liquid rich in alkalies and mafic materials could thus be produced.

Although the original camptonite was said to contain barkevikite a good deal of confusion has stemmed from the loose usage of the term ''hornblende lamprophyre'', which has been applied to camptonites with their brown hornblende and to spessartites and vogesites with their green. Undoubtedly, more work needs to be done on the amphiboles of the lamprophyres, and it is possible that in some cases the so-called barkevikite of camptonites may prove to be kaersutite. Nevertheless, it seems obvious that different mineral assemblages accompany brown hornblende and green hornblende, and that the lamprophyres containing brown hornblende, such as the camptonites and analcime- and nepheline-bearing monchiquites and fourchites have the same mineralogy, field association and tectonic environment as the alkali basalts.

Other lamprophyres, however, have a different mineralogy, chemical composition and field association and are intruded a little earlier in the stabilization of the orogenic belt. I believe that all these lamprophyres are related to one another and are members of the shoshonite series, so it is now necessary to outline the characteristics of this series and to compare them with those of the lamprophyres.

IV. Characteristics of the Shoshonite Series

The characteristics of the shoshonites are discussed elsewhere (Joplin, 1965) and only a brief outline is presented here.

These rocks fall into two groups—those that are slightly saturated, or undersaturated only with respect to olivine, and those that are completely undersaturated and contain feldspathoids. The first group ranges in composition from ultramafic to felsic: intrusive rocks include pyroxenites, olivine monzonites, monzonites, banatites, akerites and some syenite porphyries, whilst the corresponding lavas are absarokites, shoshonites, latites (in the Ransome (1898) sense) and potash-rich trachytes. The undersaturated intrusive rocks are nepheline monzonites, shonkinites, covites, ijolites, jacupirangites, leucitophyres and certain tinguites, and the lavas include such rocks as leucite absarokites, leucite shoshonites and leucite basalts. The leucite monchiquites are chemically and mineralogically related to this group.

1. *Mineral Composition.* With the exception of the ultramafic types all these rocks are characterized by the presence of potash feldspar which is commonly orthoclase in the plutonic rocks and sanidine in the lavas and minor intrusives. In addition to potash feldspar, plagioclase is commonly present, and though much work needs to be done on these feldspars, and though there is a range in composition throughout the series, the plagioclase seems to be rather a lime-rich variety and is commonly labradorite. The shoshonite lavas contain phenocrysts of both feldspar and mafic minerals, but the absarokites contain only mafic minerals as phenocrysts.

The mafic minerals of the shoshonite series are typically clinopyroxene and biotite, but green hornblende occurs in the more felsic differentiates. Pyroxene is a diopsidic type, and is commonly pale green in thin section (Boesen, 1964). Many of the undersaturated members of the series also contain these minerals as well as one or more feldspathoids which may be nepheline, leucite, hauyne or nosean. Extremely undersaturated rocks are feldspar-free. Melanite garnet is very common in these rocks and some undersaturated felsic types contain aegirine or aegirine-augite. Melilite occurs in some rare types.

In the Spanish Peaks region of Colorado, Knopf (1936) has recorded potash feldspar, plagioclase, clinopyroxene and biotite in most of the rocks of the suite and it is my belief that this is a shoshonitic province.

2. *Chemical Composition.* Because these rocks form a differentiation series, there is a range in chemical composition. Nevertheless certain chemical peculiarities are common to the whole suite.

Alkalies are high, with potash about equal to or in excess of soda; alumina, lime and phosphorus are high and magnesia a little lower than in rocks of comparable silica content in the alkali basalt series. Barium and strontium have been estimated in comparatively few of these rocks, but when these results are available they appear to be high and barium shows a range from 0·06% to 0·46%.

A rock from the Crazy Mountains of Montana, a typical shoshonite province, was originally described by Rosenbusch as a theralite, but the "plagioclase" subsequently proved to be barium-bearing orthoclase, and it would be of interest to know whether the presence of a notable amount of barium is characteristic of the potash feldspar of this rock-suite.

Knopf has stated that the Spanish Peaks rocks contain high potassium, barium, strontium and phosphorus—a further confirmation of their shoshonitic affinities.

3. *Tectonic Environment.* Ransome (1898) showed that the latites of the Sierra Nevada are interbedded with pyroclastic rocks which cover an eroded surface consisting of granites and steeply dipping schists, and that only faulting and tilting have affected this area since the outpouring of the latites. The shoshonites of Yellowstone Park are also associated with ash beds that have infilled valleys cut out of the Laramide fold mountains

TABLE 2

Some Members of the Shoshonite Series

	1	2	3	4	5
SiO_2	49·71	51·32	51·68	51·75	52·86
Al_2O_3	13·30	18·82	14·07	17·48	17·51
Fe_2O_3	4·41	4·50	4·71	6·42	5·18
FeO	3·37	2·97	4·57	1·46	3·31
MgO	7·96	3·58	7·72	4·05	4·18
CaO	8·03	6·42	6·65	8·20	6·51
Na_2O	1·49	3·97	2·45	3·33	3·22
K_2O	4·81	3·31	4·16	3·72	3·41
H_2O+	4·07	2·89	2·09	2·26	1·76
H_2O-	—	0·87	—		
CO_2	—	0·10	—	—	—
TiO_2	1·57	0·56	1·08	0·86	—
P_2O_5	0·66	0·42	0·72	0·67	0·53
MnO	0·17	0·23	—	tr	—
BaO	0·46	0·22	—	—	—
Etc.	—	0·07	0·13	0·17	0·42
	100·01	100·25	100·03	100·37	99·90

1. Absarokite, Yellowstone Park, U.S.A. Anal. L. G. Eakins
2. Latite (Minnamurra Latite), South Coast, N.S.W. Anal. H. P. White
3. Absarokite, Yellowstone Park, U.S.A. Anal. J. E. Whitfield
4. Shoshonite, Yellowstone Park, U.S.A. Anal. J. E. Whitfield
5. Shoshonite, Yellowstone Park, U.S.A. Anal. J. E. Whitfield

(Thoms, 1955), and Knopf (1936) has stated that the intrusions at Spanish Peak have occurred during a late stage of the Laramide Revolution. The great differentiated laccoliths of Montana and Wyoming, such as Highwood Mountains, have also been intruded after the cessation of folding, so all of these American examples suggest that the shoshonitic magma is associated with a late phase of the stabilization of a tectonic belt.

In Australia shoshonitic rocks occur as lavas and shallow intrusions in the Upper Permian on the south coast of New South Wales, and further south, in the differentiated intrusion of Mount Dromedary, now believed to be Cretaceous. More felsic types also occur in a series of small Cretaceous intrusions at Port Cygnet in Tasmania.

The Permian rocks on the south coast of New South Wales were laid down in either an exogeosyncline (Voisey, 1959) or on a shelf, and their very low angle of dip indicates that no orogeny has taken place since the shoshonites were emplaced. By Cretaceous time the Tasman Geosyncline in the vicinity of Tasmania and southern New South Wales was essentially stable, so in Australia also the shoshonitic magma is associated with stable or near stable conditions.

V. A Comparison of Certain Lamprophyres with Shoshonites

A comparison of the minettes, vogesites, kersantites and spessartites with members of the shoshonite series shows a number of mineralogical similarities, and some specimens of kersantite from the type area at Brest in France are almost identical with monzonite porphyries.

Although many lamprophyres contain small phenocrysts of feldspar, the phenocrysts are mainly mafic minerals and in this respect they resemble the absarokites of the shoshonite series.

Although a comparison of actual chemical analyses with average analyses is not satisfactory, and a perusal of a compilation of analyses (Washington, 1917; Joplin, 1963) will reveal that some analyses of lamprophyres are almost identical to some analyses of shoshonitic rocks, a comparison of Tables 1 and 2 will show common characteristics, particularly high alkalies and high potash compared with soda. As might be expected, the analyses of the lamprophyres compare more closely with the absarokites, the lower feldspar and higher mafic content being reflected in the lower alumina and higher magnesia.

Like members of the shoshonite series, the lamprophyres are also injected during a late stage in the stabilization of the geosyncline.

VI. An Attempt to Explain some Characteristics of Lamprophyres

If the camptonites and most monchiquites belong to the alkali basalt magma and the rest of the lamprophyres to the shoshonitic magma, then some of the characteristic features of lamprophyres find a ready explanation.

1. *Occurrence in Dykes.* If lamprophyres are derived from the alkali basalt and shoshonite magmas they are associated with late and very late phases in the stabilization of the geosyncline when it is subjected to tensional stress; dykes and dyke-swarms are the most common forms of intrusion under these tectonic conditions.

2. *Panidiomorphic Texture.* Idiomorphic crystals will develop in a fluid magma that cools relatively quickly and it is not uncommon to find this texture in many mafic lavas and small intrusions.

When it was thought that many lamprophyres were differentiates of plutonic bodies and were perhaps complementary variants of aplites and pegmatites, the panidiomorphic texture of the lamprophyre was remarkable. However, if the lamprophyres have crystallized from mafic magmas, whether they be soda-rich (alkali basalt) or potash-rich (shoshonite), and if these magmas have crystallized in relatively small intrusive bodies under fairly stable conditions, the panidiomorphic texture ceases to be remarkable and might be expected to occur.

3. *Typical Alteration.* So-called deuteric alteration is fairly common in mafic rocks and many examples are to be found among the members of the alkali basalt series. Nevertheless, the camptonites and monchiquites belonging to this suite are perhaps less altered than the lamprophyres which I believe belong to the shoshonite series, so the question arises, why should shoshonitic rocks be more altered?

If during the stabilization of the geosyncline, the shoshonitic magma precedes the alkali basalt, it probably makes its way up through only partly consolidated sediments still containing much water and organic matter, whereas the later alkali basalt invades a more consolidated and drier environment. Although almost stable, the site of the old geosyncline is probably transgressed by shallow seas at the time when the shoshonite magma is coming in and the magma becomes charged with carbon dioxide and sulphur and has a high water content. Phenocrysts brought up by the magma are no longer stable under these near surface conditions and are thus partly resorbed or pseudomorphed completely. The high water pressure also may explain the presence of common green hornblende and the rare occurrence of orthopyroxene in these rocks.

4. *Presence of Xenoliths and Xenocrysts.* The abundance of xenocrystal material in some lamprophyres has led to a suggestion that the lamprophyres are contaminated rocks, though few petrologists have accepted this theory.

If magma is extremely fluid with a high water and high carbon dioxide pressure, it is capable of rifting fragments of the country rocks and mechanically disintegrating them, so it is not surprising that shoshonitic rocks would contain abundant foreign material (Wilshire and Hobbs, 1962).

VII. Rare Types of Lamprophyre

Alnöites and other less common types such as the leucite lamproites (Prider, 1960) are not dealt with in this paper. They may represent a group derived from an ultramafic magma. The alnöites are typically associated with carbonitites and with kimberlites (Campbell-Smith, 1956) and Prider has suggested mica peridotite as the parent of the leucite lamproites.

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Observations on the Opaque Ore Content of some Meteorites, especially from New South Wales

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Summary

Sixteen well-polished sections of meteorites examined under reflected light conditions, and which are mostly falls or deposits from New South Wales (one troilite nodule from an iron, two pallasites, one achondrite, the remaining ones chondrites), contain principally the same content of opaque minerals as the common members of their groups. The wide distribution of hitherto and rarely-mentioned components such as native copper, chalcopyrrhotite and ilmenite and the rarity of magnetite in unweathered material are again confirmed. The variability of the chromite is especially noted; a few new special textures and distributions are discussed. This material also shows the absolute necessity for collecting more diverse data before setting up "rules" or even "laws". This will avoid gross errors in drawing conclusions.

Introduction

During two winter seasons (1960-61 and 1961-62) in Washington, U.S.A., the author had the opportunity to examine about 130 meteorites, mainly material from the large collection of the American National Museum (Smithsonian Institute) in Washington and from the American Museum of National History in New York (Ramdohr and Kullerud, 1962; Ramdohr, 1963).

This examination covered mainly the study of composition and texture of opaque minerals in stony meteorites and their related mesosiderites. Pallasites and sulphide or silicate portions of iron meteorites were studied only for the purpose of comparison. This procedure was based upon the consideration that iron meteorites had been studied extensively by ore-microscopical methods for almost a hundred years and that, for example, the excellently illustrated monograph by Perry (1949) is available. However these studies were by no means exhaustive—one often observes phenomena which may prove quite important but which were missed by previous observers. Hardly anything was known about the opaque mineral content of the stony meteorites and what was known was incomplete and partly misinterpreted. Thus, as the result of these present observations, eight minerals which were known from terrestrial occurrences, but not from meteorites, were observed in part as common components; a certain number of others was recognized as accessory although they were considered earlier as a great rarity, e.g. native copper, ilmenite. About fifteen components were established which were known neither as terrestrial nor as meteoric minerals.

These studies are to a certain extent preliminary: many of the observations cannot yet be explained in any way; most of the newly discovered minerals were described without knowing their distribution, frequency, or chemical composition. It will probably be several decades before this work is completed. Genetical interpretations were not attempted at all.

In order to ensure availability of the material and in order to enable experts from all over the world to examine it, the material was placed in the Department for Meteorites of the Smithsonian Institute, Washington. At the same time the rights of the original owners of the Australian specimens, i.e. the Australian Museum, Sydney, were safeguarded. At the same location the author's original observation cards (in photocopies) are available.

Material

Fifteen fall or find locations are discussed. One of these is represented by two very different samples (Nardoo); twelve are chondrites, one (Binda) an achondrite, two pallasites (Molong and Mt. Dyrring) and a sulphide nodule of a meteoritic iron (Delegate).

When compared with the material examined at Washington, which was about eight times as rich, few basically new observations could be made, yet many things are worthwhile mentioning and of importance, furthermore some structures are larger, more typical or more "photogenic" compared to what the writer has observed hitherto.

General Aspects

Weathering

Eleven of the examined samples were "finds" and were, in varying degrees, superficially weathered. They contain, more or less independently of the original mineral composition, a number of components typical of meteorite weathering in semi-arid regions. Kamazite and later also taenite (here abbreviated "α-Fe" and "γ-Fe" without regard to the nickel content) form magnetite, often in well developed rhythmical colloidal forms, which frequently partly transforms into maghemite; the transformation into needle-iron ore (goethite) generally begins later. Primary magnetite is very rare in almost all chondrites (the hydrocarbon-bearing ones are an exception) and occurs almost wholly as an exsolution product. This fact is opposed to some newer literature wherein mineral component data are based upon electronic calculations from powder diagrams and which naturally cannot distinguish between primary cosmic composition and terrestrial weathering. The considerations of W. Wahl (1951) that magnetite in normal chondrites should not be present, are therefore quite correct. Nickel goes into solution when nickel-rich iron weathers, and in most cases is not immediately precipitated with iron in magnetite or needle-iron ore. On account of its great affinity for sulphur it is precipitated as pentlandite upon the surface or in fractures in troilite. It is remarkable, if compared with terrestrial pyrrhotite ($Fe_{x-1}S_x$), that troilite is more resistant to weathering than α-Fe containing approximately 6% Ni. But finally even troilite submits to weathering during which it forms firstly fine-grained pyrite and the "Zwischenprodukt" consisting of marcasite (which extinguishes simultaneously with troilite) and finally needle iron. Typical "birds-eye" weathering is mostly absent. Schreibersite weathers more slowly than both irons and troilite.

The Molten Crusts

These are similar in nearly all meteorites. A molten outer crust, consisting almost always of black glass with numerous skeletons of magnetite, in part excellently developed, is followed by a crust up to four and five times thicker which shows glass or troilite films on the grain boundaries of the silicates etc. In other words, during the passage through the atmosphere the finest cracks soaked up a part of the molten material. In some cases the outermost parts of the magnetite skeletons are already partly "martitized" by heat, a fact that can easily be observed in good relief-free sections and by means of occasional internal red reflections in imperfectly-polished sections. In one sample (Nardoo No. 1) an ilmenite accidentally located in the melt-crust was observed to be roasted to pseudobrookite. Since ilmenite is very rare this was an exceptional case but nevertheless to be expected when ilmenite is strongly heated in the presence of oxygen.

Textures

Chondrules

A great amount of literature is available about the examination of chondrules. In a previous publication (Ramdohr, 1963) it was demonstrated that these chondrules, hitherto mostly studied in transmitted light, show many of the details of structure and genesis better in a polished section than in thin section (Figure 3). It is appropriate here to draw attention to some of the unknown (or nearly so) types. For example Adelie Land contains chondrules (Stillwell, 1923) (Figure 4) which are exceptionally rich in troilite, chromite and iron, occurring in the centre of the chondrule and not, as occasionally (Barratta), in the mantle. Peculiar "small chondrules" occur, too, which carry in their central part an aggregate of coarse closely packed chromite grains which, towards the outer portions, grade into a finer and finer impregnation of chromite in silicates (Nardoo No. 1). Nardoo occasionally also offers "giant chondrules" of about 1 cm diameter.

Fracture (Friction) Melting

Fracture melting occurs not only in specimens which, without doubt, are recognizable as breccia chondrites but also those which at first appear to be uniform. It is not known what causes the temperature increase necessary to melt the iron, troilite and silicates in such a short time. It is hardly conceivable that this temperature increase is merely the result of fracturing and the accompanying friction and displacement which, as could be proved in several instances, amounts to less than 100μ. Anders and Goles' (1961) idea that hot gas containing FeS has been forced through fracture lines may occasionally be correct, but cannot be generalized since the fracture melting occurs too frequently and often without the necessary introduction of troilite. The melting embraces the silicate minerals (olivine less than pyroxene and plagioclase), iron and troilite. The width of the melting zone is very small, the temperature decrease towards the unaffected parts very great. Very strongly pressure-twinned grains of ilmenite show recrystallization only immediately adjacent to the melting zone. Fracture melting may be observed in the Australian chondrites from Binda, Coolamon and Elsinora (Figures 5a, 5b, 5c).

SPONTANEOUS MELTING

The author, during research in Washington, recognized another type of melting which, as far as is known, is restricted to irregularly-distributed, minute spots (approx. 50μ diameter) in the centre of the meteorite and which has no connection with fractures or pressure zones nor, naturally enough, with the melting crust. This may appear in the most diverse aggregates but also in single grains, for example grains of iron. The heat, very local and of short duration, must have been extreme since the silicates have been completely molten and homogenized in the melt—if one disregards original coarse grains—and even chromite has been very strongly corroded. About a quarter of all chondrites contain such spontaneous melts—of the Australian examples examined: Coolamon, Hermitage Plains, and both samples from Nardoo (Figures 6, 6a). Where both fracture and spontaneous melting appear together, as in the specimens from Coolamon, they readily differentiate from one another.

Mineral Content

The collective table (Table 1) may be referred to for the discussion on the mineral content. Occurrences and properties correspond with the average as described by the author in his earlier works except in cases which are especially noted. It is understandable that not all of the previously mentioned minerals were observed in the few occurrences discussed here. It can be seen immediately that *both irons* occur by themselves and nearly everywhere also in the form of a plessitic intergrowth. If γ-Fe is not everywhere mentioned it still could be present; small amounts might have been overlooked since on account of the general distribution it was not always especially noted during the examination. *Troilite* is always present, also *chromite* (with the exception of one pallasite). *Copper* occurs nine times but not in the one pallasite and the sulphide nodule *ilmenite* occurs eleven times (again not in the pallasites and sulphide nodule). *Chalcopyrrhotite* has been observed ten times and *valleriite,* always genetically connected here with the former, six times (both again not observed in the pallasites). On the other hand, *schreibersite* (except in the iron-rich members) occurs only in one chondrite, pentlandite only twice, graphite and some rarities only once. The total result reflects almost exactly the more comprehensive statistic (Ramdohr, 1963).

The *irons,* e.g. *kamazite,* α-iron with a maximum of approximately 6% Ni, *taenite* γ-(Fe,Ni) with highly variable Ni-content, sometimes up to 60% Ni and the intergrowth of both, *plessite,* are present everywhere. They are irregular in their distribution, at least much more complicated than it was assumed previously. The consideration that the so-called highly reduced stony meteorites (meteorites in which the FeO content of olivine and pyroxene is reduced to Fe and which therefore only contain forsterite, enstatite and pigeonitic diopside) should carry only a relatively low Ni-content in the metallic iron phase (α-Fe), is true only with many reservations. Centres of disequilibrium are present throughout so that within short distances α-Fe with very little nickel, plessite or even fairly compact masses of taenite may be observed. In the case of pallasites (and naturally in the case of Fe-meteorites) where the temperature and probably also the length of the formation period for obtaining the equilibrium were more favourable, the situation is significantly different. However, even here so-called "plessite-eggs" (areas of rounded shapes) do occur which must be considerably richer in nickel than the main mass (Molong). A remarkable "development" by weathering is shown in Figure 8.

Schreibersite, observed in chondrites to a far greater extent than hitherto known, was recorded in the N.S.W. samples only from Binda and Nardoo; it is present abundantly in the pallasites and the sulphide nodule from Delegate, the Molong specimen being especially beautiful (Figure 2, 21).

Cohenite, rare in stony meteorites, was nowhere observed, not even in pallasites.

Graphite has been observed several times in weathered iron grains from Elsinora, partly in grains altered to limonite but especially in those altered to magnetite. But the graphite appears here also to be primary and not the product of weathering or the breakdown of cohenite.

Native copper is, as shown in the table, very common. It is especially rich, when compared with the average, in samples from Hermitage Plains and Nardoo No. 1. The mode of occurrence is normal, i.e. within an α-Fe-γ-Fe intergrowth in taenite which borders troilite. Along with the copper there are always a few troilite traces roughly similar in their size to the copper grains and included in the iron.

One copper grain in the chondrite from Nardoo No. 1 is associated with a grain of a remarkable green coloured opaque mineral. Either this green coloured grain represents a hitherto unknown mineral phase in meteorites or it may be a copper arsenide-type compound. The latter has been observed in other instances and is of a very light blue-grey colour when freshly polished but copper arsenides generally tend to tarnish, for reasons unknown, to varying shades of green.

The Barratta chondrite contains little or no primary copper but copper as a secondary development in very typical form was observed and is assumed to have originated from chalcopyrrhotite.

The presence of native copper in so many chondrites (ca. 70% of all examined samples) and with such a uniform appearance certainly is of genetic importance. Firstly it should be noted that copper must have formed at quite low temperature such that γ-(Fe,Ni) (which shows unlimited solubility for copper at high temperatures) was unable to dissolve any more copper. The copper is not to be thought of as an exsolution product but rather as a decomposition of a copper-bearing sulphide which, due to the loss of sulphur, forms γ-(Fe,Ni), then Cu and finally the small troilite grains. But even so it is remarkable how an iron-sulphide could form adjacent to the highly chalcophile copper.

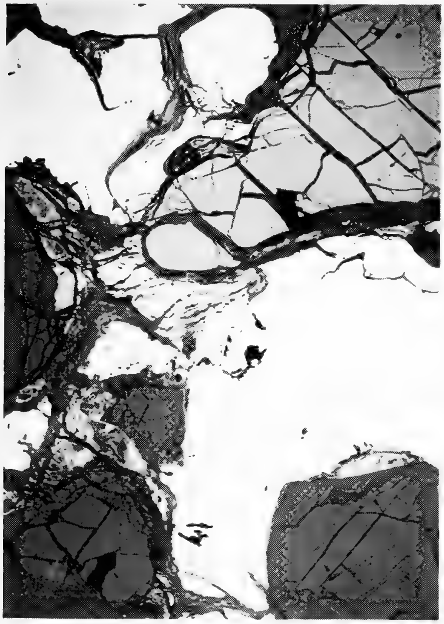
Chalcopyrrhotite demands a more accurate treatment since it was never recognized in earlier meteorite examinations. First with respect to the name, the old and discredited terminology was revived by Borchert (1934), and used for the high-temperature form of chalcopyrite with a little dissolved FeS. It is easily prepared from a mixture almost corresponding chemically to cubanite ($CuFe_2S_3$) and can be preserved if quickly cooled. It occurs, for example, naturally in basalt inclusions. Some nickel deposits of high formation temperature in norites carry it too. In the latter case it is stabilized by its nickel content as shown by pentlandite-rich decomposition products. On the whole the name is unfortunate since the composition, the properties and the occurrences vary markedly. "Undercooled high temperature mix-crystal of (Cu,Fe,Zn,-Ni,Sn,....)S with a sphalerite structure"[1] would be more adequate, but fairly clumsy. In the present study it appears to be the above mixture in most cases, being more or less analogous to cubanite. Yet it may well be that in a more general sense the later-discussed (see page 49), much darker brown coloured composition "c", also belongs here. In many cases the chalcopyrrhotite exhibits in the meteoritic occurrences, as well as in the terrestrial ones, abundant exsolution of "valleriite" with the latter's extremely strong and characteristic anisotropy. Just recently this determination has become doubtful since the discovery of *mackinawite* (a FeS with tetragonal layer structure) whose optical properties are strikingly similar to those of valleriite.

Conceivable, in fact most probable, that in this and in the author's earlier works, many mineral grains named as valleriite are really mackinawite.

Microscopically chalcopyrrhotite is easily overlooked adjacent to and within troilite. Its colour corresponds roughly to the average value of troilite and the hardness is very similar too. Under crossed polars the isotropy is easily recognized but a careless observer might mistake it for a basic section of troilite. Of great assistance then are the striking exsolution bodies of valleriite (Figure 13), if present. But with some experience it is possible to recognize chalcopyrrhotite relatively easily in the absence of valleriite exsolution bodies, but only if using oil immersion techniques. Delegate should be especially mentioned here as chalcopyrrhotite as well as valleriite were observed for the first time in an iron meteorite.

Pentlandite—According to the author's previous experience pentlandite is to be expected if, and logically, the meteorite is so rich in sulphur that all iron (except silicate iron) is able to form troilite. At first the metal phase changes its composition towards the nickel-rich taenite (Ni is thus more siderophile than Fe); finally the sulphur binds the nickel also to form pentlandite $(Ni,Fe)_9S_8$.

[1] The presence of copper, suggested by "chalco", is not always necessary.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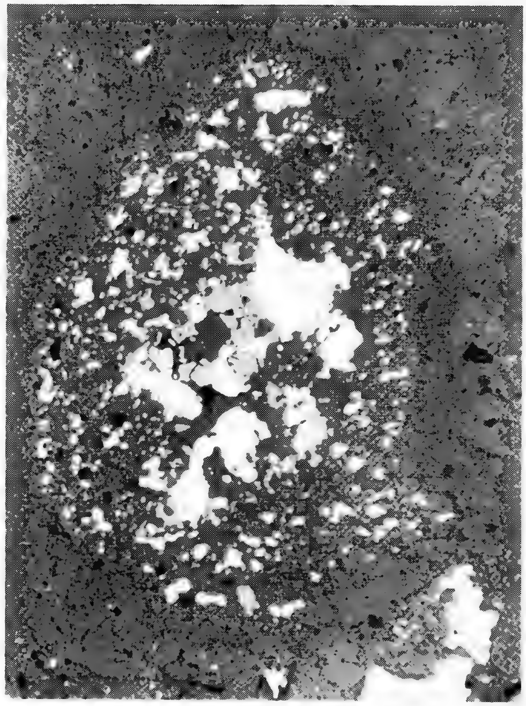
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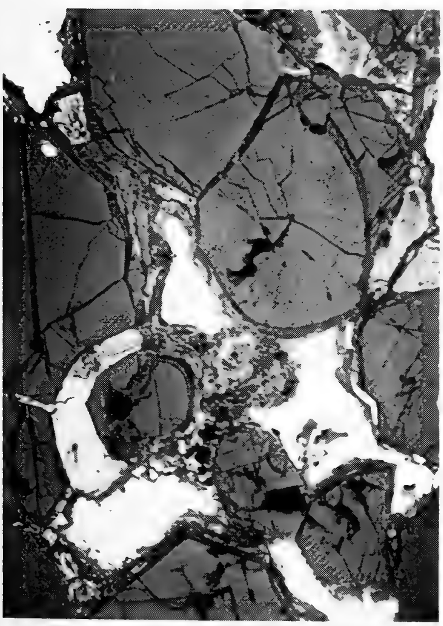
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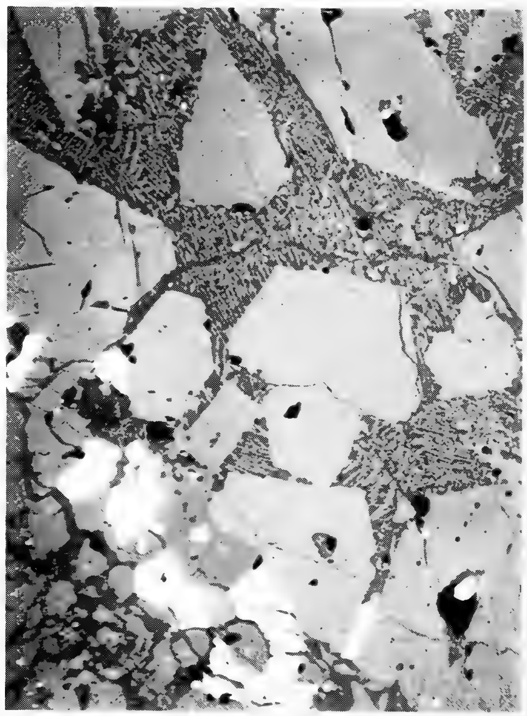
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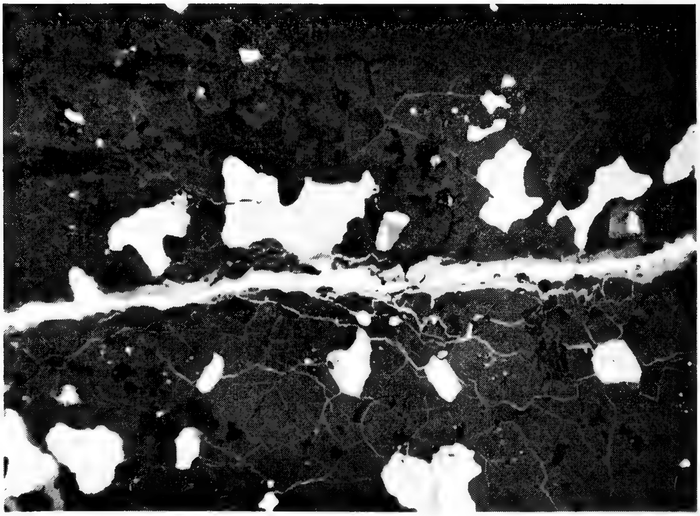

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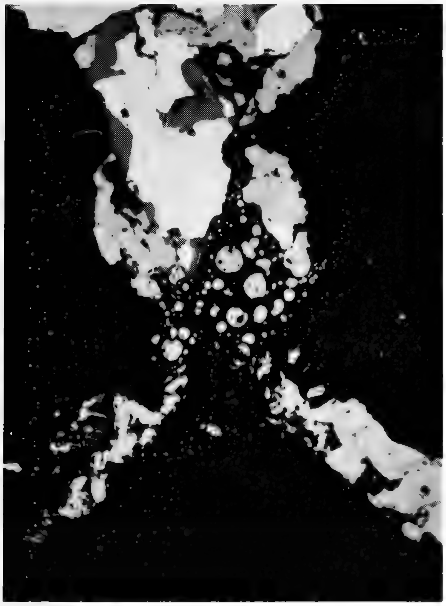

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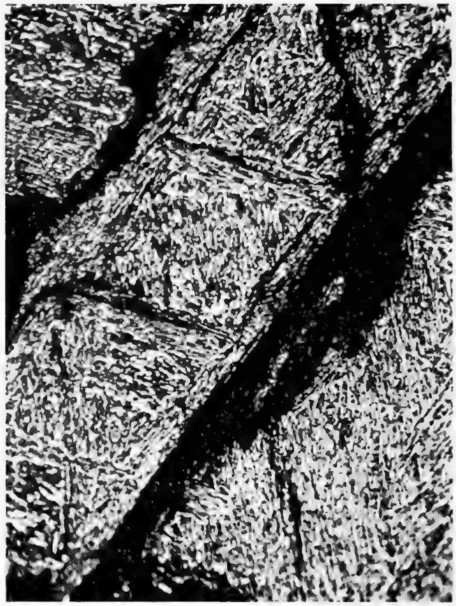

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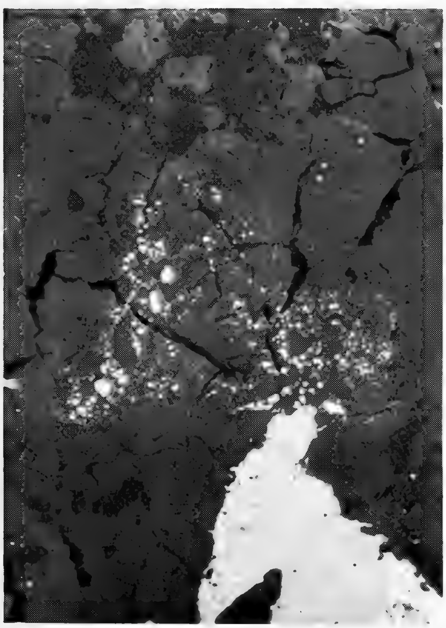

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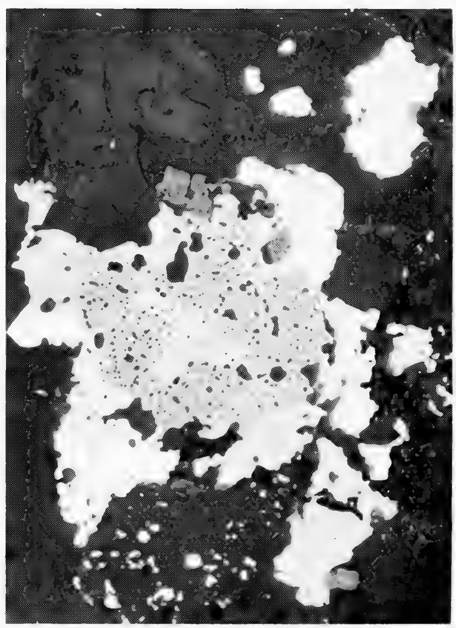

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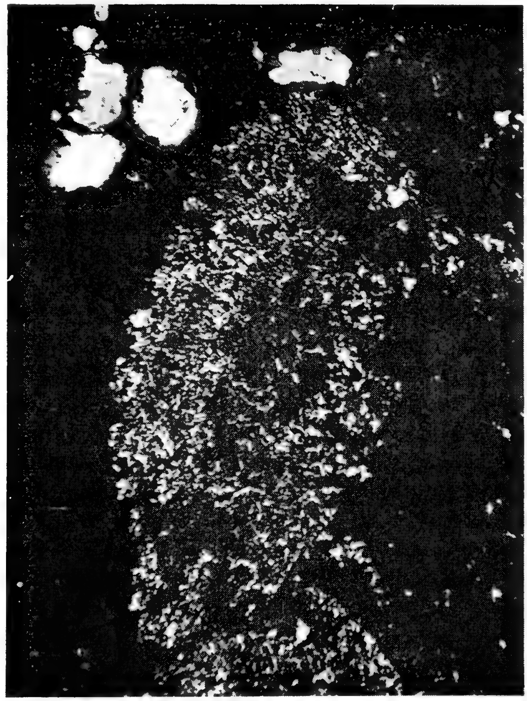

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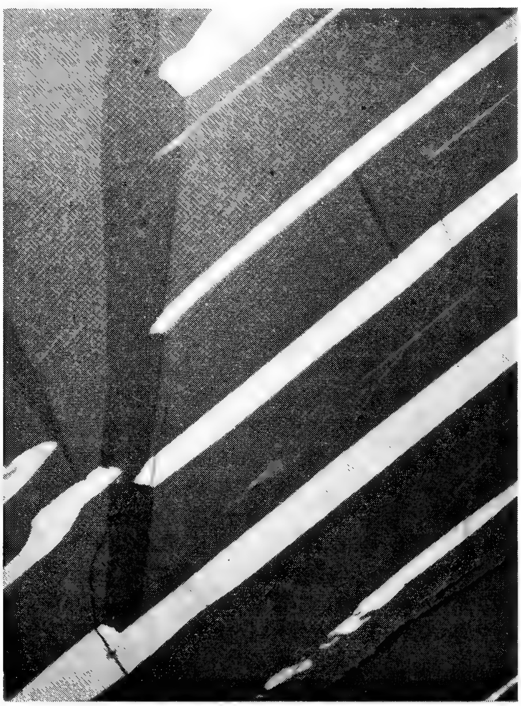

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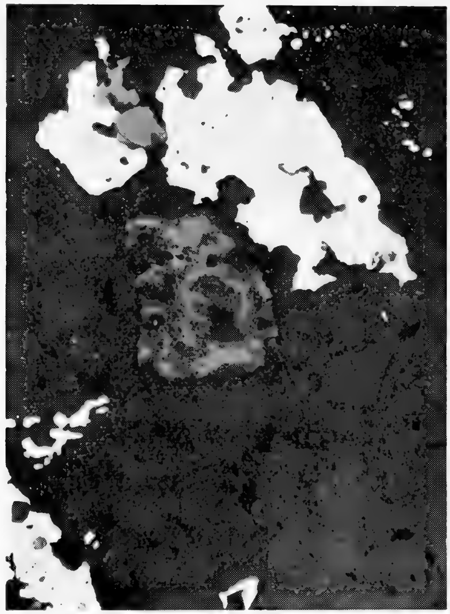

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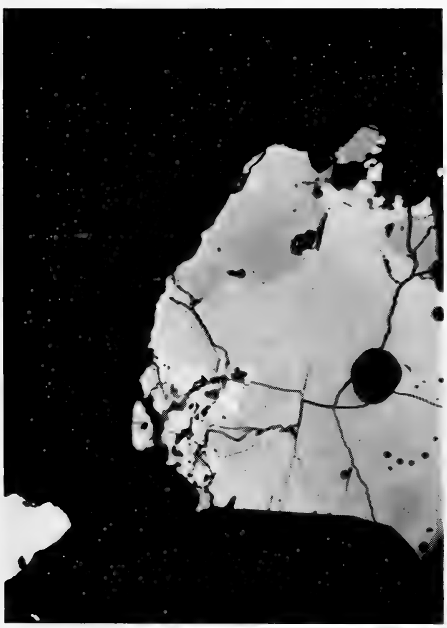

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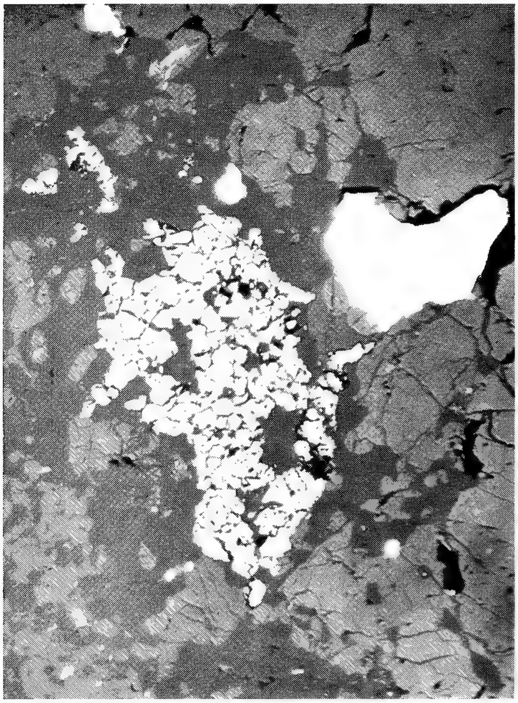

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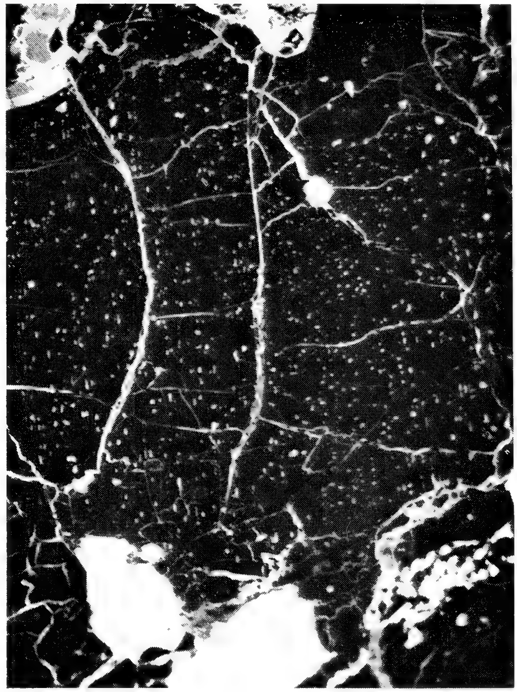

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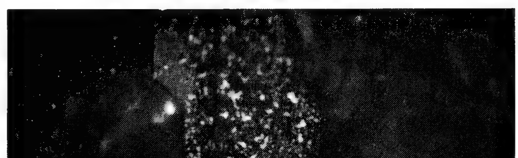

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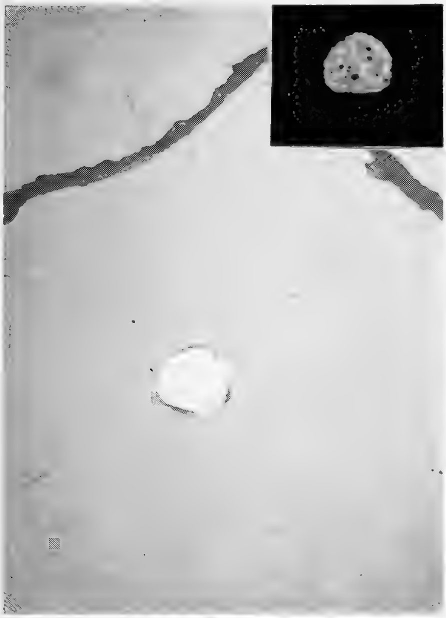

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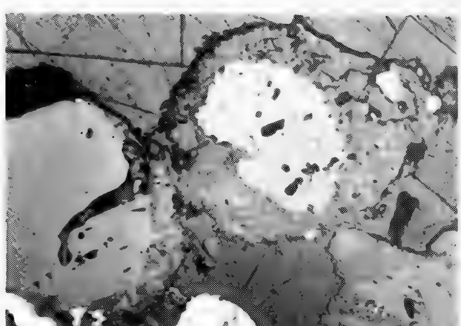

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Like a text-book example this is true for Karoonda, also an Australian example, which was discussed in the author's earlier work. But it can also occur under lower sulphur content conditions on account of unfavourable equilibrium adjustments. For example Elsinora carries pentlandite though only in exsolution lamellae in troilite. Especially worthwhile mentioning is the relatively rich occurrence—here too as exsolution bodies in troilite—in the sulphide nodule from Delegate; even here there is not complete equilibrium in the above sense. Furthermore the forms of the exsolution bodies are more simple than is usual from other meteorites or from the numerous terrestrial occurrences.

Independent of the above, pentlandite occurs very frequently as an intermediate product of terrestrial weathering. Kamazite and partly taenite weather more quickly than troilite. During this process nickel goes partly into solution without entering the contemporaneously-forming magnetite or goethite. But the nickel is almost immediately precipitated as a pentlandite "cement" by the practically intact troilite. The pentlandite then forms thin, slightly lighter crusts at the surface or along fractures of the troilite. In extreme cases the crusts will become so thick that the properties of the pentlandite (e.g. octahedral cleavage) may be determined without doubt, thus eliminating what was first suspected to be millerite. Almost all specimens which are not too deeply weathered exhibit this phenomenon.

Chalcopyrite is very rare in stony meteorites and was determined only once or twice in about 130 samples. On the other hand chalcopyrite appears to be common in the sulphide nodules of iron meteorites and was observed several times in material from Delegate.

Of the approximately fifteen phases newly observed by the author and which have not yet been determined, only the green tarnished mineral (described above under copper) and the dark brown isotropic component, designated earlier (Ramdohr, 1963) as "c", have been found in this investigation. The latter occurs as typical grains in the meteorite from Mt. Browne. It is here so intimately intergrown with native copper that one is inclined to think of it as a copper compound.

Of the oxide minerals *chromite* demands a more intensive treatment. In an earlier publication (Ramdohr, 1963) it was shown that this mineral may appear in one and the same meteorite in completely different types and with different properties. Yet they point to the fact that a genetic interpretation should be very complicated and that all interpretations of meteorite genesis have to take this into account. Following an earlier publication (Ramdohr, 1962) the author intends to distinguish, in slightly more detail, seven clearly defined types.

"Coarse" chromite is apparently the only type which has been observed until now, although sometimes it represents only a fraction of the total mass. It is relatively coarse with a grainsize up to 1/10 mm and larger, but usually only one-quarter thereof. It always exhibits idiomorphic form towards iron and troilite but, with the exception of Forest Vale and chromite-rich chondrules, is mostly quite xenomorphic towards silicate minerals (Figure 15). The "coarse" chromite can develop very irregular shapes, for example, a coarse intergranular mass between silicates with very fine exsolution bodies of ilmenite so that *one* uniform individium is still present. Exsolution bodies in chromite are usually restricted to meteorites whose temperature of formation was fairly high as measured by other criteria. Differences in the composition are easily noticeable by means of the relative frequency of internal reflections (changing amounts of FeO and/or MgO). Material from Barratta is especially high in MgO. Sometimes "coarse" chromites are already fractured during their cosmic history (Mt. Browne) but occasionally recemented by heating. In two cases, clearly-separated, loosely-porous outer zones occur (Figures 16, 17), the outer zones in both instances exhibiting idiomorphic outlines even towards the silicates. This is in contrast to the other "coarse" chromites of the same meteorite.

"Aggregate" chromites consist of loose to compact accumulations of idiomorphic or xenomorphic grainlets of roughly equal size. In single cases the aggregates tend to bake together. It is possible that such baked aggregates may be a preliminary step towards the formation of the "coarse" chromites. But this consideration is not very probable since "aggregate" chromites, baked or unbaked, occur in many instances without transition in the very same meteorite, alongside typical coarse chromites. Well-developed "aggregate" chromites are present in the Barratta, Elsinora, Forest Vale, Mt. Browne, Nardoo and Rowena (Figure 18) meteorites.

"Scattered" chromite (also dust-chromite) refers to chromite grainlets, a single grain of which is as large as the component of the "aggregate" chromite, the single grains being

roughly evenly distributed in small amounts throughout the whole meteorite. These grainlets are easily overlooked and are more common only in Coolamon and Nardoo No. 1.

"Pseudomorph" chromite includes chromite which originates during the breakdown process (observable in all stages) of chrome-rich silicates. A small amount is traced back to chrome-diopside; by far the greatest amount to a silicate with an originally fairly high reflectivity. On decomposition it supplies about 25 per cent of the chromite area (i.e. roughly one-third of the weight). The remaining portion is a weakly (feldspar-like) reflecting silicate mineral. The nature of the original primary material is still unknown but is being further studied. Typical examples of this type of chromite are supplied by Adelie Land (Figure 19) and Narellan. The material consists of roughly even-sized small grainlets, apparently idiomorphic. On account of the fineness of grain they exhibit a relatively light brown internal reflection.

"Exsolution" chromite in contrast to that previously described, originates as a typical exsolution product with very even distribution, from the small amount of chromite dissolved in olivine. Crystallochemically this solution should be understood in an analogous fashion to that of magnetite in olivine which has been known for some time. The (111) oxygen layers of the spinel structure correspond to the close-packed oxygen layers in the pseudo-hexagonal layer of the olivine. Barratta, Elsinora, Gilgoin and Rowena material carry such chromite in typical form (Figure 20), though not very spectacular in form, size or frequency.

"Myrmekite" chromite, in which the chromite shows a myrmekitic intergrowth with silicates, was not present. It appears to be restricted to mesosiderites.

"Chondrule" chromite is the term applied to the idiomorphic chromite of certain chondrules. With respect to grainsize it compares with coarse chromite but it shows sharper developed crystals which are also idiomorphic towards silicates. Further it appears to be characteristic that the internal reflections are much lighter, i.e. the MgO component is fairly large. It was observed in specimens coming from Mt. Browne and Nardoo, in the latter in two varieties.

As an appendix the chromite in the pallasite from Molong should be mentioned. It appears to be the first chromite observed in a pallasite. A very happy incident caused it to be in the first pallasite sample examined by the author. The chromite occurs as a bean-shaped, rounded single grain of almost 2 cm in the longest dimension (Figure 21) surrounded by xenomorphic iron and rounded olivine together with some schreibersite and troilite. The grain contains numerous very long but extremely thin exsolution lamellae (Figure 22) of a silicate-like reflecting mineral and ilmenite plus single minute melt drops (Figure 22 below) of troilite with pentlandite which were locked in during crystallization. This chromite exhibits relatively well-developed cleavage fractures (otherwise very rare in chromite) and, very rarely, internal reflections. This suggests a very high FeO content.

Ilmenite, a frequently overlooked, common though sparse component of many stony meteorites (possibly in 60% of all cases and >70% in typical chrondrites), was observed in nine of the Australian specimens. The occurrences of Hermitage Plains and Nardoo are especially beautiful and rich. Mt. Browne contains, in addition, rutile produced by the peculiar reduction process $FeTiO_3 - O = Fe + TiO_2$ (see Ramdohr, 1963, p. 2028). In the Binda occurrence it forms overgrowths of minute but numerous crystals (up to 12 on one grain in one cross section plane) on chromite, and is at least partly crystallographically oriented. In many cases handsome pressure lamellae are developed (Hermitage Plains, Adelie Land, Figure 24). Nardoo carries ilmenite crystals, sometimes embedded in iron, in which the numerous, well-developed faces cover the whole of the crystal. These were certainly formed while in suspension. In one instance ilmenite in the melt crust was transformed into pseudobrookite (see page 46).

Magnetite as mentioned above (page 46) is very rare in normal chondrites and no magnetite was observed that could not be interpreted as a weathering product of terrestrial origin. The skeletal magnetite always present in the melt crust is naturally excluded.

Spinel, although several times mentioned as a meteorite component, appears to be very rare here. An assumed spinel with numerous exsolution discs of ilmenite observed by the author, proved to belong to the spinel family but is a new mineral, Mg_2TiO_4. On the other hand, Forest Vale material appears to contain unambiguous spinel. Less reflectant than the above mineral, it exhibits light brown internal reflections, a rounded shape and an indication of idiomorphism. As Figure 23 shows clearly, the material is not homogeneous and possesses quite different reflectivity within the same grain.

Discussion

The material here under investigation does not (by chance) contain any specimens of unusual type, as for example the "carbonaceous chondrites" or the interesting intermediate members of the mesosiderites and chondrites. The very unusual case from Karoonda (South Australia) has just been discussed exhaustively by Mason and Wiik (1962) and is contained in the present author's summary (1963).

The following points are made in summary form:

1. An accepted rule that taenite occurs only in chondrites if the relative proportion troilite:iron is high does *not* hold although the explanation would be trivial. This fact shows that the equilibrium conditions in the stony meteorites are generally very incomplete, and this is also the case for those components which are considered to react readily.
2. Schreibersite is by no means a rarity in chondrites.
3. The fact that graphite was only once observed does not completely agree with its more frequent occurrence as indicated by the earlier statistics.
4. The very frequent occurrence of native copper, and indeed almost ubiquitous development adjacent to α-Fe and γ-Fe, is surprising since γ-(Fe,Ni) dissolves Cu to a large extent, at least at higher temperatures. Therefore copper must have been precipitated during its paragenesis at a fairly low temperature—either as exsolution from γ-Fe or by decomposition of a compound—but in both cases the texture does not reflect this. There is no indication that larger amounts of copper have remained in solution. The visible copper corresponds roughly with the total analytically determined copper.
5. The multiple forms of troilite—not in the invariably xenomorphic development of the aggregates, but in the internal structure—are hardly related in any known way to the behaviour of the remaining components. An occasional undular extinction caused by local pressure is by no means always present where it might be predicted, nor should one, on the other hand, postulate a pressure influence from its presence. Fine-grained "recrystallization" (secondary troilite in the sense of Hentschel) need not necessarily be connected with some previously present condition of internal stress of the earlier troilite.
6. "Chalcopyrrhotite" proves to be more frequent after an intensive search than was previously assumed by the author, and even now the possibility exists that the smallest grains were overlooked.
7. The above—though with some restrictions—is valid also for valleriite. It is feasible that some if not most of the "valleriite" will prove to be mackinawite (tetragonal FeS).
8. The few troilite nodules in iron meteorites tested by the author often contained chalcopyrite, partly as an unmistakeable exsolution process from troilite. Since recent experimental data (Gehlen and Kullerud, 1962) of the system FeS—$CuFeS_2$ have become available a minimum temperature (3% Cu at 700°C) is indicated for the solidification of these troilite nodules. On account of different considerations similar assumptions were obtained for the formation temperature from the few terrestrial occurrences where chalcopyrite could be definitely determined as exsolution bodies in pyrrhotite (Igdlokunguak, and some deposits in Bushveld).
9. The wide distribution and variability of chromite is also remarkable. It would be of special interest to trace the changing role which is played by chromite in several chondrules and to explain this genetically.
10. The following question may be posed: Is the "aggregate chromite" an early formation step for the formation of "coarse chromite"?
11. The phenomena of the melt crust should be examined systematically. Though the question is of little importance with respect to the origin as well as to the chemistry of the chondrites, it is of importance for the study of very rapidly occurring heat metamorphism. Furthermore the question is of vital importance for the assessment of the widely-distributed occurrences of spheroidal magnetite grainlets (partly with well-developed skeletal textures) in unmetamorphosed marine sediments (from the Zechstein to

the deep core drilling in subrecent deposits on the abyssal floor of the oceans) —the assessment of whether these magnetites are the products of meteoric showers or relics of the finest volcanic ash.

12. The variability of the chondrules is by no means embraced by the studies hitherto. The establishment and the easily-understood definition of "basic types" and "subgroups" appears to be an urgent matter. The same holds for the subsequent statistical assessment of the single meteorites as well as their groups. Reflected light appears to be a very convenient aid for this purpose.

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It was during a visit to Sydney (from May to September 1962) that the author had the opportunity to carry out this ore microscopical study on meteorites from the collection of the Australian Museum in Sydney. The material consisted almost exclusively of meteorites which had fallen in New South Wales or were found in that State.

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No.	Locality	Type	Remarks	Fusion etc.	Elements						Sulphide					Oxide			Secondary	Fusion crust
					α-Fe	γ-Fe	Plessite	Fe_3P	Graphite	Cu	FeS	Chalco-pyrrhotite	Valleriite	Pentlandite		$FeCr_2O_4$	$FeTiO_3$			
1	Adelie Land		special chondrules		X	X	Pl			X	X	X				X	X			
2	Barratta No. 3	Black chondrite		spontaneous fusion, gas bubbles	X	X		X		X	X	X	X			X	X		!	
14	Binda	Achondrite	few grains of opaques	fractures	X						X!					X!	X			
15	Coolamon		not yet described	fractures, spontaneous fusion	X	X					X	X	X			X!	X			
3	Delegate	Sulphide nodule from iron			X			X			X	X!	X	X	also chalcopyrite $CuFeS_2$	X			!	
4	Elsinora		weathered	fractures	X	X	Pl		X	X	X!	X	X	X		X!			!	
5	Forest Vale		very fresh	gas bubbles	X					X	X	X				X!		Spinel		
6	Gilgoin No. 1	Bronzite-chondrite			X	X	Pl			X	X!					X!	X		!	
9	Hermitage Plains	Grey chondrite		spontaneous fusion	X	X	Pl			X!	X	X	X			X	X!		!	
7	Molong	Pallasite	severely rusting		X		Pl	X		X	X					X!			!	
8	Mt. Browne		very fresh		X	X				X	X	X	X		?C	X		Rutile		
10	Mt. Dyrring	Pallasite	strongly rusting		X	X!		X			X!						X		!	
12	Nardoo 1		both very different from each other	spontaneous fusion	X	X	Pl			X!	X!					X!	X!		!	Pseudo-brookite
16	Nardoo 2			spontaneous fusion	X		Pl	X			X					X	X		!	
13	Narellan		almost fresh		X	X					X	X				X	X			
17	Rowena		fell 1962		X					X	X	X!	X			X				!

Explanation of Figures

Fig. 1

Pallasite, Mt. Dyrring, N.S.W. Typical pallasite texture. Large rounded olivine grains, connected by iron which has been forced into interspaces and also by troilite (in the present case crescent shaped). Grey material is limonite, originated by terrestrial weathering. x 6

Fig. 2

Pallasite, Molong, N.S.W. The composition is more complex and the Fe-proportion relatively higher than in Fig. 1. Troilite is here more common, decomposed and fairly dark grey; schreibersite is white with multiple fractures; the light grey, severely fractured mineral is a relatively very large grain of chromite. Limonite is again present. x 6

Fig. 3

Adelie Land, Antarctica. Part of a chondre, consisting of well-developed crystals of olivine with filling of the interstice of delicate pyroxene skeletons in glass or feldspar. The outer rim of the chondrule contains much troilite. x 150

Fig. 4

Adelie Land, Antarctica. Ore-rich chondrule. White: iron; light grey: troilite; middle grey: chromite. The grainsize in the centre of the chondrule is considerably larger than in the outer zone. x 150

Fig. 5a

Elsinora, N.S.W. Fracture melting, healed by iron. The large lamellae in the neighbourhood, exhibiting a lighter colour, are predominantly troilite. Further present are two different silicates and formation of branching limonite by weathering. x 75

Fig. 5b

Elsinora, N.S.W. Fracture melting especially marked by strings of troilite drops. White: iron; dark grey: silicates. x 150

Fig. 5c

Elsinora, N.S.W. Fracture melting marked by fine troilite drops. White: iron, strongly rusted; black: silicates. Note: the fractures in 5a, 5b, 5c are all roughly parallel. x 250, oil immersion.

Fig. 6a

Nardoo, N.S.W. ''Spontaneous melting'', here relatively large. The silicates are only partly molten, but their extent is well marked by the globules of troilite (partly with iron). x 50

Fig. 6b

Barratta, N.S.W. ''Spontaneous melting'', in typical forms: globules of troilite, partly with iron. Some of these globules contain smaller globules of glass. The larger areas of iron, respectively troilite, are not changed. x 250, oil immersion

Fig. 7

Forest Vale, N.S.W. Peculiar droplets of molten silicates are present in iron, troilite and, to a lesser extent, in chromite. Probably a ''spontaneous melting'' which affected only silicates which melt easily. x 150

Fig. 8

Mt. Dyrring, N.S.W. Plessitic iron from pallasite. Micro-Widmannstatten-texture developed by weathering. Taenite is preserved, kamazite is weathered. x 250, oil immersion

Fig. 9

Delegate, N.S.W. A very coarse grain of troilite, cut approximately || (0001). Orientation of the twin lamellae according to three directions. Polars approximately crossed. x 250, oil immersion

Fig. 10

Hermitage Plains, N.S.W. Large xenomorph grain of troilite, tectonically strained and therefore exhibiting an undulatory extinction. Black portions, partly with internal reflections, are silicates. Polars approximately crossed. x 250, oil immersion

Fig. 11

Large aggregate of troilite, composed of even, round grains of different orientation, probably recrystallized material. Polars crossed. x 250, oil immersion

Fig. 12

Barratta, N.S.W. Cloud of fine-grained troilite in silicates. The silicates are very dark; top right: three rounded grains of iron, respectively iron + troilite. x 150

FIG. 13

Mt. Browne, N.S.W. Aggregate of differently orientated troilite grains. Chalcopyrrhotite with inclusions of exsolution bodies of valleriite (white, respectively almost black), surrounding silicates are black.
x 250, oil immersion

FIG. 14

Ehole Meteorite. ''Valleriite'', extraordinarily coarse-grained, adjoining chalcopyrrhotite in troilite. The same area in two different positions, i.e. turned 90° against polarizer. x 600, oil immersion

FIG. 15

Hermitage Plains, N.S.W. Clover-like shaped grain of ''coarse chromite'', xenomorphic against the silicates.
x 250, oil immersion

FIG. 16

Forest Vale, N.S.W. ''Coarse chromite'' with a porous outer zone. It cannot be stated whether the porosity is primary or secondary. Pure white: iron; grey-white: troilite; medium grey: chromite (but different in a compact grain if compared with a porous grain). A higher and a lower reflecting silicate. x 150

FIG. 17

Gilgoin, N.S.W. Aggregate of idiomorphic chromite grains with porous outer zone; to the greater extent embedded in iron with a little troilite. Silicates are very dark grey. x 150

FIG. 18

Nardoo, N.S.W. ''Aggregate'' chromite from an aggregate; here xenomorphic, sometimes slightly baked grains. White: iron; dark grey in two clearly distinct hues: silicates (pyroxenes, respectively plagioclases). x 150

FIG. 19

Adelie Land, Antarctica. Pseudomorphic chromite, consisting of finest grains which originated from a silicate which is only very little preserved and relatively high reflecting (visible in the south-east corner). The lower refracting silicate which formed due to the decomposition is not visible under oil immersion here.
x 250, oil immersion

FIG. 20

Elsinora, N.S.W. Exsolution chromite. Almost the whole field is occupied by an olivine grain which carries very evenly distributed exsolution bodies of chromite. White: troilite. The grey fracture fillings are ''limonite''. x 250, oil immersion

FIG. 21

Molong, N.S.W. Large bean-like body of chromite in pallasite. Very clear cleavage || (111). The strongly fractured area is schreibersite; white: iron; dark grey: olivine. x 10

FIG. 22

Molong, N.S.W. Detail of previous figure (Fig. 21). A small inclusion of sulphide in chromite. The black streaks are exsolution bodies of an unknown nature, but they are reflecting as silicates would. Ilmenite lamellae occur in the very same manner within the same sample. The troilite inclusion is once more presented on the small photo at the side, this time with an especially high contrast. Now the pentlandite grainlets are recognizable which are present everywhere within the troilite. x 500

FIG. 23

Forest Vale, N.S.W. Spinel as core of a ''miniature'' chondrule, next to it two different silicates—strongly scratched embedding medium. White: iron; grey-white: troilite; medium grey, with a reflection intensity very similar to spinel: chromite. x 150

FIG. 24

Adelie Land, Antarctica. Large grain of ilmenite with well-developed twin lamellae. An inclusion of troilite which shows also effects of strain. The grey-white, black surrounding consists of silicates. A large grain of iron is pure white. Polars approximately crossed. x 250

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A Contact Metamorphic Axinite Paragenesis at London Bridge, Near Queanbeyan, N.S.W.

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Abstract—Axinite occurs with epidote, tremolite and calcite (all of which have been analysed) in a narrow band within a group of calcareous shales and limestones, now typically epidote-amphibole-(calcite) hornfelses and calcite marbles, near an intrusive quartz-feldspar porphyry. The axinite is richer in Mg (4·20% MgO) than others recorded and its low refringence (α 1·659; γ 1·668) extends the known range for this mineral. The assemblage axinite-epidote-tremolite-calcite is shown to be a characteristic product derived from calcareous shales and marls in the albite-epidote hornfels facies where small amounts of boron are available.

Introduction

A natural arch of limestone, known locally as London Bridge, crosses Burra Creek, a tributary of the Queanbeyan River, at a place some 2½ miles NW of Burra and 11 miles SSW of Queanbeyan. The area was mapped by J. J. Veevers (1951) while an Honours student in the University of Sydney and Dr. Veevers has kindly given permission for use to be made of his thesis in the preparation of these geological notes. Near London Bridge a sequence of non-calcareous subgreywacke sandstones and shales, some six to eight thousand feet thick, overlie unconformably Ordovician low-grade schists and phyllites. Above the sandstones and shales, the Silurian succession is marked by lenticular beds of limestone (the arch occurs in one of these) associated with calcareous subgreywackes, siltstones and marly shales. This calcareous sequence has a maximum thickness of 1,500 feet and, on palaeontological evidence gathered by Veevers, the London Bridge limestone is of Wenlock age. Intrusive quartz-feldspar porphyry bodies are apparently associated with a thick pile of acid volcanic rocks which lies above the limestones. At London Bridge acid material has invaded and locally metamorphosed the calcareous rocks. It is in an exogenous contact zone thus formed that axinite occurs.

Veevers has, in fact, recognized two porphyry bodies intruding the calcareous sequence. The Keewong Foliated Quartz Porphyry has a roughly concordant relation with the country rocks but details are now obscured as a result of post-consolidational deformative action. This intrusion extends well beyond the confines of the London Bridge area but its precise limits are not known. The London Bridge Massive Quartz Porphyry is, on the other hand, largely restricted to the outcrop area of the Silurian calcareous rocks near London Bridge and occurs as isolated small bodies, irregular in outline, often discordant with the sediments. It has locally invaded the Keewong body and appears to have escaped extreme deformation. A zone of contact-altered sediments, variable in surface width from about 50 feet to more than 500 feet, outcrops along the eastern margin of the Keewong porphyry. The massive porphyry is closely associated with hornfelses WSW and SW of London Bridge but elsewhere in the vicinity it occurs with limestones outside the recognized contact zone. Field evidence indicates that the main thermal influence was connected with the larger Keewong body. In this case there seems to have been little assimilation of country rocks by the porphyry but, on the other hand, a distinct zone of contaminated material was observed by Veevers within the London Bridge porphyry. This latter endogenous facies is local and patchy in its distribution; some contacts against calcareous sediments display few signs of such mutual reaction.

Petrography

Keewong Foliated Quartz Porphyry

This body consists typically of bluish-grey material forming prominent "tombstone" outcrops, determined by the ubiquitous crude foliation. Small phenocrysts (ca. 2 mm diam.) of quartz and feldspar occur in a fine-grained matrix. All gradations exist locally from types with dominant quartz to others with a preponderance of feldspar phenocrysts. Microscopically, the quartz phenocrysts are strongly embayed and all display undulose extinction. Many are shattered and pass into crudely aligned aggregates of small grains. Patches of granular calcite and quartz commonly lie in the foliation planes adjacent to relic phenocrysts. Sodic oligoclase ($An_{15\text{-}20}$) is the typical phenocryst feldspar. Its high 2V and positive sign suggest low-temperature adjustment. Many grains are twinned (with albite law commonest, Carlsbad and pericline less abundant) and all are clouded with fine inclusions —white mica and carbonate alone being recognizable visually. Post-consolidational action has led to the fracturing of many feldspar phenocrysts with the development of irregular aggregates. Some phenocrysts, not so intensely fractured, are traversed by bands about 0·2 mm wide of fine feebly pleochroic pale greenish mica flakes arranged roughly in accord with the crude foliation in the adjacent groundmass regardless of the orientation of the bands. The groundmass of the porphyry now consists chiefly of fine granular quartz, white mica and chlorite with a little calcite and opaque material (apparently haematite/limonite after magnetite and/or pyrite). Most of the original biotite has been shredded and replaced by pale chlorite. The high content of white mica in parts of the groundmass suggests the former presence of alkali feldspar but unaltered relics are extremely rare.

London Bridge Massive Quartz Porphyry

This is characteristically porphyritic in quartz, feldspar and, less often, biotite. Quartz phenocrysts up to 4 mm in diameter tend to be euhedral where not resorbed. Compared with the strained phenocrysts in the main (Keewong) porphyry the quartz here is relatively untouched by deformation though some exhibits undulose extinction. The feldspar phenocrysts, typically subhedral and as much as 3 mm across, are extensively altered to clays. Some appear to be oligoclase, others are too altered to allow of sure identification. A few biotite phenocrysts (3 mm) occur but most of the biotite, which never seems to exceed 10% of the rock, appears as small flakes in the base. Much of it is altered to green chlorite but where original mica has been preserved it is strongly pleochroic from light yellow to dark green. Apart from minor opaque phases, biotite represents the sole primary dark mineral. The fine-grained groundmass contains quartz and subordinate altered feldspar as well as scattered biotite. Some examples show micrographic quartz-feldspar intergrowths in the groundmass.

Where the London Bridge porphyry has assimilated calcareous sediments it acquires a distinctive character. Addition of material is marked first by the development of small amounts of greenish actinolite. With more lime the amphibole content is enhanced and aggregates of epidote granules appear—especially in the feldspars. As actinolite and epidote become more prominent the quartz content declines. Very little quartz appears in the most modified types of porphyry which consist largely of epidote and amphibole, in roughly equal proportions, and feldspar. The remains of feldspar phenocrysts in such rocks are ragged and carry minute inclusions as well as clusters of epidote granules. Between the inclusions the feldspar ($An_{6\text{-}10}$) is clear and unzoned. Small amounts of untwinned clear granular albite occur interstitially in the groundmass. As well as being included in feldspar, epidote is scattered throughout as aggregates of anhedral grains of variable size (up to 0·5 mm). The larger grains are slightly pleochroic from colourless to pale yellow with $2V_x \approx 80°$ and $\gamma - \alpha \approx 0{\cdot}038$. The amphibole appears as subhedral units, up to 1 mm long and with ragged margins, or as bundles of fibres in subradiating groups or, again, in fine decussate patches. Typically the amphibole has $Z \hat{} c = 21°$; $2V_x \approx 70°$; X = colourless to pale dirty yellow, Y = yellowish green, Z = light bluish green. Small brownish granules of accessory sphene are found throughout the groundmass but biotite, the typical dark mineral of the normal porphyry, does not appear in the contaminated facies.

Exogenous Contact Rocks

The main contact zone associated with the Keewong porphyry is marked by fine-grained green or yellowish-green calc-silicate hornfelses. Some display signs of bedding but most are fairly massive. Purer limestone bands have been recrystallized to fine marble. The calc-silicate rocks appear to have resisted deformation more effectively than the adjacent porphyry. Some dislocation occurred in the hornfelses but within the country rocks mechanical action was more pronounced in the marbles and along the marble-calc-silicate hornfels boundaries. Throughout most of the contact zone there is a notable uniformity of mineral assemblages developed in rocks of similar composition. The calc-silicate rocks consist principally of tremolite/actinolite and epidote or these phases with diopsidic pyroxene. Calcite is not usually abundant and quartz rarely exceeds the status of an accessory mineral. The dominant phases are arranged irregularly with discrete patches rich in amphibole and others of epidote or diopside. Amphibole is normally present in decussate groups with some individuals as much as 0·5 mm in length though most are finer. In some cases where pyroxene is present amphibole has formed overgrowths the *c*-axes of which lie coincident with those of the host pyroxene. The amphibole of the hornfelses is weakly pleochroic from colourless to pale green and has $\gamma = 1{\cdot}642$, $2V_x \approx 80°$, $Z\hat{}c = 22°$. Yellowish amphibole adjacent to occasional scattered and altered pyrite (?) grains probably owes its colour to staining. Epidote in the hornfelses is granular and nearly colourless with $2V_x \approx 85°$, $\gamma - \alpha \approx 0{\cdot}038$. Grains of nearly colourless pyroxene ($2V_z \approx 60°$), where present, attain a maximum size of 0·4 mm but like the other phases are usually finer. The marbles need not be described in detail. Typically, they are granoblastic calcite rocks in some of which calcite grains show dimensional preferred orientation; some carry accessory amphibole and/or epidote.

Whereas the contact zone as a whole is characterized by amphibole-epidote or amphibole-epidote-diopside hornfelses and calcite marbles, two variant metamorphic types are developed locally. Of these, that consisting of axinite-epidote-calcite-tremolite outcrops as a concordant band some 10-15 feet wide and 350 feet long within the calc-silicate rocks about ½ mile SW of London Bridge. The band lies some 100 feet from the Keewong porphyry and about this same distance from an outcrop of the contaminated London Bridge porphyry. Gossanous haematite/limonite-tremolite rocks appear in a narrow, discontinuous zone more than 800 feet long, parallel to the axinite band and situated between it and the Keewong porphyry. Over much of its length the gossan serves to separate calc-silicate rocks from a narrow belt of marble in direct contact with the porphyry. Another gossanous body was also found by Veevers in an area of poor outcrop south of London Bridge. This second occurrence seems to lie outside the aureole of the Keewong porphyry but is not far from an outcrop of the massive porphyry. However, it is not clear whether the London Bridge porphyry has more than an accidental association with either the gossans or the axinite rock. The gossanous material, unlike the massive calc-silicate rocks, is marked by strong dimensional preferred orientation of amphibole which occurs as subhedral to euhedral individuals up to 1 mm in length. It is typically clear and colourless and apparently iron-poor despite its present association with abundant iron oxides. In places, amphibole rods are bent or fractured but generally post-crystallization deformation was not severe. Most of the haematite/limonite appears in fine granular aggregates or in dark red-brown earthy patches surrounding amphibole. Larger granules of translucent haematite afford poor uniaxial figures. That part, at least, of the iron oxide material replaced pyrite (?) is suggested by patches with square outlines in the dark parts of the gossans. Little attention has been devoted to these rocks but it seems unlikely that they are isochemical products. Accession of iron, as sulphide (?), probably post-dated the iron-poor amphibole which may have formed, originally with calcite, in a tremolitic marble. The zones, now gossanous, apparently suffered some deformation before the formation of pyrite (?) and its subsequent alteration and probably also before the advent of the London Bridge porphyry.

The axinite-bearing rocks tend to be coarser-grained and more obviously heterogeneous than the typical calc-silicate rocks. Again, calcite is generally more abundant in the axinite rocks. In outcrop and hand specimen they are marked by irregular bands and patches. Patches rich in calcite (practically calcite marble), some several inches across, are often lens-shaped and follow roughly a crude foliation. This foliation is even more marked locally by narrow bands rich in amphibole. Pale brown patches, rich in axinite and epidote, tend to be isolated by the calcite- and amphibole-rich parts. Despite the crude foliation, the axinite-epidote patches appear to be massive.

In addition to axinite, calcite, epidote and tremolite which, in varying proportions, constitute the bulk of these rocks, brownish granular sphene is a minor accessory; accessory quartz occurs rarely. The axinite is colourless in thin section and usually forms subhedral units up to about 4 mm across though grainsize is highly variable. The coarsest material is confined to axinite-rich patches; finer axinite (and epidote) appears where calcite is more abundant. Where axinite is common the crystals tend to be broadly elongate but euhedral outlines are rare because of the clustered growth. Some are poikiloblastic with inclusions of calcite while others carry bladed crystals of epidote. However, many of the axinite porphyroblasts are free from included material. As a rule, cleavages parallel to (100) are most prominent and {011} cleavages less well-defined; cleavages or partings parallel to (110) and (001) have been recognized but these are usually poorly-defined and discontinuous. Twinning is rarely evident but a few crystals show broadly lamellar twinning with composition plane apparently near {011}. Fine lamellar banding, somewhat like twin banding in appearance, occurs in some axinites but careful examination shows this can pass from one grain to its neighbour, regardless of crystallographic orientation. These bands may be curved within a single axinite crystal and where this feature is seen the host displays undulose extinction. Presumably the banding was related to deformative action. Evidence of deformation is commonest in the larger axinites some of which have been twisted and fractured, the fractures usually being filled with granular calcite (Figure 1). Unlike the larger axinites, small elongate wedge-ended crystals of axinite occur disseminated in calcite. These smaller crystals often have ragged boundaries against calcite in contrast to the sharp margins characteristic of the clustered axinite. Optical and chemical data for the axinite are listed in Table 1.

Epidote (see also Table 1) associated with axinite is colourless or slightly yellow-brown and at most feebly pleochroic. It occurs both as euhedral bladed crystals elongated (a few as much as 3 mm) in *b* or as rather ragged smaller porphyroblasts and grains. The largest individuals are developed with the coarsest axinite and, like the latter, these epidotes may be twisted and display undulose extinction. Crystalloblastic relations between epidote and calcite are variable. In places calcite seems to be euhedral against epidote; more commonly the reverse holds. Epidote is usually euhedral against axinite.

The amphibole is always finely fibrous, no larger units such as appear in the normal calc-silicate hornfelses being found in the axinite rocks. Even fairly uniform patches of amphibole as much as 0·5 mm across and 5 mm long seem to consist of bundles of parallel fibres. Most of the amphibole occurs in smaller groups which are commonly twisted round epidote or axinite crystals. Bundles of fibres may be enclosed in the associated phases—especially in the granular calcite. Pale green in hand specimen, the amphibole is colourless to faintly yellow in thin section and barely pleochroic. Further details are given in Table 1.

The irregular distribution of granular cal-

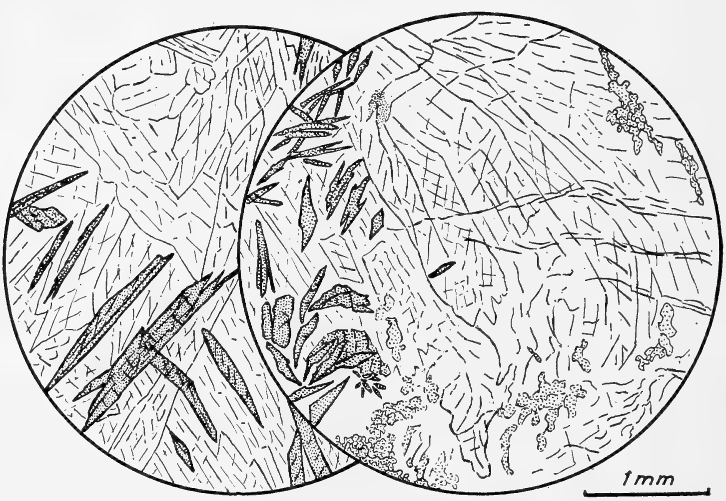

Fig. 1

Axinite-bearing hornfels, London Bridge. The fields illustrated are of patches rich in axinite and bladed crystals of epidote. On the right, elongate axinites which have been twisted and fractures contain ragged aggregates of calcite grains. (From sketches kindly prepared by Dr. G. A. Joplin.)

cite has been noted. It varies from a predominating position in the patches and bands which are essentially calcite marble to the status of a minor constituent in the silicate-rich parts of the axinite rocks. Notable contrasts in fabric are related to the calcite content. Some marble patches consist of aggregates of grains showing strong preferred dimensional orientation. Rarely, coarse grains, 5 mm or more in diameter and markedly twinned with lamellae bent, are embedded in these granular patches. It seems likely that the present fabric of the marble patches resulted from recrystallization induced by deformation after the development of the axinite-epidote-calcite-tremolite assemblage. This recrystallization, the results of which seem so evident in the calcite-rich material, must have involved changes in grain-shape only for there are no signs of chemical alteration of any of the phases present.

The association axinite-epidote-calcite-tremolite locally in the exogenous zone at London Bridge appears to be contemporaneous with the epidote-tremolite and epidote-tremolite-diopside hornfelses and calcite marbles. Certainly all of these metamorphic products have been influenced to some extent by deformation which apparently ante-dated the massive porphyry. No high grade of thermal metamorphism was attained within the aureole and the assemblages of the calc-silicate hornfelses are typical of the albite-epidote hornfels facies. The occasional appearance of diopside suggests a higher-temperature subfacies.

Table 1

Chemical and Physical Data for the Constituents of an Axinite-bearing Hornfels, London Bridge, N.S.W.

(Univ. Syd. spec. 18103). Anal: T.G.V.

	Axinite	Epidote	Tremolite	Calcite
SiO_2	42·39	37·90	55·93	
Al_2O_3	17·10	24·19	2·04	
Fe_2O_3	1·68	10·74	1·54	
FeO	5·18	0·32	5·96	nt. fd.
MgO	4·20	0·55	18·46	nt. fd.
MnO	1·38	tr.	nt. fd.	nt. fd.
CaO	20·31	23·69	13·44	55·97
Na_2O	0·06	0·05	0·17	
K_2O	0·03	0·04	0·08	
H_2O+	1·67	1·86	1·99	
H_2O-	0·31	0·55	0·32	
B_2O_3	5·52			
CO_2				43·94
Total	99·83	99·89	99·93	99·91

Calculated Formulae:

	Axinite 32 (O.OH.F)		Epidote 13 (O.OH.F)		Tremolite 24 (O.OH.F)		Calcite 6(O)
B	1·789						
Si	7·962		3·014		7·852	8·000	
Al					0·148		
Al	3·786	4·023	2·268	2·911	0·190		
Fe^{3+}	0·237		0·643		0·163	4·915	
Fe^{2+}	0·814		0·021		0·700		
Mg	1·176		0·065		3·862		
Mn	0·220	6·327		2·117			
Ca	4·088		2·019		2·022		2·000
Na	0·022		0·008		0·046	2·082	
K	0·007		0·004		0·014		
OH^-	2·093		0·987		1·864		
C							2·000

Physical Characters:

	Axinite	Epidote	Tremolite	Calcite
α	1·659	1·722	1·610	ϵ 1·487
β	1·665	1·736		ω 1·660
γ	1·668	1·749	1·632	
$2V_x$	76°	81°	75°	
$Z^\wedge c$			18°	
D	3·19	3·31	2·99	2·70

Chemical Discussion

All four phases present in the axinite-bearing hornfels have been separated and analysed. In each case there is reasonable agreement between the calculated and appropriate ideal formulae. Observed physical characters of the epidote accord with those of similar compositions quoted by Deer, Howie and Zussman (1962). Refractive indices of the amphibole are somewhat lower than might be predicted from these authors' compilation but it should be noted that fluorine was not determined because of the limited amount of sample. The deficiency in the $(OH)^-$ group of the calculated formula may be due to the presence of fluorine. Compositionally the amphibole falls within the range of tremolites accepted by Deer, Howie and Zussman (1963); its Al_2O_3 content is not exceptional for tremolites. Despite its association with phases carrying varying amounts of Fe^{2+}, Mg and Mn, the carbonate is pure $CaCO_3$. The analysed axinite is notable for its high Mg content—higher, in fact, than any previously recorded—and for this reason, as well as its apparent rarity in Australia, will be considered in more detail than the other phases.

In connection with the high MgO value quoted for the axinite it may be mentioned that estimations of FeO, MgO, MnO and CaO were duplicated to check initial results. Despite addition of bromine water to separate Mn with the "R_2O_3" hydroxides it was found that measurable amounts of Mn remained in the filtrates after precipitation with ammonia. Both calcium and magnesium estimations had to be corrected for co-precipitated Mn salts. As a final check, total MnO was determined in a separate portion. The magnesian character of this mineral from London Bridge was noted by Veevers (1951) though its identity with axinite was not recognized at the time. Veevers recorded the following composition: SiO_2 47·66, Al_2O_3 15·85, Fe_2O_3 3·49, FeO 4·87, MgO 4·03, MnO 1·41, CaO 20·18, H_2O 1·09, TiO_2 0·10, total 98·68. Apart from the high SiO_2, which is clearly erroneous due to the undetected presence of boron, there is a general resemblance between this analysis and that given in Table 1.

Milton, Hildebrand and Sherwood (1953) have shown that axinites exhibit a four-fold variability in composition—the variables being Ca, Fe^{2+}, Mn^{2+}, and Mg. The formula $H(CaFeMn)_3Al_2BSi_4O_{16}$ given by these authors recognizes the fact that the Ca content is not fixed as had been accepted following the work of Schaller (1911). They indicate that while up to two atomic positions in the $(CaFeMn)_3$ group may be occupied by Mn (tinzenite = manganoan axinite) the majority of analysed axinites approach the case in which two positions are taken by Ca with the remaining place shared largely between Fe and Mn. The variety of axinite called severginite by Barsanov (1951) and for which the ideal formula is given as $Mn_3Al_2BSi_4O_{15}(OH)$ in fact shows much less Mn/Ca substitution than tinzenite (cf. Serduchenko and Pavlov, 1962). No undoubted cases with Ca = 3 are known; some old analyses list high CaO but the reliability of these is doubtful. Milton *et al.* recognize some substitution of Mg for Ca/Fe/Mn but clearly regard this as minor. A similar view is expressed by Deer, Howie and Zussman (1962, vol. I, p. 324).

Considering the difference in radii between Ca^{2+} (1·06 Å) and Mg^{2+} (0·78 Å) it is unlikely that a complete series through to axinites of the type (Ca_1Mg_2) analogous to (Ca_1Mn_2) in manganoan axinite will be found. Even the most iron-rich axinites known do not quite reach the case (Ca_2Fe_1). From published information it is clear that Mg-substitution in axinite is less extensive than the variability among Ca, Fe and Mn but the present data serve to widen the observed compositional limits. Only one other axinite with comparable Mg content seems to have been recorded. This has 4·13% MgO and is associated with prehnite in a diabase from Silbach, Westphalia (Steinwachs, 1929). Both this and the London Bridge material approximate the case $(Ca_2Mg_{0\cdot5}(FeMn)_{0\cdot5})$. These and other analysed axinites with $(Ca_2(FeMnMg)_1)$ are plotted in Figure 2 to illustrate variability in the common Ca_2 axinites. Only examples with the number of Ca atoms per formula unit within the limits 1·9-2·1 have been used in this diagram though some analyses which fulfil this requirement were rejected because the calculated formulae suggest analytical error or impurity (the commonest defect is excessive Fe^{3+}). A notable feature of the group plotted is that whereas several axinites approach (Ca_2Mn_1) no instances of (Ca_2Fe_1) or (Ca_2Mg_1) axinites are known. Furthermore there is not a simple reciprocal relation between Fe^{2+} and Mn^{2+} in the series. The most manganiferous are practically Mg-free but increase in Fe is usually accompanied by increase in Mg.

Specific gravity and refractive indices of

FIG. 2
Diagram showing variations in Fe^{2+}.Mg.Mn in the formulae of analysed axinites with Ca $\approx$ 2.

the London Bridge material are low compared with those of other ($Ca_2(FeMnMg)_1$) axinites. The refractive indices are, in fact, outside the range previously noted for this mineral and one is drawn to correlate low refringence with high Mg content. Efforts made in the past to connect chemical and physical characters in axinite achieved only limited success. Thus Gädeke (1938) and Harada (1939) attempted to relate refringence and specific gravity to MnO content and claimed evidence of a decline in the intermediate refractive index with increasing MnO. In these studies it was assumed that variations in physical properties are due to changes in the Fe/Mn ratio. Collation of all available data on analysed ($Ca_2(FeMnMg)_1$) axinites suggests that these authors' conclusions are of doubtful value. When refractive indices are plotted against the proportion of Mn in the FeMnMg group there is found to be an apparent slight increase in refringence towards the Mn-rich end. But we have seen that the more Mn-poor axinites are richer in Mg as well as Fe. It is also worth noting that the refractive indices determined by Gädeke for his Mn-poor examples are distinctly higher than those recorded by others for axinites of similar compositions. The present writer believes, on the evidence available, that mutual substitution of Mn^{2+} and Fe^{2+} causes little change in physical properties. One would expect a (Ca_2Fe_1) axinite, if found, to have only slightly higher refringence and specific gravity than the analogous (Ca_2Mn_1) type. On the other hand, the Mg content appears to be of great significance in reducing specific gravity and refractive indices. As one example, if we assume as an approximation that the unit cell volume is constant throughout the group (Ca_2Fe_1)-(Ca_2Mn_1)-(Ca_2Mg_1), the calculated specific gravities based on cell dimensions given by Ito and Takeuchi (1952) are, respectively, of the order 3·33(5), 3·33(0) and 3·15. While the present sample has a lower observed specific gravity (3·19) than the calculated value (3·23) for this composition, the agreement is better (obs. 3·22; calc. 3·23) for Steinwachs' material. It is unfortunate that Steinwachs did not record refractive indices but extrapolation from available data suggests a value for γ about

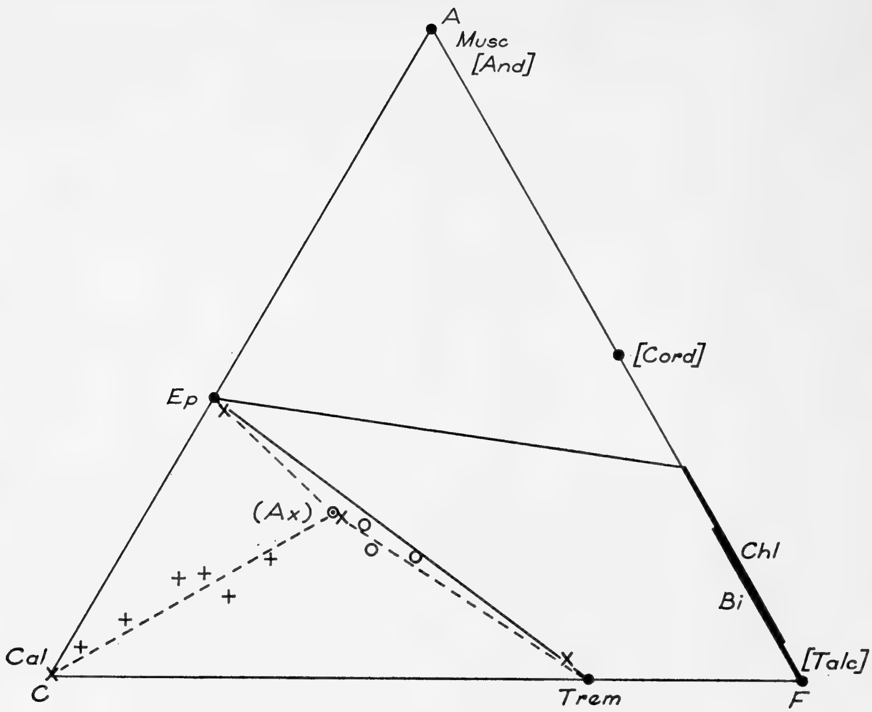

FIG. 3

ACF diagram for the albite-epidote hornfels facies, with calculated compositions of calc-silicate hornfelses (o) and axinite-bearing rocks (+) plotted as well as the analysed phases (x) from one of the latter. The joins to axinite are dashed to signify that axinite strictly does not fall on the ACF plane.

1·64 for (Ca_2Mg_1) axinites if such are found to exist.

No bulk analyses of contact rocks at London Bridge have been made but a rough idea of the rock compositions has been obtained by calculation using modes and assuming mineral compositions and specific gravity values are of the same order throughout. Thus the common calc-silicate rocks appear to have the compositions of calcareous shales. Though the amphibole of these hornfelses may be a little richer in iron than that found with axinite, calculations suggest the hornfelses carry 5-10% by weight MgO. From the calc-silicate rocks there is a gradation to pure $CaCO_3$ rocks and as the sediments outside the contact aureole appear to be of similar chemical character (calcareous shales, marls, limestones) it is reasonable to regard the hornfelses lacking axinite as essentially isochemical products. The seeming absence of dolomite from the vicinity leads one to consider the Mg present in the epidote-amphibole hornfelses as derived from the clay fraction of the calcareous shales. Calculated compositions of the axinite-bearing hornfelses (Figure 3) fall within the range of the other contact rocks—except for the obvious presence of boron. The axinite rocks appear to have been derived largely from marly limestones but can scarcely be isochemical products. While the case for boron accumulation is clear it might also be argued that Mn has been concentrated in the axinitic rocks though it would be unwise to assume that epidote and amphibole occurring without axinite are lacking in Mn.

The source of boron at London Bridge is not obvious. Restriction of axinite to a narrow zone within the aureole might have been due to local access of boron from the Keewong porphyry but neither tourmaline nor any other boric phase has been noticed in the porphyry while the observed mineral replacements in the intrusion cannot be assumed to result from magmatic volatile attack. The alternative view, concentration of boron from the marine sedimentary rocks, is equally lacking in proof. Geochemical work overseas suggests that boron is rarely abundant in lime-

TABLE 2

	London Bridge, N.S.W.			Ontario	
	axinite	epidote	tremolite	axinite	epidote
$\frac{Fe^{2+}}{Fe^{2+}+Mg+Mn}$	0·37	0·24	0·15	0·48	0·30
$\frac{Mg}{Fe^{2+}+Mg+Mn}$	0·53	0·76	0·85	0·20	0·70
$\frac{Mn}{Fe^{2+}+Mg+Mn}$	0·10	0·00	0·00	0·31	0·00
$\frac{Al}{Al+Fe^{3+}}$	0·94	0·78	0·54* (0·67)	0·94	0·89

*Al^{vi} only.

stones though notable amounts have been detected in some marine argillaceous sediments (Goldschmidt, 1954). The restricted distribution of axinite at London Bridge leads one to favour an extraneous source for the boron.

Though the origin of the boron may be in doubt, it is clear that the extra component locally in the system has led to the appearance of an extra phase and there seems no reason to doubt that axinite formed in equilibrium with the epidote, calcite and tremolite. Development of axinite also had the effect of abstracting part of the supply of components elsewhere available to form the other phases. Atomic ratios listed in Table 2 indicate differences in the distribution of some elements between the silicate phases. Most notable is the concentration of Fe^{2+} and, especially, Mn in axinite relative to the other minerals. This is not surprising when one recollects the likely diadochic situation in axinite. That all three silicate phases here have notable Mg contents is surely a reflection of the magnesian character of the country rocks. With axinite competing for available Mn and Fe^{2+} it is likely that epidote and amphibole forming in equilibrium with it will have rather less of these elements but more Mg than these same phases developed together in rocks of similar grade and composition but lacking boron. The high value for the ratio $Al/Al + Fe^{3+}$ in axinite is apparently a general feature of this mineral. Few reliable analyses of axinite give values less than 0·9 for this ratio whereas $Al.Fe^{3+}$ substitution is more extensive in amphiboles and, certainly, in epidotes. Examination of distribution patterns of elements in similar axinite parageneses is impossible as no other analyses of undoubtedly coexisting axinite, epidote and/or amphibole have been noted. An epidote from Porcupine, Ontario, studied by Bruce and Greenland (1924) is claimed to be similar to epidote occurring with an axinite analysed by Walker and Parsons (1925); as a matter of interest the appropriate ratios are listed in Table 2. Axinites and epidotes from Bourg d'Oisans, Dauphiny, have been analysed and described in the literature but the present writer is unaware of the mode of occurrence. Using homogenization of liquid-gas inclusions as a temperature indicator, Koltun, Liakhov and Pisnur (1961) claim the Dauphiny axinite formed at temperatures below 200°C, so it may not have developed with epidote.

Axinite in Contact Metamorphism

Despite the lack of chemical data on axinite parageneses the mineral is not especially rare in contact environments. Probably best known are the associations with andradite, hedenbergite, calcite and quartz in the aureoles of the Dartmoor and Land's End granites in SW England. In this region datolite is a rare associate in metamorphosed calcareous sediments while some recrystallized basic rocks carry axinite with amphibole and tourmaline (e.g. Reid, 1912; Harker, 1939; Deer, Howie and Zussman, 1962, vol. I, p. 307). Similar examples have been recognized elsewhere overseas. In a few localities, axinite occurs with the rare Ca-borosilicate danburite (e.g. Harada, 1939). Near Dundas, Tasmania, rocks containing some relic clinopyroxene with actinolite, axinite, calcite, datolite, danburite, quartz and Fe and Cu sulphides appear to be the product of contact pneumatolytic action by a granitic body (tourmaline-quartz porphyry) on pyroxenite (Twelvetrees and Petterd, 1899). Apart from the relic pyroxene, largely altered to amphibole, the complex assemblage appears to exist without obvious signs of mineral alteration. The occurrence points to the likelihood that the three borosilicates may coexist stably under certain conditions, the most obvious being the availability of sufficient boron. However, the metamorphic status of axinite parageneses must be interpreted with caution. Thus some axinite occurrences show disequilibrium characters and it is likely that the phases now coexisting represent mineral adjustments over a wide range of physical and chemical conditions (e.g. Mozgova, 1964). Indeed, of the borosilicates mentioned above, each has been recorded in metamorphic environments ranging from those of diagenetic character to others of fairly high grade.

Figure 4 serves to summarize some suggested compatibility relations in the albite-epidote hornfels facies where B_2O_3 exists as an extra component (borosilicates like serendibite and kornerupine with compositions which also fall in the tetrahedron A-C-F-B_2O_3 are excluded as they seem to be confined to high-grade environments). Probably similar relations hold in the hornblende hornfels facies with the significant differences confined to the ACF plane. Of the predicted 4-phase assemblages containing axinite and formed from impure limestones, marls and calcareous shales in low-grade contact zones—(1) axinite-calcite-epidote-tremolite, (2) axinite-calcite-datolite-epidote, (3) axinite-calcite-datolite-tremolite, (4) axinite-datolite-danburite-epidote, and (5) axinite-datolite-danburite-tremolite—only the first named is at all common. The reasons for this are probably two-fold, (a) among the rock-types mentioned, the commonest bulk compositions (ignoring boron) tend to fall within the ACF triangle rather than along the sides, and (b) boron concentrations in excess of a few per cent by weight of the bulk seem to be distinctly rare. For similar reasons axinite-calcite-Ca garnet-Ca pyroxene is likely to be the most common of axinite associations derived from marls, etc., in the hornblende hornfels facies. Tourmaline will appear in these facies where Ca concentrations are lower, typically in hornfelses formed from argillaceous sediments or basic igneous rocks. Thus near the Moonbi Adamellite at Tintinhull, N.S.W., the assemblage blue tourmaline-axinite-actinolite/hornblende-epidote-(albite) occurs locally in small patches near veins in thermally meta-

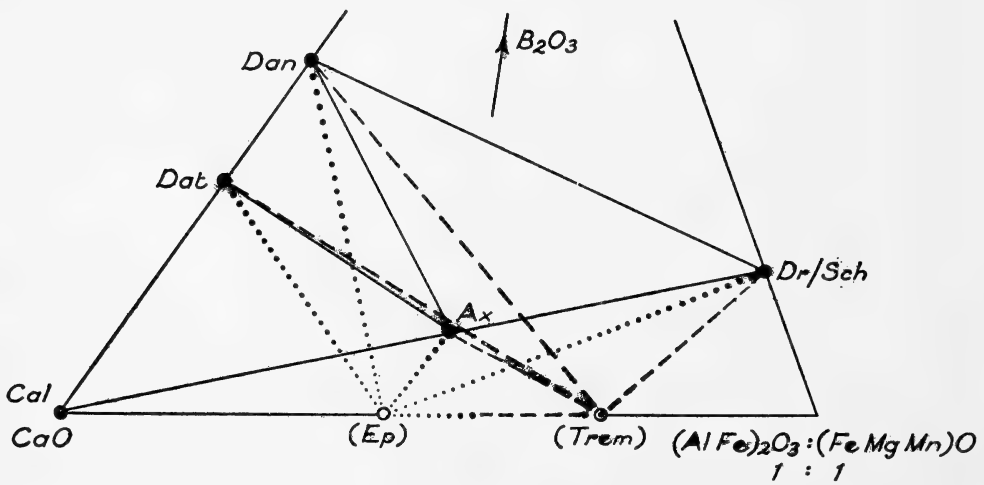

Fig. 4

A section through the tetrahedron A.C.F.B_2O_3 (with excess SiO_2) showing some compatibility relations in the albite-epidote hornfels facies. Phases lying in the plane are marked as spots (●) and the joins therein as full lines. $(Al.Fe)_2O_3$ is taken as standing behind the plane; phases thus situated are denoted (o) and joined to phases in the plane by dotted lines. Tremolite thus appears in front of the plane and is linked to other phases by rows of thickening dashes. Phases along the A.F. join are ignored. Cal = calcite, (Ep) = epidote, (Trem) = tremolite, Dat = datolite, Dan = danburite, Ax = axinite, Dr/Sch = dravite/schorlite.

morphosed spilitic rocks now consisting chiefly of albite and actinolite/hornblende (e.g. Univ. Sydney spec. 23304). At London Bridge where all the contact rocks are calcareous it seems clear that the axinite-bearing hornfelses are isofacial with the associated calc-silicate rocks and marbles.

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Some Aspects of Calc-Alkali Rock Genesis

J. F. G. Wilkinson

Abstract—The paper summarizes the main proposals relating to calc-alkali rock genesis and directs attention to the possibility that silicic alkalic liquids have been participants, through hybridization processes, in the production of a range of calc-alkali compositions.

Introduction

The voluminous calc-alkali rocks of the orogenic belts have always presented many outstanding problems when reasonably precise evaluation of their genesis has been attempted. The situation is understandable. The coarse granitoid fabric of the slowly-cooled intrusives tends to obscure textural or mineralogical evidence of processes which might have been operative early in their history. Moreover, compared with the differentiates of a single intrusion where the composition of the parent magma and some degree of spatial continuity of the differing phases are available, the petrogenesis of members of a bathylithic complex (often mutually intrusive, or else separated from one another by country rocks) is more difficult to interpret in terms of continuous processes.

Magma has been assigned the major genetic role in the high-level calc-alkali intrusives, evidenced by their close geochemical affinities with calc-alkali volcanic rock sequences and also by the development within the rocks of a variety of structures consistent with upward movement of magma (*cf.* Buddington, 1959). Relatively small high-level masses may still retain evidence of an earlier high-temperature (volcanic) mineralogy (Tuttle and Bowen, 1958, p. 116). The close relation between the compositions of granitic rocks in Washington's tables (with 80 per cent or more of normative Qz + Ab + Or) and the thermal valley on the liquidus surface in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O (Tuttle and Bowen, 1958) constitutes strong evidence that processes involving crystal $\rightleftharpoons$ liquid equilibria have been operative in the genesis of the bulk of these granites.

However Reynolds (1958) has pointed out that, as a consequence of the salic composition prerequisites necessary for any correlation with this synthetic data, Tuttle and Bowen omitted from discussion the origin of some of the most common "granites" of orogenic zones, namely the tonalites, granodiorites and adamellites whose normative Qz + Ab + Or may often be significantly less than 80. In some bathyliths true granites may be minor to more "basic" granitic rocks.

Fractional crystallization of basaltic magma, fractional crystallization of basaltic magma modified by sialic contamination, hybridism and partial fusion of crustal rocks of varying compositions are some of the mechanisms that have been proposed in calc-alkali genesis. Each of these proposals will be briefly evaluated in the following discussion.

Fractional Crystallization of Basaltic Magma

Bowen's (1928) proposal that the calc-alkali series has been derived by the fractional crystallization of (oversaturated) basaltic magma is well known. Cogent objections to this view have centred primarily on the demonstrably excessive volume of potential differentiates and the differing trend (alkali enrichment rather than iron enrichment) provided by the calc-alkali series on an AMF diagram (*cf.* Figure 1). Thus Edwards (1942, p. 609) and Wager and Deer (1939, p. 323), although conceding that small volumes of calc-alkali rocks may be produced by the fractional crystallization of tholeiitic magma, dismiss this mechanism as a generalized mode of origin. Poldervaart and Elston (1954, p. 159) have listed several specific limitations to a hypothesis of calc-alkali genesis based on fractional crystallization of basaltic magma. Following an extensive survey of North American granitic rocks, Buddington (1959, p. 740) found no evidence for excessive volumes of gabbroic residua in the mesozone or katazone of the orogens if these are assumed to be prerequisite to the development of higher-level granitic rocks.

Recently Osborn (1959, 1962) has proposed the origin of the calc-alkali rocks of the orogens by the fractional crystallization of tholeiitic magma, oxygen pressure remaining at a high level during crystallization. The resultant precipitation of magnetite yields silica-rich liquids.

The difficulties associated with the volume of the more felsic differentiates still remain. Moreover certain aspects of the mineral chemistry of some calc-alkali series are not consistent with crystallization under conditions of relatively high oxygen pressure. Titanomagnetites in some Japanese andesites and dacites are essentially Fe_3O_4-Fe_2TiO_4 solid solutions (Akimoto, 1954, 1955), the Fe_2TiO_4 spinel end-member requiring a low Po_2 for its formation. In more evolved granitic members from the Southern California Bathylith (Larsen and Draisin, 1950) and from the northern end of the New England Bathylith (northeastern New South Wales) (Shaw, 1964), the hornblendes and biotites reveal a considerable degree of Mg-Fe^{2+} substitution, trending in their compositions towards ferrohastingsite and annite respectively. The degree of iron enrichment of these minerals is analogous to the development of fayalitic olivine and ferroaugite-ferrohedenbergite in advanced differentiates at Skaergaard, New Amalfi and other basic intrusions characterized by absolute iron enrichment.

In some areas, basaltic rocks may play an extremely minor role relative to the volumes of the associated felsic rocks. Boyd (1961) has estimated that the volume of rhyolite erupted to form the rhyolite plateau of Yellowstone National Park exceeded 400 cubic miles. Although basalt flows (including high-alumina types) are numerous, nevertheless "the volume of the basalt is not more than a small fraction of 1 per cent of the volume of the associated rhyolite" (Boyd, *op. cit.*, p. 400).

Following their detailed study of the San Juan region, Larsen and Cross (1956) concluded that crystal fractionation "from a parent basaltic magma of rather uniform composition" was adequate to explain the diversity of rock types in the area. Turner and Verhoogen (1960, p. 276) have listed mineralogical and other criteria inconsistent with the concept of simple linear differentiation. Earlier, Larsen *et al.* (1938, p. 429) had assumed the mixing of partially crystalline magmas in order to explain some anomalous mineral associations in certain lavas. The choice of basaltic magma as the parent of the San Juan province is, as Carmichael (1963, p. 123) has pointed out, somewhat surprising in view of the paucity of basalt in the Potosi series or the San Juan region as a whole.

Fractional Crystallization of Basaltic Magma Modified by Sialic Contamination

After a critical survey of basaltic-intermediate calc-alkali relationships, Tilley (1950) concluded that basaltic magma is the essential material in the evolution of the orogenic volcanic series and the great subsequent bathyliths—"basaltic magma modified by sialic contamination to set it on its course of variation which fractional crystallization appears most competent to yield". A similar type of mechanism is implicit in the views of Waters (1955, p. 713). Kuno (1950, p. 1012) related the genesis of the Hakone hypersthenic series to the assimilation of granitic rocks by "olivine-basalt magma". Differences in the successive ejecta from Paricutin volcano are explicable, according to Wilcox (1954), in terms of a combination of fractional crystallization of olivine-bearing basaltic andesite (SiO_2 = 55 per cent) and assimilation of salic country rock.

Emplacement into the crust of large volumes of basaltic magma at temperatures in excess of 1000°C and its subsequent prolonged contact with the sialic envelope may well result in partial melting of the latter, the products of partial melting presumably possessing compositions appropriate to the low melting portions of the $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O system. Analytical data on glasses produced by partial melting of igneous and sedimentary rocks under natural conditions indicate a behaviour analogous to the movement of liquids in the synthetic system (Wyllie, 1961; Butler, 1961).

Some indication of the approximate chemistry of the most siliceous material necessary to change the composition of the average "central basalt" (Nockolds, 1954, p. 1009) to the composition of the average andesite is afforded by examination of the oxide variation curves linking the average central basalt, andesite, dacite, rhyodacite, dellenite and calc-alkali rhyolite-obsidian on a Harker diagram (*cf.* Bowen, 1928, p. 76). This material, referable to the "granite system", has the normative parameters $Qz_{35}Or_{46}Ab_{19}$, and although relatively potassic, plots close to the quartz-alkali feldspar cotectic at 2,000 bars water pressure. Its subsequent blending with basaltic liquid was considered by Tilley to be most adequately achieved by convective circulation.

TABLE 1

Analyses of some Calc-Alkali Volcanic Rocks and High-Alumina Basalts

	1	2	3	4	5	6	7	8
SiO_2	51·33	50·19	48·27	54·20	55·7	63·58	62·5	73·66
TiO_2	1·10	0·75	0·89	1·31	0·9	0·64	0·7	0·22
Al_2O_3	18·04	17·58	18·28	17·17	17·0	16·67	15·7	13·45
Fe_2O_3	3·04	2·84	1·04	3·48	3·0	2·24	2·3	1·25
FeO	5·70	7·19	8·31	5·49	4·8	3·00	3·2	0·75
MnO	0·16	0·25	0·17	0·15	0·1	0·11	0·1	0·03
MgO	6·01	7·39	8·96	4·36	4·9	2·12	3·2	0·32
CaO	10·07	10·50	11·32	7·92	8·3	5·53	5·6	1·13
Na_2O	2·76	2·75	2·80	3·67	2·8	3·98	2·9	2·99
K_2O	0·82	0·40	0·14	1·11	1·8	1·40	3·1	5·35
H_2O+	0·45	—	0·15	0·86	0·6	0·56	0·6	0·78
H_2O-	—	—	0·07	—	—	—	—	—
P_2O_5	0·16	0·14	0·07	0·28	0·1	0·17	0·1	0·07
Total	—	99·98	100·47	—	—	—	—	—
				Norms				
Qz	2·2	—	—	5·7	8·1	19·6	17·3	33·2
Or	5·0	2·22	0·56	6·7	10·6	8·3	18·3	31·7
Ab	23·6	23·58	23·58	30·9	23·6	34·1	24·6	25·1
An	33·9	34·47	36·97	27·2	28·6	23·3	20·6	5·0
C	—	—	—	—	—	—	—	0·9
Wo	6·4	7·08	7·66	4·2	4·9	1·3	2·7	—
En	15·0	14·70	3·50	10·9	12·3	5·3	8·0	0·8
Fs	6·1	7·92	4·09	5·3	5·0	2·8	2·9	—
Fo	—	2·66	13·30	—	—	—	—	—
Fa	—	1·63	7·14	—	—	—	—	—
Mt	4·9	4·18	1·39	5·1	4·4	3·3	3·3	1·9
Il	2·1	1·52	1·67	2·4	1·7	1·2	1·4	0·5
Ap	0·3	0·34	0·34	0·7	0·3	0·3	0·3	0·2

1. Average central basalt (56 analyses) (found in association with the typical calc-alkali andesites, dacites and rhyodacites at volcanic centres) (Nockolds, 1954, p. 1021).
2. Average parental high-alumina basalt of Japan and Korea (11 analyses) (Kuno, 1960, p. 141).
3. High-alumina basalt, Warner Flow, Medicine Lake Highlands, California. Anal. J. H. Scoon (Yoder and Tilley, 1962, p. 362).
4. Average andesite (49 analyses) (Nockolds, 1954, p. 1019).
5. Composition obtained from mixture of 80 per cent central basalt and 20 per cent average calc-alkali rhyolite + rhyolite-obsidian (Analysis 8).
6. Average dacite + dacite-obsidian (50 analyses) (Nockolds, 1954, p. 1015).
7. Composition obtained by mixing 50 per cent central basalt and 50 per cent average calc-alkali rhyolite + rhyolite-obsidian (Analysis 8).
8. Average calc-alkali rhyolite + rhyolite-obsidian (22 analyses) (Nockolds, 1954, p. 1012).

Within the best of calc-alkali variation (Figure 1), the initial stages of calc-alkali geochemistry are represented by addition of the most alkali-rich calc-alkali end-member to material of central basalt composition. Thus a mixture of 20 per cent average calc-alkali rhyolite + rhyolite-obsidian ($Qz_{36·9}Or_{35·2}Ab_{27·9}$) and 80 per cent central basalt yields a composition not dissimilar to the average andesite (Table 1, Analysis 5), perhaps the most notable difference being the respective alkali contents. These differing alkali contents are obviously conditioned in this instance by the choice of the acid end-member and anomalies become more apparent in the composition represented by equal amounts of the end-members. Low melting material with relatively higher soda and lower potash contents is indicated, particularly in view of the displacement of the minimum towards the Ab apex in the granite system with increasing water pressures (Tuttle and Bowen, 1958, Figure 38; Wyllie, 1961, Table 2).

Tholeiitic basalt may occupy a parental role to certain andesites, e.g. the Columbia plateau basalts. However attention is directed to the composition of Nockolds' average central basalt found associated at volcanic centres with "typical calc-alkali andesites, dacites and rhyodacites" (Nockolds, 1954, p. 1009)

(Table 1, Analysis 1). With an alumina content in excess of 17 per cent, the composition of the average central basalt is similar to the composition of the average high-alumina basalt of Japan and Korea (Kuno, 1960) (Table 1, Analysis 2). Kuno elevated high-alumina basalt to the status of a primary magma and rejected the concept of its derivation from tholeiitic magma, either by fractionation of the latter or its contamination by granitic or argillaceous rocks.

A mixture of 80 per cent average tholeiite and 20 per cent calc-alkali rhyolite + rhyolite-obsidian does result in a composition similar to the average andesite, the most notable difference being the relatively low alumina content of the mixture (14·0 per cent Al_2O_3). The mixture plots within the belt of calc-alkali variation on an AMF diagram but away from the iron-enriched trend indicated by the average tholeiite and tholeiitic andesite (Figure 1, points γ and TA).

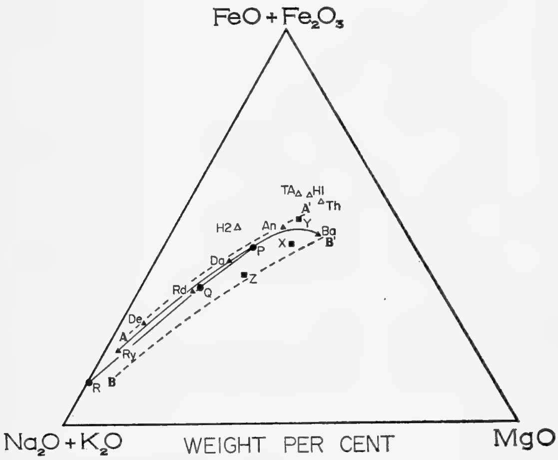

FIG. 1

The plot of some calc-alkali igneous rocks for the oxides $FeO+Fe_2O_3$ (F), MgO (M), and Na_2O+K_2O (A). The dashed lines AA′ and BB′ define the belt of composition variation of calc-alkali igneous suites (after Tilley, 1950, Figure 4). Ba, An, Da, Rd, De and Ry represent the average calc-alkali lavas, central basalt, andesite, dacite, rhyodacite, dellenite and rhyolite (Nockolds, 1954). Q, P and R are respectively the Dundee adamellite-porphyrite, its recalculated basic fraction and groundmass (Table 2, Analyses 1-3). X and Z represent mixtures of the average central basalt and average calc-alkali rhyolite + rhyolite-obsidian in ratios of 80:20 and 50:50 (Table 1, Analyses 5 and 7). Point Y represents a mixture of average tholeiite and calc-alkali rhyolite + rhyolite-obsidian (80:20). Th and TA are Nockolds' average tholeiite and tholeiitic andesite. H1 and H2 are respectively a high-alumina porphyritic olivine-basalt from Huzi volcano and an aphyric andesite, occurring as a thin schliere in H1 (Kuno, 1960, Table 5).

Although recognizing non-porphyritic high-alumina basalts as members of a magma type, Yoder and Tilley (1962, p. 417) have demonstrated that the aphyric high-alumina basalts do not appear to be characteristic of any specific basalt type, rocks with more than 17 per cent Al_2O_3 being present in the Hawaiian and Hebridean alkali successions. On the basis of experimental work on the Di-An-H_2O and Di-Fo-An-H_2O systems, Yoder and Tilley concluded that relatively high water pressure may bring about the production of high-alumina magmas. The oxygen pressure resulting from the equilibrium $2H_2O \rightleftharpoons 2H_2+O_2$ increases with increasing water pressure (*cf.* Osborn, 1962, p. 220 and his views on calc-alkali genesis).

Although the mechanism of sialic contamination outlined above is chemically adequate to bridge the gap from central basalt to andesite, in some areas large volumes of basaltic liquid have acquired no evidence of sialic contamination in their passage through the crust. A notable example is provided by the Eocene-early Pliocene Cascade-Coast Range area of the Western United States where an estimated 75,000 cubic miles of uniformly low-Al_2O_3 tholeiitic lava were extruded (Waters, 1955, p. 712). The sequence is characterized by little or almost no differentiation, and rocks of andesitic composition are generally absent. The extensive New England (N.S.W.) alkali olivine-basalt province, extrusive through Palaeozoic geosynclinal sediments and the New England Bathylith, retains its initial undersaturated nature throughout, and shows no direct evidence of acquiring any sialic material. Osborn (1959, p. 646) and Waters (1955, p. 713) would seek to explain the absence of any differentiation or sialic contamination of these magmas as a result of their eruption through essentially inactive non-orogenic belts.

Hybridism in Calc-Alkali Genesis

Nockolds (1934) cited many instances where there is evidence for the production of diorite, tonalite and granodiorite from interaction of acid quartzo-feldspathic magma with solid basic igneous material. He presented a generalized sequence of events in calc-alkali evolution, namely: "... composite bathyliths and laccoliths where there is a series of gradational intrusions with sharp contacts against one another. Here there would be a series of acid injections following the basic one. The first would be contaminated with the basic material which formed the roof through which it broke. The next acid injection would be contaminated largely with the first contaminated injection and so on—in this way each intrusion when solid would appear to be more acid than the last. . . ."

As the majority of demonstrable examples of hybridism[1] of this type have dealt with calc-alkali complexes with comparatively small areas, many petrologists have been reluctant to extend the process to the more extensive bathylithic complexes. However Chayes (1956), from a consideration of modal data and the evidence of hybrid nature in outcrop, has proposed that the tonalites of the Southern California Bathylith have arisen by mechanical mixing of previously solidified gabbro with granodiorite magma. Somewhat similar views are held by Joplin (1959), namely that the rock suite characteristic of the discordant bathyliths is formed from two magmas, basaltic and granodioritic, that the basic rocks are emplaced among the geosynclinal sediments before the introduction of the acid magma, and that the intermediate rocks are hybrids.

Any reluctance to assign acid liquid a major role in the genesis of the calc-alkali intermediate rocks has probably centred to some extent around the apparently small *actually* demonstrable bulk of the former. Smith (1960) has drawn attention to the volumes of silicic material present in multiple source ash-flow fields, some of which have volumes greater than 2,000 cubic miles—"... it is inferred that greater volumes of magma were not erupted but were left behind to congeal as large plutons" (Smith, *op. cit.*, p. 835). Larsen and Cross (1956, p. 95) estimated that the Miocene Potosi volcanic series of the San Juan province contains 2,300 cubic miles of rhyolitic volcanic rocks, constituting as Buddington (1959, p. 681) has pointed out, the equivalent of a granitic bathylith 230 square miles in area and 10 miles deep.

[1] The writer follows Joplin (1959, p. 366) in distinguishing a hybrid as a rock formed by incorporation of basic igneous rocks and a contaminated rock as one which has assimilated sediments.

Rhyolitic glasses (sodi-potassic types) from New Zealand ash showers (Ewart, 1963, Figure 6) and rhyolites from Yellowstone (Boyd, 1961, Figure 7) group close to the minimum in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O.

Experimental evidence indicates that sediments (shales, arkoses, feldspathic sandstones) will be partially melted, in the presence of water vapour, at temperatures which could be reached at no great depth in the orogenic belts (Wyllie and Tuttle, 1960, 1961). Although there appears to be little detailed analytical data on the glasses produced in these experiments, the liquid product of partial melting has been referred, mainly on refractive index measurements, to granitic or granodioritic (Wyllie and Tuttle, 1960). The remelting at depth of certain acid rocks, e.g. granodiorite, would yield a more acid granitic liquid, remelting being a fractional process (*cf.* Tilley, 1950, p. 59).

If partial melting produces low-melting liquids conforming in their chemistry to the cotectic minima of the "granite system" (*cf.* Wyllie, 1961; Butler, 1961), their relationships to the voluminous more basic members (adamellites, granodiorites, tonalites) of the orogenic intrusive series are to be explained.

Several intrusions of the Dundee adamellite-porphyrite (Qz + Ab + Or = 66·0-70·0) comprising approximately 280 square miles of outcrop of the New England Bathylith (north-eastern N.S.W.) are believed to furnish in their mineralogy, textures and geochemistry an example of large-scale hybridism whereby disrupted biotite-diorite was invaded and mixed with low-melting silicic alkalic liquid (Wilkinson, Vernon and Shaw, 1964). The adamellite-porphyrite is composed of phenocrysts of quartz, andesine, hornblende, biotite, augite (and minor orthopyroxene) which are set in a fine-grained quartz-alkali feldspar groundmass whose compositions are appropriate to the low-melting region in the $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O system. The composition of a rock represented by the silicate phenocrysts of the adamellite-porphyrite (which themselves reveal widespread evidence of cataclasis) is similar to that of the average biotite-diorite (Table 2, Analyses 1-3). Silicate phenocrysts are similar in type and composition to the minerals in xenoliths in the adamellite-porphyrite.

While conceding a major role to the voluminous andesites of orogenic belts, many workers have tended to regard the diorites which exhibit a close similarity in bulk chem-

TABLE 2

Analyses of some Calc-Alkali Rocks

	1	2	3	4	5	6	7	8	9
SiO_2	64·51	53·6	75·03	52·97	54·4	56·3	54·37	53·35	57·04
TiO_2	0·58	1·0	0·12	1·60	1·0	1·1	1·14	0·56	0·47
Al_2O_3	16·25	19·5	12·87	18·19	16·5	17·3	19·64	19·22	19·11
Fe_2O_3	1·36	2·4	0·67	1·97	1·6	1·9	4·30	3·28	4·37
FeO	3·34	5·4	0·49	6·29	6·4	6·3	4·87	4·48	2·48
MnO	0·12	0·1	0·02	0·13	0·2	0·1	0·07	0·15	0·12
MgO	1·82	3·5	0·03	4·75	6·6	4·7	2·94	4·86	3·94
CaO	4·16	7·5	1·04	7·61	7·8	7·9	8·07	9·76	7·34
Na_2O	3·50	4·2	2·92	3·50	3·5	3·1	2·55	2·89	3·48
K_2O	3·55	2·0	6·45	1·65	1·7	1·2	1·01	0·99	1·16
H_2O+	0·64	0·7	0·27	1·00	—	—	0·96	0·77	1·09
H_2O-	0·07	0·1	nil	—	—	—	0·11	—	—
P_2O_5	0·19	—	0·25	0·34	0·3	0·1	0·34	0·10	0·08
Total	100·09	100·0	100·16	—	—	—	100·37	100·44	100·70
					Norms				
Qz	17·9	—	31·8	2·2	0·5	8·1	12·7	5·0	11·5
Or	21·1	11·7	38·4	9·4	10·0	7·2	6·1	6·1	7·2
Ab	29·3	35·6	24·6	29·3	29·3	26·2	21·5	24·6	29·3
An	18·4	28·6	2·8	29·2	24·5	29·7	38·9	36·1	32·8
Wo	0·7	3·6	0·2	2·7	5·1	3·6	—	4·8	1·2
En	4·5	7·0	0·1	11·9	16·5	11·7	7·3	12·1	9·8
Fs	4·0	5·2	0·3	7·5	9·1	8·3	3·7	4·6	0·3
Fo	—	1·3	—	—	—	—	—	—	—
Fa	—	0·8	—	—	—	—	—	—	—
Mt	2·1	3·5	0·9	3·0	2·3	2·8	6·3	4·9	6·5
Il	1·2	2·0	0·2	3·0	2·0	2·1	2·1	1·2	0·9
Ap	0·3	—	0·7	0·8	0·7	0·3	0·7	0·3	0·3

1. Average of 4 Dundee adamellite-porphyrites, New England Bathylith, N.S.W.
2. Recalculated composition of basic fraction of adamellite-porphyrite (assuming 5 per cent modal quartz).
3. Average of 2 analyses of microcrystalline groundmass of Dundee adamellite-porphyrite (Analyses 1-3 from Wilkinson, Vernon and Shaw, 1964, Table 6).
4. Average hornblende-biotite diorite (16 analyses) (Nockolds, 1954, p. 1019).
5. Parental magma of Scottish Caledonian calc-alkali series (average of four analyses of pyroxene-mica diorite) (Nockolds and Allen, 1953).
6. Parental magma of Southern California Bathylith (average of two quartz-biotite norites and "Bonsall tonalite") (Nockolds and Allen, 1953).
7. Quartz-mica diorite (basic parent), Moyne Farm, Little Hartley, N.S.W. (Joplin, 1931, Table 9).
8. Cognate inclusion in dacite of Chaos Crags, Lassen Peak (Williams, 1931, Table 1) (includes SrO 0·03 per cent).
9. Cognate inclusion in hypersthene-andesite, Brokeoff Cone, Lassen Peak (Williams, 1932, p. 258) (includes SrO 0·02 per cent).

istry to andesites (*cf.* Tyrrell, 1955, p. 420; Turner and Verhoogen, 1960, p. 348) as being relatively insignificant from the volumetric point of view. However the major development of dioritic variants in the Southern California Bathylith is to be noted. Buddington (1959) has cited many instances where it is normal for volcanic rocks to be associated in space, time and tectonics with epizonal plutons of equivalent compositions. The compositions assigned to parental magmas of 10 calc-alkali intrusive and extrusive series (Nockolds and Allen, 1953) are intermediate in type, with rather high alumina (16·9-19·2 per cent Al_2O_3) (Table 2, Analyses 5 and 6); at more basic compositions indicated on a modified Larsen diagram there is a scatter of compositions away from a proposed liquid line of descent. Yet intermediate rocks with compositions similar to those listed by Nockolds and Allen are relatively minor, compared with the bulk of the granitic members of some bathyliths.

It is suggested that the comparatively minor development of dioritic types in some bathylithic complexes is the result of their participation in hybridization processes with later acid liquids. The resultant hybrids need not be abnormal chemically. On a Harker diagram the variation among different members may be defined by nearly straight line curves (Joplin, 1931; Holmes, 1932). The bulk composition represented by a mixture of 3 parts of the groundmass and 1 part of the dioritic fraction of the Dundee adamellite-porphyrite (Table 2, Analyses 2 and 3) is similar to Nockolds' average adamellite. Mixtures of these end-members in varying proportions yield compositions within the belt of calc-alkali composition (Figure 1).

In rocks containing large amounts of potential "granitic material", a slight increase in temperature above the minimum melting temperature of granite produces a large volume of liquid because of the minimum-type melting relations. It has been suggested that partial melting of crustal rocks may produce the range of liquid compositions represented by the calc-alkali series (*cf.* Hess, 1960, p. 184; Turner and Verhoogen, 1960, p. 257). At 5,000 bars water pressure the beginning of melting curve for syenite is close to 700°C. At the same water pressure the beginning of melting curves for olivine-tholeiite and high-alumina basalt lie between 750°C and 800°C (Yoder and Tilley, 1962, Figure 33). Although partial melting of basic rocks would yield small amounts of granitic liquid, the difficulties of relative volume relationships are again apparent. At 5,000 bars water pressure, temperatures at least of the order of 800°C-900°C are probably necessary to produce any significant volume of dioritic or tonalitic "liquid" through partial or complete melting. Experimental data on this point are necessary. In the highest grade regional metamorphic terrains, detailed examination of products considered to be of partial melting origin possibly may yield some information on the production of liquids significantly more basic than granitic compositions.

Any hypothesis advocating acid liquid/solid basic rock hybridism must seek to provide adequate explanation of the mixing process, particularly when the relatively high viscosities of the acid liquid are considered. High gas pressure would reduce viscosity and, particularly at high levels, probably facilitate mixing. In discussing this problem in relation to the genesis of the Dundee adamellite-porphyrite, the following mechanisms were offered to explain continued fragmentation of the earlier biotite-diorite and its subsequent fairly thorough mixing with silicic alkalic liquid. (1) Partial or complete solution of interstitial quartz (Nockolds, 1933). (2) The expansion of dioritic fragments as a result of heating by the acid liquid. (3) Convective circulation (Tilley, 1950). (4) Fluidization processes (Reynolds, 1954).

Buddington (1959, p. 735) concluded after an extensive survey of North American granitic rocks that their emplacement in the epizone is consequent on "block foundering in, or some kind of stoping, by magma . . ." He commented on the lack of desirable supporting evidence of sunken blocks in the plutons of deeper levels, suggesting that such blocks have been indistinguishably incorporated in magma. The degree to which pre-existing material may be fragmented is indicated by the study of the Dundee adamellite-porphyrite, a rock which superficially yields little real indication of the volume of dioritic material involved (40-60 per cent).

Concluding Remarks

The preceding discussion represents an attempt to summarize some of the salient features of calc-alkali genesis. Clearly no single mode of origin is applicable to the series and all proposals possess limitations when detailed syntheses of primitive histories of these rocks are attempted. Probably the most serious problem associated with widespread hybridism is the mixing process involved. It would be difficult to prove, on a basis of evidence afforded by the rocks themselves, whether sialic contamination of basaltic magma has been the prime mechanism inasmuch as liquid-liquid mixing is implied and the development of phenocrysts, even in the vitrophyric lavas, represents an episode subsequent to contamination.

Tilley (1950) has emphasized the necessity for detailed mineralogical and chemical data on these vitrophyric rocks, in particular, the nature of their groundmass chemistry. The glassy dacites from Lassen Peak, described by Williams (1931), raise interesting speculations concerning the relative merits of the two differing hypotheses cited above.

These dacites contain 40-75 per cent glass whose refractive indices indicate a highly siliceous composition. Two analyses of the glasses indicate a granodiorite or adamellite composition (Hague and Iddings, 1883). Although the granodioritic glass is relatively lime-rich the two glasses in question plot within the low-melting region in the synthetic granite system. Some of the dacites and andesites are characterized by basic inclusions, composed of andesine-labradorite, hornblende and/or pyroxene (Table 2, Analyses 8 and 9). The dacites, their glasses and the inclusions plot with the belt of calc-alkali variation (Tilley, 1950, Figure 4) and within that belt provide a continuity of composition similar to that indicated by the compositions of the average Dundee adamellite-porphyrite, its microcrystalline groundmass and the recalculated "basic fraction" (equivalent to the silicate phenocrysts plus 5 per cent modal quartz) (Table 2, Analyses 1 to 3; Figure 1).

Do these relatively low-melting siliceous groundmasses represent quenched products of fractional crystallization? Or are they acid liquids introduced from an external source into material represented by the inclusions? Williams (1931) comments on the fractured nature of many of the plagioclase phenocrysts in the dacites. Similar queries may be directed at certain Katmai andesites whose glassy groundmass (comprising 50 per cent of the rock) is rhyolitic in composition (Bowen, 1928, p. 118).

Problems of ancestry of these rocks will no doubt be clarified when analytical data on the minerals and glasses become available, to indicate in particular whether the compositions of the phenocrysts are appropriate to the bulk chemistry of the rocks in which they occur, whether there are compositional changes in the mineral chemistry consistent with concepts of fractional crystallization or whether the phenocrysts possess certain characteristics more appropriate to and inherited from a deep-seated cooling history. Similar studies on relatively quickly cooled high-level porphyritic intrusives may also provide critical information relating to the more primitive phases of calc-alkali evolution. The rapidly cooled Dundee adamellite-porphyrite, containing disordered plagioclase in some phases, represents an ideal subject for detailed investigation, as it allows a relatively more complete reconstruction of its petrogenetic history before critical evidence was obscured by protracted cooling, reciprocal reaction, deuteric activity and so on.

At present the writer inclines to the view that many of the intermediate and "basic" acid calc-alkali intrusive rocks are the products of silicic alkalic liquid/basic or intermediate rock hybridism, the silicic end-member in the process originating from partial melting of deeply-buried igneous, metamorphic or sedimentary rocks of suitable compositions. Although liquids ranging in composition from granitic to granodioritic may be involved in this process, it would be expected that lime-poor granitic liquids would be more easily generated as a consequence of their lower liquidus temperatures. It is highly likely that the calc-alkali series is polygenetic. For certain rocks a relatively complicated origin is possible, e.g. a basic granodiorite may arise from silicic liquid/solid diorite hybridism, the dioritic end-member resulting initially from the sialic modification of basic magma with high-alumina affinities.

Several lines of research appear promising in more precisely defining some aspects of calc-alkali genesis. Data on the isotopic composition of strontium may indicate whether some calc-alkali series are adequately referable to contamination, remelting processes or to fractional crystallization of basaltic magma (Faure and Hurley, 1963). Analytical data on schlieren within lava flows are desirable to delineate differentiation trends provided by the rocks themselves (*cf.* Kuno, 1960, pp. 139-140). In Figure 1 points H1 and H2 are respectively a high-alumina porphyritic olivine-basalt from Huzi volcano and an aphyric andesite, occurring as a thin schlieren in H1. The trend of differentiation is not typically that of the calc-alkali series. Of particular importance in future studies is the more precise evaluation of the nature of the basic rocks that have participated in calc-alkali genesis, particularly the role of the so-called "central basalts".

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VOLUME 100

PARTS 1 - 4

1966-67

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Journal and Proceedings, Royal Society of New South Wales, Vol. 100, pp. 1, 1966

The Centenary Dinner of the Royal Society of N.S.W.

On 8th June, 1966, the Centenary Dinner of the Royal Society of New South Wales was held in the Sapphire Room of the Australia Hotel, Sydney.

The Royal Society of New South Wales appears to have had as its progenitor the Philosophical Society of Australasia, founded in 1821. It functioned actively for only a brief period, but was revived in 1850 as The Australian Philosophical Society. This was remodelled five years later as The Philosophical Society of New South Wales, and in 1866, by Royal assent, assumed its present title, the event whose centenary was celebrated.

Since its inception Vice-Royalty has always been associated with the Society, and, indeed until 1880, the State Governor was its *ex-officio* President. At present it is under the joint patronage of the Governor-General and the State Governor.

The Society was most grateful that on the occasion of its Centenary Dinner His Excellency the Governor of New South Wales, Sir Roden Cutler, V.C., K.C.M.G., C.B.E., and Lady Cutler were able to be present.

After the proposal of the toast to Her Most Gracious Majesty Queen Elizabeth II, the President of the Royal Society of New South Wales, Professor A. H. Voisey, welcomed the Governor and Lady Cutler to the function and commented on the traditional association of Royalty and Vice-Royalty with the scientific societies since the founding of the Royal Society of London by King Charles II in the year 1660.

His Excellency replied and commented upon the importance of scientific work in our modern civilization and on the contributions of Australian scientists.

The toast to Modern Science was then proposed by Professor Le Fevre.

Journal and Proceedings, Royal Society of New South Wales, Vol. 100, pp. 3–5, 1966

The Toast, Modern Science

R. J. W. Le Fevre (June 8, 1966)

Mr. President, Your Excellency, Ladies and Gentlemen :

I submit that it is appropriate that science should be honoured in this country and by the present company.

History shows that the utility of pure science cannot be tested in advance. Many here present will have seen the tablet, unveiled in 1822 by His Excellency's distinguished predecessor, Sir Thomas Brisbane, which stands on the south head of Botany Bay. Below the date 1770 it states : " Under the auspices of British Science these shores were discovered by James Cook and Joseph Banks . . . This spot once saw them ardent in the pursuit of knowledge ". As Cook's expedition was organized at the request of the Royal Society of London, and its main purpose was to observe the transit of Venus from Tahiti, Australia's very beginning was thus a by-product of pure science . . . an unforeseen utility from astronomical research.

It happens therefore that the growth of Australia has been roughly contemporaneous with the growth of modern science.

Fifty years ago it used to seem that no century could surpass the nineteenth for the scope, velocity, and complexity of its events. After all, the nineteenth century had seen the fall of Napoleon, the British conquest and administration of India, the American Civil War, the political reunification of Germany and Italy, the slow spread of religious toleration, of education, and a sense of public responsibility. The conditions of economic life were changed by steam power, the iron industry received an unexpected impetus from coal, and Britain, a half-century before the rest of Europe, was building up a type of industrial capitalism destined to be copied all round the world. More by man's increasing power over nature than by advances in the art of government, the population of Europe and the U.S.A. grew, over about 100 years, by hundreds of millions. To feed, clothe, house, transport, keep in health, and employ such numbers, the results of science became more and more used in manufacturing, in agriculture, in hygiene, in medicine . . . . new forms of power and rapid communication were found in the applications of electro-magnetism, and the first of a new variety of technologically-based industries arose, the chemical industry.

In short, science seemed to be entirely justified by its advantageous results.

But the record of the nineteenth century pales before that which we already know of the twentieth, during which the reciprocal stimulations of science and technology have induced the production of new knowledge at exponential rates, so that by about 1920 science was already a complicated network of facts and theories, too vast for any one man's comprehension.

Nevertheless, science had brought, and was continuing to bring, many benefits to human happiness, health, comfort, and convenience . . . it was helping commerce and industry . . . it was adding to amusement, culture, and the arts. Synthetic fibres, plastics, drugs, air travel, electronic entertainment . . . all these things were at least bringing profits to their promoters !

It is, however, worth remembering that these technological applications were derivatives of, and were made possible by, pure scientific discoveries fundamentally due to a few pioneers working internationally with common aims, with—as one might say—no tariffs or visas to hinder the flow of new ideas.

I put it to you that even in the middle twenties, science exhibited many admirable qualities, of which I will mention three : it was *international* in spirit and operation (conducing more to the uniting of men than the dividing of them), it was *intellectual* (accepting that science is the attempted correlation of observed phenomena to rational schemes, science depends on honesty and truth), and it was *non-political.*

Even after the First World War, science was still almost disregarded by governments.

It certainly had been before. The story is told that Faraday, when demonstrating to Gladstone what in effect was a prototype electric motor, was asked: "What is the use of that?", and replied: "Some day you may be able to tax it". I mention this to illustrate the likelihood that the nineteenth century official view was that science was a harmless amusement of a small minority of the population. Even in more recent times it is, in retrospect, remarkable how little attention was paid to Einstein when, in 1905, he drew attention to the inter-relationships of matter and energy, or to Rutherford when, in 1919, he effected the first atomic disintegration . . . and yet what consequences have come from these ideas.

The whole situation has been changed by the Second World War, after which our society has rapidly developed a science-based technology.

Can we now hope that the advantages of science will continue to flow without abatement? It may well be that mankind has eaten the fruit of the tree of knowledge, and that angels with flaming swords are already visible on the horizon and are beginning to hinder progress.

Many of mankind's problems arise from the differences in the rates of change of science and technology on the one hand, and of social systems and attitudes, on the other. These different rates are causing tensions both of an intra- and international kind. The international tensions are clearly displayed and are mainly due to the applications of science to warfare. Intra-national tensions may be less immediately obvious but can be seen in the difficulties caused by automation, the struggle to maintain standards of living among expanding populations . . . or in the social consequences of the widening distribution of oral contraceptives — yet *we* remember that these substances are merely the outcome of pure research into physiology, anatomy, pharmacology, organic chemistry, biochemistry, endocrinology, etc.

Most governments now recognize that scientific research and its application is vital to the maintenance and progress of a nation; unfortunately it is often thought that technological achievements have international prestige values; and it is undeniably true that science and technology together are requiring great increases in the expenditure of public moneys, particularly for education and what is called "defence". Some governments are creating Ministers of Science. In fact, science is now part of "active" politics—a situation which would have been unthinkable about 1910.

One of the greatest difficulties for science today is its reconciliation with politics. Governments are not in general controlled by the governed, and politicians take a short view—depending on the intervals between elections—of their policies. Serious science is not nearly as popular as the popularity of science fiction would suggest.

Can we be confident that, faced with future catastrophic change, our rulers will act scientifically, or could a shallow analysis be produced to show that "science is to blame"? Would science be made a scapegoat? Perhaps . . . remember that when things were not smooth in early Rome, it was convenient to persecute the Christians; and in our time Hitler took similar action against the Jews. Political pressures *have* been applied already, during the last two decades, to scientific workers in Russia and the U.S.A.

We have grown familiar with "secret" work, and we are aware that scientific advances are often being equated with "national security". It is no longer a valid boast that "science has no frontiers".

Then there are other hindrances which come from the very success which science has had. For example, there are difficulties arising from numbers . . . 90% of all scientists who have ever lived are now at work; associated with them are science-based industries, technological and other workers; a high fraction of these are engaged directly or indirectly "with defence". What would happen if peace should really break out? Could we be confident that there would be re-employment or deployment, or would there be unemployment among what, for brevity, we could call the intelligentsia?

Another hindrance to progress is the sheer volume of scientific publication. It is reported that the numbers of scientific papers are doubling every fifteen years, and in chemistry every eight to ten years. In 1963, in pure chemistry alone, some 32,000 papers appeared, i.e. 85 to 90 per day . . . So you see it is quite impossible for a man to be well-informed and educated *even* in that part of science which he considers to be his specialty.

Yet another difficulty arises from education and recruitment. The ratio of science graduates to those in arts is falling in most universities in the English-speaking world.

Accordingly, with official secrecy on one hand, and with a diminishing proportion of scientific understanding in the total population on the other, can we depend on an accurately-informed future general public? Now . . . " democratic government, when it cannot run on knowledge, is liable to do so on prejudice ".

Then there are hindrances of a more general kind, which, however, to scientific workers are quite serious. By nature these are ethical. We know that all knowledge can be used for good or evil. Are we justified in doing good when the foreseeable consequences are bad? Take a country tottering on the verge of starvation; is it good to rid it of malaria by applying scientific knowledge, and thus add another million to its already too large population?

To an individual there may come a more personal problem. If one isolates from a plant or a bacterium a substance which proves to be even more poisonous than botulin, and does so by an operation so simple that even a second-year chemistry student could repeat it, should one publish this work as a contribution to knowledge, or should one suppress it, and thus prevent it being used by potential criminals?

Behind all this, though, is the great growth of human population . . . man's fundamental problem at the present time, if he only knew. In 1956 the mean growth rate was quoted at 1·6% per annum, recent figures give 1·8%. This means that every nine years the contents of another India are added, or every year another 26 cities of Sydney. If the annual rate is divided into 70 one obtains the doubling time by compound interest . . . but the tragedy of human increase is that it is not just compound interest, but compound interest with the rate itself increasing.

There are said to be 24 reliable estimates of the world's population from the time of Christ up to 1958. These can be fitted to an empirical formula, and with this one can estimate that the rate will become infinite in A.D. 2027. I do not suggest that this situation will be reached, because before 2027 there will be too many people for the food available . . . worse, civil disturbances, famines, pestilences, etc., will interfere with the extrapolation, but A.D. 2027 is a vivid way of reporting the continuing trends of the last 1900 years.

What is the cause? Is science to blame? If Adam had not eaten the apple . . . if we had not had the knowledge on which to base our scientific, technological, and medical advances, this situation would not have occurred. Adam would still be in the Garden of Eden if a dictator had cut down the Tree *before* it produced the fruit!

There are well-meaning people among us now who think that certain types of research should be suppressed for fear of the consequences of uncontrolled experiment. Perhaps the science of matter has outstripped the science of man.

To summarize and conclude: the analytical and synthetical operations of human minds have produced a body of knowledge capable of use for immense good—and immense evil. Modern science deserves to be honoured and can justly be honoured as the greatest co-operative achievement in the history of mankind. Let us work and hope that in the balance it may ultimately be the salvation and not the destruction of our successors.

Thinking tonight more of the brighter aspects, I give you the toast " Modern Science ".

Journal and Proceedings, Royal Society of New South Wales, Vol. 100, pp. 7–8, 1966

Reply by K. E. Bullen to toast 'Modern Science' (June 8, 1966)

Mr. President, Your Excellency, Ladies and Gentlemen, in being asked to respond to the toast 'Modern Science', I have been granted a very great privilege.

Within the lifetime of the Royal Society of New South Wales, science has brought into being such things as wireless waves, the aeroplane, the nylon stocking, penicillin, and the space vehicle. Science has transformed the whole mode of life in many communities. It has shortened communications, contributed to a population explosion, and altered the whole machinery of war. It has changed the tempo of living and added countless human amenities.

So great has been the material and technological impact that it is sometimes overlooked that science has qualities beyond the merely material—has what might be called a spiritual side.

I am one of those who still like to look at science in the old-fashioned way as the advancement of knowledge for the sake of knowledge. Under this simple definition, science has, over the last several centuries, come to be respected for an intellectual integrity unsurpassed on this planet. This integrity, the spiritual essence of science, is to my mind more precious than all the current material manifestations, undeniably great as the latter are. A paradox of our times is that the very advances of modern science have led to new problems in guarding the spiritual tradition. It is perhaps fitting that a reply to the toast 'Modern Science' should take a look, even if necessarily superficial, at some of these problems.

I mention first a troublous question which demands the clearest thinking that mankind can bring to bear. This is what to do about discoveries that are or can be turned to human disadvantage—the might of nuclear energy and the lethal potentialities of some germ cultures, for example. The question goes of course beyond the fields of science that are involved, and I mention here only one aspect which touches on scientific integrity. This is the tendency on the part of some groups of scientists (I am not questioning their good intentions), when discussing the question, to identify their private consciences with what they refer to as the scientific conscience, a very different thing. It is then but a short step to involving the scientific conscience in matters of political controversy and, so far from helping with the problem, aggravating it and also damaging outside respect for science. This is but one instance of a new class of problem affecting scientific integrity.

The wider problem is the general entanglement of scientific discoveries with the burning human controversies of the day. Time was when the average scientist could pursue his lonely way, perhaps mildly exasperated that most of the world couldn't care less about even his best work, but at least assured that he could unmolestedly pursue knowledge for the sake of knowledge. Nowadays there are few fields in science which do not have some political aspects. Fortunately, the majority of scientists have so far been able to maintain the expected integrity and to keep their judgments on scientific questions unsullied. But there is still a problem to be watched. For example, one sometimes notices a remarkable correlation between the interpretation of results in fields such as nuclear fall-out and the left- or right-wing views of the scientists concerned.

Perhaps more menacing at the moment is the problem that springs from the colossal scale of expenditure now needed in advancing knowledge in some fields. The problem arises because those who hold the purse-strings are often puzzled to know where the greatest needs genuinely lie. Increasing numbers of scientists now take time off scholarly activities for the purpose of case-making, and the making of cases presents a challenge to intellectual honesty. Disconcertingly often, one hears 'off the record' comments that a little straining of the facts is a necessary precaution against being left behind in the ruthless race for funds. How to avoid this creeping encroachment on scientific integrity is becoming one of the more serious problems of the day.

The problem is closely linked with the many-sided problem of science and publicity—how to communicate some understanding of science to those outside. In a forthright address to the Australian Academy of Science last month, Lord Casey made a strong plea for scientists to give more attention to publicity, and especially to make their findings more intelligible to those in the higher echelons of government. The problem as I see it is how to publicize without at the same time destroying the soul of science.

At present we sometimes see publicity campaigns in the name of Science, successfully squeezing needed finance from governments as well as businessmen by methods which make the scholar squirm. Even on better levels, attempts to publicize commonly concentrate heavily on the spectacular and utilitarian sides. These sides are not to be disparaged, but the result is often a serious imbalance in the representation of science.

I think it is probably too high an aspiration to suppose that modern science can ever be really put in proper perspective to the layman, however much scientists might wish it. Years of hard discipline are a pre-requisite to any real comprehension of the depth of scientific contributions to man's cultural needs. I think much can be done towards rectifying the worst publicity distortions, though only by a long process of sound education. For the present, I think Australia acts wisely in delegating responsibilities to committees chaired by scientists of the calibre of Professor Robertson.

How to go about the process of education is yet another big problem. The intensity of the problem is illustrated by what goes for news in science in even the better sections of the daily press. Sometimes items are selected as newsworthy which are not much more than a mimicry of meaningless jargon. We see a big disproportion in the press assessment of scientific worth—the building up of great scientists from local and self-assessments, the creation of father figures, the bolstering of the showy and the disdaining to notice unostentatious work of significant importance—all contributing to the false public image of science. Of course it is not always quite as bad as that, and it is perhaps unfair to make a scapegoat of the press which generally means well and is after all a mirror of public thinking. The level of public thinking on science is, however, an index of the difficulty in getting the message of science through to the community. The problem is accentuated by the population explosion inside the ranks of science itself, resulting in a widening spectrum of scientific integrity where questions of publicity enter.

The problem of education cries out for attention if only for the reason that some understanding of the workings of the natural world has become as much a part of needed everyday culture as are music, literature and the arts. What is basically wanted is not superficial accounts of the latest scientific sensation or technological triumph, but some notion of the processes of thought through which the great ideas are arrived at. And yet even on the first level of elementary science teaching, it seems to me that false steps are taken.

Amid all the recent fanfare on school syllabuses and laboratory amenities, we have heard little about the vital need for clarity of thought and expression in science. So far from being models of clear argument, modern text-books in elementary science put out elementary fallacies that would not be countenanced in the oft-despised humanity subjects. There is a serious risk of modern science teaching becoming a training in ritual and authoritarianism rather than in scientific method. How can the non-scientist see science as a culture if his teachers and his text-books proffer arguments that are palpably unsound ?

I have made scattered comments on a few problems that seem to me to require vigilant attention. I hasten to add that they have come upon modern science as a direct consequence of its very greatness, and I would not like to leave the forest of greatness obscured by a few of the trees. Whatever the problems, nothing can detract from the grandeur of modern scientific endeavour and attainment—the toast to which we have just drunk with fitting enthusiasm. At its best, modern science is perhaps the masterpiece of the human race.

I should also be remiss if I did not take this opportunity of paying, on behalf of us all, high tribute to our Royal Society of New South Wales in respect of all the matters I have mentioned. The Society has been a guardian of scientific integrity throughout its whole century of history. In its interpretation of scientific happenings to the community, it has made unobtrusive but notable contributions to this city's culture. May the Royal Society of New South Wales and Modern Science together flourish far into the future.

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The Clarke Memorial Lecture for 1965

The Early Upper Cambrian Crisis and Its Correlation

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Abstract—In the early Upper Cambrian in Australia and elsewhere a profound faunal change passed by in conditions of physical, depositional continuity at the turn of the Mindyallan and Idamean stages. All species of the earlier, Mindyallan, populations of trilobites expired abruptly and were immediately followed by new forms in the Idamean time. The crisis was sudden but transient and involved the life of the shallow seas in the first place; the phyletic continuity of the trilobite class, however, was not interrupted because the oceans offered chances of escape not available in the shallows.

The honour of being invited to deliver the Clarke Memorial Lecture for 1965 gives me the opportunity of presenting some results of my studies concerned with the geological history of the Cambrian Period. I have been engaged in the study of Australian Cambrian geology and palaeontology since 1948 as an employee of the Commonwealth Bureau of Mineral Resources, Geology and Geophysics; after retirement I was invited to carry on with the same work in the same Bureau and with its facilities—an office room, laboratory, library, collections and assistants. I wish to present now some of the results of my current palaeontological and stratigraphic investigations, part already published, and part even in the form of 'desk notes'.

The notion of a faunal crisis, and not simply of a 'palaeontological break' came in sight as a consequence of the study of the early Upper Cambrian Agnostacea of north-western Queensland against the background of a review of all hitherto known agnostids and their geographic and temporal distribution. The findings regarding the critical faunal change at the turn of the stages were published first somewhat dogmatically (Öpik, 1963) because at that time almost nothing was known in print of the large and diversified trilobite fauna of the Mindyallan of Australia. This blank in palaeontological and stratigraphic information is about to disappear (Öpik, 1966) and I am exploiting in this lecture the forthcoming evidence regarding the reality of the early Upper Cambrian faunal crisis and its correlation.

Arriving at the topics of the lecture, I shall present first a brief summary of its contents and follow up with stratigraphic data which are necessary for a coherent presentation of the rest.

The faunal crisis is manifest in the extinction of the marine fauna of the early Upper Cambrian Zone of *Glyptagnostus stolidotus*—the final zone of the Mindyallan Stage. The event refers to a rather brief interval of time at the turn of the Mindyallan and the Idamean Stages. None of the eighty species of trilobites recorded in the *Glyptagnostus stolidotus* Zone in Australia survived to cross the turn of the stages and to pass over into the initial Idamean. At the onset of the Idamean a new fauna appeared in the region and gradually gained in numbers of taxa and populations. An abrupt faunal break contemporaneous with the Mindyallan crisis was discovered already half a century ago in the early Upper Cambrian of China, and afterwards in North America. Faunal breaks are common in marine sequences at various levels of the geological time scale, and are referable to non-deposition, or to epochs of uplift and erosion, or to intervention of volcanic episodes, as well as to combinations of several kinds of geological events. The faunal crisis at the turn of the stages, however, is no such break: it passed by in conditions of continuity of deposition and without any signs of concurrent physical changes in the character of strata.

The crisis represents an exceptional case of simultaneous extinction of marine populations in diverse places remote from each other. It needs, therefore, elucidation regarding the scale position and stratigraphic correlation of the involved sequences and a review of the extinct and survived faunas; why the phyletic continuity of the trilobites in general was not interrupted by the crisis must also be explained, and possible cause, or causes discussed. I will also comment briefly on the stratigraphic utility of the datum provided by the crisis at the turn of the stages.

Geological events of an inorganic or biological nature must be dated by referring them to positions in the geological time scale. The Cambrian part of the time scale relevant in dating the crisis is as follows:

(D) Middle and late Upper Cambrian: not considered further

EARLY UPPER CAMBRIAN:

(C) Idamean Stage, of five zones. The initial zone of this stage is
The Zone of *Glyptagnostus reticulatus* and *Olenus ogilviei*

The faunal crisis at the turn of the stages

(B) Mindyallan Stage:
Zone of *Glyptagnostus stolidotus*
Zone of *Cyclagnostus quasivespa*
Zone of *Erediaspis eretes*
Zone of the Middle/Upper Cambrian passage

(A) LATE MIDDLE CAMBRIAN and older; not considered further.

The designation Early Upper Cambrian covers the Idamean Stage (above) and the Mindyallan Stage (below): these stages are applicable in Australian stratigraphy in the first place, but are also recognizable by correlation in other lands in which different names and terms are in use for the same interval of geological time.

In America, for example, "Early Upper Cambrian" carries the name Dresbachian; our Mindyallan would be lower Dresbachian, and the Idamean equivalent was recently named the Pterocephaliid Biomere by Palmer (1965*a*, 1965*b*). In south-eastern Asia the Kushanian corresponds to the Mindyallan, and Paishanian to the Idamean, of Australian usage. The names Mindyallan and Idamean were introduced by Öpik (1963). The scale of zones and their names are finalized in Öpik (1966).

In our chart the compartment allotted to the faunal crisis at the turn of the stages occupies a span too wide as compared with the actual duration of the event itself, which passed almost in a nick of time: its duration amounted presumably to a fraction of the duration of a zone too short to be shown as a scale division.

As a matter of fact, in Australia, in China, and in North America palaeontologically well documented and uninterrupted sequences are known which display an abrupt discontinuity of the taxonomic contents between the populations of the Mindyallan and the Idamean ages. These palaeontological breaks are inseparably close to each other in time and even contemporaneous in the perspective of past time and within the accuracy of dating provided for by the geological scale. Hence, a datum is evident at the turn of the stages; it implies the simultaneity of the incidence of faunal breaks in diverse places and evokes the notion of a single event governed by a common cause.

We note that the record of the crisis is preserved in continuous sedimentary sequences and is independent of their lithological character; in such sequences there are no signs of physical events concomitant with the rapid and even dramatic biological change.

The phrase 'continuity of deposition, or of sedimentation' is usually applied as a positive corollary regarding the absence of visible physical breaks in a sequence of strata. The continuity of deposition at the turn of the stages, however, is particular in its geological significance and needs direct evidence as well.

It stands to reason that in conditions of continuous sedimentation some commingling of Mindyallan and Idamean faunal elements was inevitable in some places at the contact of the zonal sequences. Such sites of commingling are, however, rare; one example is known in the literature, described by Rasetti (1965, p. 30). He mentions that in one locality in Tennessee the "basal *Aphelaspis* Zone faunule yielded several species of trilobites representing a holdover of *Crepicephalus* zone forms"—the most convincing proof of continuity of deposition. Equally convincing is Rasetti's (ibid.) statement that 'at Russell Gap, a faunule that is considered to belong to the *Aphelaspis* Zone appears 3 feet above the typical *Crepicephalus* fauna, in a succession of massive limestone beds of uniform lithology". Consequently the *Aphelaspis* (early Idamean) and the *Crepicephalus* (=Mindyallan) zones and faunas succeed each other in time, and no intervening zone or fauna separates these divisions. Hence, palaeontological data are fully reliable in locating, or interpolating of, the position of the contact of the zones. This contact marks the position of the critical turn of the stages and in Queensland "manifests itself in the disappearance of the older and abundant Mindyallan fauna within a few feet of strata, followed by the immediate, gapless, arrival of the initial Idamean fauna with *Glyptagnostus reticulatus*" (Öpik, 1966, p. 35).

Visible physical breaks are common in all parts of the geological column, including the Upper Cambrian and its early part. Such episodic and local breaks eliminate pages of the palaeontological record and in sections of the early Upper Cambrian may prevent the study, and any conclusion regarding the character and position, of the turn of the stages. The crisis whose evidence is found in continuous sequences cannot be attributed to a physical break or breaks which are ultimately diastrophistic in nature. The continuity of the sequence, furthermore, excludes the presence of a hidden break, or a concealed physical hiatus separating the faunal entities at their contact. The term 'paraconformity' refers to such hidden physical breaks which are recognized only from the discontinuity of the fossil record known to be continuous in another place. The disguising factors are the geometrical conformity of strata and the invisibility of physical criteria of the discontinuity; local non-deposition leaving intact the floor of the paraconformity is one of several explanations. The significance of paraconformities in stratigraphy has been exhaustively discussed by Newell (1962).

The problem of paraconformities and invisible physical breaks has some bearing on the correlation of the Mindyallan and Idamean faunas and strata, as seen in the following two quotations regarding two sections in Nevada:

1. Palmer (1965, p. 4) writes: 'The lowest beds containing an *Aphelaspis* (i.e. Idamean) fauna at McGill, Nev. are the temporal equivalent of the highest beds containing a *Crepicephalus* (i.e. Mindyallan) fauna in the Snake Range and elsewhere to the east';

2. According to Palmer (1962, p. 9), 'The only alternative would be to require disconformities at McGill and in the Snake Range, for which there is no positive faunal or physical evidence'. Note that this alternative preserves the correct superpositional order of the *Crepicephalus* fauna below *Aphelaspis* and invalidates the untenable idea of their temporal equivalence.

It appears to me that two paraconformities are indicated, one at McGill and another in the Snake Range, each in a somewhat different position, and that the denial of a 'positive faunal evidence' is plain injustice in the face of the palaeontological information produced by Palmer himself.

The evidence in hand is solely biological and is based on the comparison of the taxonomic composition of the Mindyallan and Idamean populations of trilobites. Comparison is relevant of the fauna of the latest Mindyallan Zone of *Glyptagnostus stolidotus* with the fauna of the earliest Idamean Zone of *Glyptagnostus reticulatus*, as developed in Queensland. These faunas have been recently described by Öpik (1966 and 1963 respectively). In the multizonal Mindyallan Stage 170 species of polymerid trilobites and agnostids have been identified and in its final Zone, of *Glyptagnostus stolidotus*, 81 species are concentrated. All these disappear at the turn of the stages and none survived to pass into the Idamean. The fauna of the early Idamean Zone of *Glyptagnostus reticulatus* is quite small, of about ten recorded species only. The number increases steadily with the advance of time and the total of Idamean species of trilobites reached an estimated 100. The temporal correlation on this level of the scale is remarkably accurate: *Glyptagnostus reticulatus* (Angelin) is a known ubiquitous time marker, and *Glyptagnostus stolidotus* Öpik (1961) occurs also in Siberia (under that name, but also disguised under the nomen nudum of "*G. fossus*") and in North America, in sequence with *G. reticulatus*.

Of particular significance in correlation of the Mindyallan with the Kushanian of China are the numerous species of the Damesellidae found in Queensland, in New South Wales (at Kayrunnera, west of Darling), in Tasmania, and at Cambridge Gulf in Western Australia. In Queensland, the damesellid *Stephanocare richthofeni* Monke, originally described from Northern China, occurs at the base of the *stolidotus* zone. The correlation with the Kushanian is also supported by the occurrence of three species of the Liostracinidae (*Liostracina* Monke) in the *stolidotus* zone; *Liostracina krausei*, a first discovery in China by Monke (1903), occurs in Central Australia. The Damesellidae and the Liostracinidae were hitherto believed to be trilobites endemic in south-eastern Asia; their presence in Australia in force, by the way, favours the notion that the present position of the Australian continent in relation to Asia is palaegeographically the same as it was in the Upper Cambrian.

In China according to Walcott (1913, 1914) the Kushanian (=Mindyallan) fauna is immediately and abruptly replaced by the Paishanian (=Idamean) fauna without a single species or genus common to both, and, apparently for this reason, he regarded the Kushanian as the topmost division of the Middle, and the Paishanian as the initial Upper Cambrian stage. Furthermore, according to Kobayashi (1933) 'no interruption of sedimentation can be supposed to have occurred between the Middle and Upper Cambrian' (that is, between the Mindyallan and Idamean), 'but so far as the Asiatic Cambrian is concerned, the Kushan fauna completely disappears at the end of the Kushan period'. Consequently, the biological crisis at the turn of the stages is recorded in China as emphatically as it is in Australia.

In North America the profound faunal break separating the *Crepicephalus* zone (late Mindyallan in our terms) from the *Aphelaspis* zone (Upper Dresbachian; lower part of the Pterocephaliid Biomere; early Idamean of Australia) is a well established fact. It is exhaustively discussed by Lochman and Wilson (1958) and by Palmer (1962) and needs no further comment.

In the wake of the crisis large taxonomic entities of trilobites and populations of trilobites became extinct in the seaways of the globe. It is, however, important to consider that neither the phyletic continuity of the trilobite class nor its vitality was affected. The trilobites continued to diversify and proliferate, and expired gradually late in Palaeozoic time. Hence, at the turn of the stages areas of marine biotops existed in which extinction was prevalent, and other biotops whose populations had good chances to escape the impact and continue on the path of evolution.

The seaways in Mindyallan and Idameans times were open, and communication was maintained even between remote regions as seen from the palaeogeographic distribution of a number of species of agnostids and even polymerid trilobites. The postulated biotops were also communicating and received non endemic itinerants, even in swarms. Itinerants which at the onset of the crisis arrived in the wrong area died out, but populations of the same or related species in unaffected waters had a chance of survival. In brief, the trilobites were extinguished not according to taxonomic rolls, but according to their sites of occupation.

The extinction roll that follows refers, of course, to the 'present state of palaeontological knowledge', which is neither complete nor perfect: the number of unknown species is probably much larger than the few hundred species hitherto described from the Mindyallan sequences; the taxonomy of genera is fluctuating, and a genus of a wider vertical stratigraphic span can become split by a palaeontologist into smaller units, each of a shorter duration, and vice versa. Furthermore, a quantitative evaluation of the biological effect of the crisis is rather difficult: the numbers of taxonomic names in fossil lists provide for no quantitative measure because the number of species in the higher taxa is inequal; even at the generic level, some genera have only one species whereas, for example, *Pseudagnostus* has 36; and, needless to say, the number of specimens in a site can never be established. Furthermore, an individual trilobite grew by moulting and its exuviae would render any count of the number of individuals illusory.

The Agnostacea were severely depleted. Their diversification culminated in the Mindyallan as evident in Queensland. The stocks that survived comprise the Pseudagnostinae (*Pseudagnostus*), Agnostinae (but not *Agnostus*) and Trinodidae. These groups existed already in the Mindyallan, whose species, however, disappeared in the crisis. *Glyptagnostus*, as the genus, occurs on either side of the turn of the stages; the late Mindyallan *Glyptagnostus stolidotus*, however, differs greatly from the early Idamean *Glyptagnostus reticulatus*, which is phyletically unrelated to his predecessor. The Mindyallan and early Idamean species of *Aspidagnostus* are also quite distinct from each other. Of interest is the Idamean *Peratagnostus nobilis* Öpik (1966)—a rather modified peronopsid epigone whose roots are in the early Middle Cambrian; an Upper Cambrian peronopsid seems to be therefore an anachronism. The agnostids expired in the Middle Ordovician.

The polymerid trilobites constitute the bulk of their class; it is convenient to refer first to the fate of the Mindyallan species and to follow up with taxa of the higher ranks. All Mindyallan species expired in the crisis. Rasetti (1965) mentions a holdover of several species, however, that passed from the *Crepicephalus* zone into the base of the *Aphelaspis* (=Idamean) zone of Tennessee, but not higher up. Rasetti's (ibid. p. 36) list shows a total of six species in the lowermost part of the lower *Aphelaspis* zone three of which constitute the holdover. In the Idamean, especially in the Georgina Limestone of Queensland, the genus *Proceratopyge* is represented by several species and other species of the same genus are known in the late Middle Cambrian of Scandinavia—an example of a phyletic continuity within a genus, as well as of a stock that succeeded in by-passing the dangers of the crisis. The same applied to the Idamean *Corynexochus plumula* Whitehouse—an anachronistic epigone of several Middle Cambrian predecessors.

The Damesellacea, Nepeacea (Nepeidae and Menomoniidae), Liostracinidae, Crepicephalidae (*Crepicephalus*, *Tricrepicephalus*, *Meteoraspis*) and Cedariidae are examples of taxa which disappeared without progeny at the end of the Mindyallan time. The Lonchocephalidae and Catillicephalidae, however, deserve mentioning as survivals; these small trilobites common in the Mindyallan and close in size to the agnostids were possibly pelagic and continued their chain of diversification after the crisis. Notable in the Mindyallan of Queensland is the presence of Saukiidae, Dikelokephalinidae and Asaphidae hitherto thought of as late Upper Cambrian and Ordovician forms. Represented by few specimens each they were apparently visitors not really belonging to the biotops in which they perished.

To quote from Öpik (1966, p. 36), " it seems at first that with the disappearance of the Mindyallan fauna in Queensland the place became vacated and thus ready to receive the replacing Idamean trilobites. This picture is as erroneous as simple. Of course, a replacement is evident because nothing was left of the older populations. But if the Mindyallans (or their progeny) were still present, the Idameans would not be prevented from arrival and from commingling with the existing populations. This is born out by the fact that the Mindyallan fauna itself was composed largely by an influx from outside, and did not evolve on the spot."

The influx of the Idameans was rather modest; they arrived in a small number of taxa, and individuals, of about ten species in Queensland and somewhat less in North America. They drifted about as solitary itinerants or, rarely, in small swarms, as for example, *Olenus ogilviei* Öpik (1963), and reached finally the burial grounds of the Mindyallans. Equal in all respects to the Mindyallans and of a similar fertility, they cannot be regarded as " invaders " and were unfit to eliminate local populations, if such were present.

The cause of the crisis is obscure because its reality is revealed only in biological data related to the palaeozoogeographical scenery of its time. The biological effect is evident in the already presented extinction bill; the overall palaeozoogeographical marine scenery was, of course, multifacial; it consisted:

(1) Of a background of biotops in which the phyletic continuity of the trilobites was not affected by the crisis, and
(2) Of areas of action—the scenes of extinction.

The cause, presumably, acted universally, but its effect was redoubled and became lethal in combination with particular environmental conditions that prevailed in the areas of action. The universality of the cause and its transient character are sufficiently evident and should be accepted, but its intensity in terms of physics was low, and not everywhere intolerable in biological terms.

I postulate a sudden and transient increase of solar heat as a possible cause of the crisis. It has the merit of convenience for the presentation of all aspects of the event in a coherent form and shelves the difficulties and failures encountered in the search for biological and other terrestrial explanations. An explanation presuming an increase in cosmic radiation also has its merits, but its discussion is reserved for another occasion. Transient and recurrent epochs of decrease in solar heat are recorded in the glaciations of the past and of increase of heat in the history of terrestrial floras. In principle, therefore, our assumption is legitimate, but the possibility of an increase of solar heat of an intensity which lethally affected marine life in habitats remote from each other seems exceptional. Similar episodes were unknown hitherto in the geological history but future discoveries may lend support to the case in hand.

It can be speculated that the life of shallow coastal seas as well as of the surface waters of the oceans was simultaneously exposed to the impact of the cause. In the oceans the third dimension of the deep, upwelling, cool polar waters and the circulating currents offered chances of escape not available in the shallows. Thus, the oceans continued to supply itinerants, migrants, and ' invaders ' (Palmer, 1965) in all directions including the areas depleted in the crisis.

In the shallows, however, where the water was not deeper than the euphotic region, the water was heated up but remained out of reach of the relieving cool currents. The heat increased manifold the speed of oxidation of organic matter which extracted the oxygen in its turn. To claim that the temperature reached the boiling point in daytime would be science fiction, of course; but whatever it was the trilobites stopped breeding and died out.

The crisis provides for a datum level in the temporal scale of the Cambrian Period. The early recognition of its palaeontological break in China was exploited in stratigraphy; it was taken as the Middle/Upper Cambrian boundary by Walcott (1913, 1914) and accepted as such in the literature in the following decades, and the *Crepicephalus* fauna was also sometimes placed in the Middle Cambrian by correlation. To note, Monke (1903) who first described the Kushanian fauna placed it correctly in the Upper Cambrian ; Lu (1954), following an early suggestion of Sun Y. C., favoured its Upper Cambrian age, and in Australia Öpik (1956–1966) placed the Mindyallan in the early Upper Cambrian.

I conclude with quotations from Öpik (1966) regarding the practical stratigraphic value of the datum of the turn of the stages : In the history of the Cambrian Period and its life the Mindyallan/Idamean crisis was an important event, but the stratigraphic, applied significance of its physical aspect should not be overestimated. The crisis was real, abrupt as regards the brevity of its own time scale, and geographically universal. But being referable to inorganic causes which left no record in the rocks the event is not demonstrable on its own merit. The inorganic event was no crisis by itself, but its impact induced the biological crisis. Hence, the inorganic happening has little significance in correlation and dating of sequences because it is a phenomenon which itself must be uncovered and dated by biological means. In western Queensland it is dated, and correlated on the basis of universal fossil species that lived before (e.g. *Glyptagnostus stolidotus*) and immediately after (*G. reticulatus*) the crisis. The stages Mindyallan and Idamean, and their distinction from each other, are established solely on biological criteria. Even in absence of fossils of one of the stages the other, once known, can be safely identified and correlated without supporting evidence. The position of the turn of the stages in a section, however, can be established only on faunal evidence from both the stages in sequence.

No system or series boundary adheres to the turn of the stages, and its significant biological crisis. The nearest in time is the Middle Cambrian–Upper Cambrian transition which cannot be referred to as an exact ' boundary ' ; but no necessity exists to declare the Mindyallan–Idamean boundary a series boundary and thus create another set of Cambrian series.

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Occultations Observed at Sydney Observatory During 1964-65

K. P. Sims

The following observations of occultations were made at Sydney Observatory with the $11\frac{1}{2}$-inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. Since the observed times were in terms of coordinated time (UTC), a correction which was derived from *Mount Stromlo Observatory Bulletins A* was applied to convert to universal time (UT2). For 1964–65 a correction of +0·00972 hour (=35 seconds) was applied to the time in UT2 to convert it to ephemeris time with which *The Astronomical Ephemeris for 1964* and *The Astronomical Ephemeris for 1965* were entered to obtain the position and parallax of the Moon.

Table I

Serial No.	Z.C. No.	Mag.	Date	U.T.2	UT2–UTC	Observer
449	1308	4·7	1964 Mar. 23	13 31 37·87	—0·13	R
450	1208	6·4	1964 May 16	7 53 04·32	—0·07	W
451	1586	7·5	1964 May 19	11 42 55·03	—0·07	R
452	1897	7·4	1964 May 22	8 29 50·38	—0·07	R
453	2331	6·4	1964 Jun. 22	15 04 22·91	—0·10	R
454	2043	6·6	1964 Jul. 17	8 29 43·78	—0·11	S
455	2921	6·1	1964 Aug. 20	15 06 01·87	—0·13	S
456	2445	7·4	1964 Sep. 13	11 14 35·96	—0·04	R
457	2567	7·1	1964 Sep. 14	11 16 50·71	—0·04	S
458	2714	6·1	1964 Sep. 15	9 40 00·71	—0·04	R
459	3478	6·5	1964 Oct. 18	12 40 42·84	—0·07	W
460	3284	7·1	1964 Nov. 13	10 42 20·40	—0·08	R
461	3358	7·2	1964 Dec. 11	9 58 55·10	—0·13	R
462	628	4·8	1965 Feb. 10	11 38 44·96	—0·04	S
463	866	7·2	1965 Feb. 12	10 49 13·16	—0·04	S
464	1533	7·2	1965 May 9	7 43 32·77	—0·02	W
465	1621	7·5	1965 Jun. 6	9 52 21·54	—0·06	W
466	1739	6·5	1965 Jun. 7	10 48 43·57	—0·06	S
467	1976	6·9	1965 Jun. 9	15 23 18·79	—0·06	R
468	1978	6·6	1965 Jun. 9	15 53 13·68	—0·06	R
469	2088	6·2	1965 Jun. 10	16 43 59·18	—0·06	R
470	2056	7·4	1965 Jul. 7	14 15 16·02	+0·02	S
471	2008	6·6	1965 Aug. 3	9 52 53·00	0·00	W
472	2376	4·6	1965 Aug. 6	10 49 30·84	0·00	R
473	2659	6·4	1965 Aug. 8	13 53 15·71	0·00	W
474	2275	5·9	1965 Sep. 29	10 18 11·18	+0·03	R
475	2809	4·9	1965 Oct. 30	12 42 04·61	0·00	W
476	3304	6·4	1965 Nov. 3	9 29 13·67	—0·01	S

TABLE II

Serial No.	Luna-tion	p	q	p^2	pq	q^2	$\Delta\sigma$	$p\Delta\sigma$	$q\Delta\sigma$	Coefficient of $\Delta\alpha$	$\Delta\delta$
449	510	+93	+36	87	+34	13	−2·0	−1·9	−0·7	+13·7	+0·18
450	512	+97	+24	94	+23	6	−1·6	−1·6	−0·4	+13·6	+0·13
451	512	+35	−94	12	−33	88	+0·9	+0·3	−0·8	0·0	−1·00
452	512	+71	−70	51	−50	49	0·0	0·0	0·0	+ 5·6	−0·93
453	513	+98	+22	95	+22	5	−1·0	−1·0	−0·2	+14·2	−0·03
454	514	+10	−99	1	−10	99	−0·7	−0·1	+0·7	− 4·1	−0·96
455	515	+49	−87	24	−43	76	+1·0	+0·5	−0·9	+ 8·3	−0·80
456	516	+100	−10	99	−10	1	−1·4	−1·4	+0·1	+13·4	−0·29
457	516	+27	+96	7	+26	93	−0·8	−0·2	−0·8	+ 5·1	+0·93
458	516	+97	+24	94	+23	6	−1·0	−1·0	−0·2	+13·3	+0·22
459	517	+75	+66	56	+50	44	0·0	0·0	0·0	+ 6·4	+0·90
460	518	+87	−49	76	−43	24	−0·4	−0·3	+0·2	+14·3	−0·17
461	519	+81	−58	66	−47	34	+0·9	+0·7	−0·5	+14·3	−0·25
462	521	+49	−87	24	−43	76	−0·6	−0·3	+0·5	+ 9·8	−0·72
463	521	+71	−70	51	−50	49	+1·2	+0·9	−0·8	+10·2	−0·66
464	524	+78	−63	60	−49	40	+2·7	+2·1	−1·7	+ 7·4	−0·86
465	525	+46	−89	21	−41	79	+3·1	+1·4	−2·8	+ 1·2	−1·00
466	525	+99	−15	98	−15	2	0·0	0·0	0·0	+12·4	−0·55
467	525	+94	+33	89	+31	11	−0·1	−0·1	0·0	+14·8	−0·09
468	525	+98	+21	96	+21	4	−0·9	−0·9	−0·2	+14·5	−0·21
469	525	+65	−76	42	−49	58	+0·8	+0·5	−0·6	+ 4·6	−0·95
470	526	+62	+79	38	+49	62	−1·5	−0·9	−1·2	+12·9	+0·48
471	527	+36	+93	13	+34	87	−1·2	−0·4	−1·1	+10·5	+0·71
472	527	+99	+16	97	+16	3	−1·3	−1·3	−0·2	+13·9	−0·08
473	527	+66	+75	44	+50	56	0·0	0·0	0·0	+ 9·4	+0·72
474	529	+65	+76	42	+49	58	−1·9	−1·2	−1·4	+11·9	+0·54
475	530	+98	+18	97	+18	3	+0·4	+0·4	+0·1	+13·2	+0·24
476	530	+83	+56	69	+46	31	−0·4	−0·3	−0·2	+ 8·3	+0·82

The apparent places of the stars of the 1964–65 occultations were provided by H.M. Nautical Almanac Office.

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims, 1965). The observers were W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox* **1950·0** (Robertson, 1940).

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Minor Planets observed at Sydney Observatory during 1965

W. H. Robertson

The following observations of minor planets were made photographically at Sydney Observatory with the 9-inch Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular co-ordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial co-ordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in No. 1944, where the result is from only one image owing to a failure in timing the other exposure. No correction has been applied for aberration, light time or parallax but in Table I are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1965). The observers named in Table II are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Miss J. Doust and Miss B. Frank who have also assisted in the computation.

Table I

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1812	21	1965	May	12·56188	14	46	42·22	—13	01	43·8	+0·01	—3·1
1813	22	1965	July	14·67869	21	29	09·20	—33	20	20·0	+0·05	—0·1
1814	23	1965	May	26·63337	16	50	53·43	—23	36	23·6	+0·09	—1·6
1815	31	1965	July	27·63366	21	08	53·59	—53	35	49·6	+0·10	+2·9
1816	31	1965	August	17·58098	20	44	29·25	—53	56	24·5	+0·21	+2·8
1817	32	1965	June	09·59187	17	09	23·52	—17	12	16·8	+0·04	—2·5
1818	32	1965	July	05·50634	16	48	42·19	—16	15	00·5	+0·04	—2·6
1819	45	1965	July	14·59120	19	01	24·30	—15	37	36·4	+0·09	—2·8
1820	45	1965	July	26·54359	18	51	53·86	—16	26	37·7	+0·06	—2·6
1821	46	1965	June	15·62024	16	43	57·75	—18	31	53·8	+0·23	—2·6
1822	48	1965	April	13·61756	13	56	42·36	—07	48	37·9	+0·05	—3·8
1823	48	1965	May	03·55644	13	42	41·12	—06	00	46·2	+0·06	—4·1
1824	49	1965	July	07·59608	18	52	35·96	—23	11	08·6	+0·07	—1·6
1825	65	1965	Oct.	13·58839	01	26	03·19	+05	14	46·7	+0·03	—5·5
1826	71	1965	March	04·57156	10	50	20·87	—15	27	54·3	—0·03	—2·7
1827	71	1965	March	18·54179	10	33	37·76	—16	03	48·1	+0·03	—2·7
1828	76	1965	March	01·68022	12	28	24·47	—04	28	51·8	+0·07	—4·1
1829	76	1965	March	22·60563	12	14	48·63	—02	52	06·4	+0·04	—4·5
1830	78	1965	March	22·63500	13	24	51·64	—19	30	26·8	—0·01	—2·1
1831	78	1965	April	13·55910	13	03	34·27	—18	54	35·1	—0·02	—2·2
1832	80	1965	June	10·57940	16	58	15·63	—13	00	10·8	+0·03	—3·1
1833	80	1965	June	17·55237	16	51	03·81	—12	25	46·3	+0·02	—3·2
1834	90	1965	April	29·55887	13	19	41·88	—05	57	48·8	+0·08	—4·1
1835	91	1965	July	07·56314	18	40	58·51	—26	24	31·9	—0·01	—1·1
1836	91	1965	July	27·51479	18	23	17·52	—26	29	04·6	+0·05	—1·1
1837	92	1965	Oct.	13·66382	02	45	10·91	+01	53	01·1	+0·09	—5·1

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1838	96	1965	June	10·54994	16	21	15·62	−44	12	15·3	+0·03	+1·6
1839	98	1965	March	02·70954	12	57	49·60	−10	19	05·2	+0·11	−3·5
1840	98	1965	March	23·63654	12	38	15·82	−11	55	36·2	+0·10	−3·3
1841	103	1965	June	17·57863	17	54	19·38	−16	43	31·3	−0·03	−2·6
1842	103	1965	July	14·54056	17	31	53·52	−17	32	45·9	+0·13	−2·5
1843	107	1965	Sept.	23·53824	23	32	09·87	−03	06	00·1	−0·05	−4·5
1844	115	1965	March	01·64470	11	32	04·14	−10	36	08·9	+0·08	−3·5
1845	115	1965	March	23·58432	11	09	27·29	−09	24	47·5	+0·13	−3·6
1846	118	1965	August	24·64375	23	10	11·49	−18	42	44·8	+0·07	−2·3
1847	118	1965	Sept.	15·59038	22	48	47·23	−20	18	12·8	+0·14	−2·1
1848	124	1965	May	12·56188	14	48	27·50	−12	55	34·0	+0·01	−3·1
1849	154	1965	August	31·61726	23	50	50·87	−27	17	17·5	−0·05	−1·0
1850	154	1965	Sept.	22·58144	23	31	30·78	−27	55	14·6	+0·08	−0·9
1851	176	1965	March	30·58709	12	35	51·93	−09	46	26·1	+0·01	−3·6
1852	176	1965	April	22·50976	12	21	56·55	−06	34	39·2	−0·01	−4·0
1853	189	1965	April	29·62348	14	09	59·13	−11	09	16·4	+0·17	−3·5
1854	189	1965	May	04·56788	14	05	40·89	−10	36	03·3	+0·05	−3·5
1855	192	1965	March	03·67230	12	44	08·07	−08	27	36·7	+0·03	−3·7
1856	192	1965	March	23·61155	12	27	01·52	−07	24	55·7	+0·05	−3·9
1857	194	1965	Oct.	20·61568	02	22	13·77	−11	56	38·0	+0·05	−3·3
1858	194	1965	Oct.	28·59812	02	15	42·03	−13	07	47·0	+0·08	−3·1
1859	202	1965	August	17·65718	23	09	08·42	−10	21	41·9	+0·05	−3·5
1860	204	1965	April	14·57486	13	46	43·20	−10	37	08·1	−0·05	−3·4
1861	212	1965	August	03·67680	22	14	51·66	−09	31	32·0	+0·11	−3·6
1862	214	1965	April	28·67920	15	43	55·07	−24	58	08·4	+0·15	−1·4
1863	214	1965	May	04·64944	15	38	44·23	−24	49	07·9	+0·12	−1·4
1864	214	1965	June	03·53258	15	11	07·54	−23	18	52·6	+0·06	−1·6
1865	216	1965	May	12·65196	16	56	31·50	−12	45	00·7	+0·02	−3·1
1866	216	1965	June	09·56252	16	34	00·07	−10	37	59·3	+0·02	−3·4
1867	227	1965	June	01·56762	15	49	23·73	−35	34	41·3	+0·09	+0·2
1868	227	1965	June	07·53323	15	44	33·15	−35	07	57·0	+0·03	+0·2
1869	240	1965	April	29·55887	13	22	10·02	−05	21	47·1	+0·08	−4·2
1870	259	1965	Sept.	16·66310	00	54	31·19	−10	44	03·0	+0·10	−3·5
1871	259	1965	Oct.	12·58159	00	35	26·70	−12	30	16·5	+0·11	−3·2
1872	276	1965	April	22·57994	13	55	33·08	−11	41	57·6	+0·01	−3·3
1873	284	1965	April	29·59173	13	41	38·74	−16	08	48·2	+0·14	−2·7
1874	284	1965	May	05·55927	13	36	35·89	−15	07	10·2	+0·10	−2·8
1875	287	1965	Sept.	23·56858	00	12	39·16	−10	08	54·8	−0·04	−3·5
1876	289	1965	June	07·67019	18	45	25·88	−12	59	19·1	+0·06	−3·1
1877	303	1965	July	22·63816	21	03	26·20	−23	03	16·4	+0·05	−1·7
1878	303	1965	August	03·62604	20	53	26·20	−23	27	55·8	+0·14	−1·7
1879	308	1965	July	06·62952	20	15	49·07	−13	19	04·7	−0·02	−3·1
1880	308	1965	July	15·61041	20	08	42·38	−13	42	37·3	+0·02	−3·0
1881	312	1965	August	09·67364	23	08	39·66	−14	21	16·3	+0·04	−2·9
1882	328	1965	July	27·59599	20	33	38·44	−37	00	24·2	+0·02	+0·5
1883	337	1965	August	17·52948	20	10	10·22	−29	20	17·7	+0·05	−0·7
1884	338	1965	April	22·63906	15	21	25·20	−26	29	19·0	+0·01	−1·1
1885	338	1965	May	26·55154	14	53	27·00	−24	14	39·7	+0·09	−1·5
1886	345	1965	April	22·57994	13	55	46·88	−12	09	42·8	+0·01	−3·2
1887	346	1965	April	20·61952	15	08	24·31	−07	14	59·7	−0·04	−3·9
1888	346	1965	May	05·59153	14	56	06·86	−06	34	56·3	+0·03	−4·0
1889	349	1965	April	20·65197	15	40	06·02	−23	04	51·9	−0·01	−1·6
1890	349	1965	May	03·62000	15	30	00·24	−23	05	26·2	+0·03	−1·6
1891	349	1965	June	01·52635	15	04	33·89	−22	29	12·5	+0·04	−1·7
1892	362	1965	Sept.	16·63245	23	44	59·56	−09	53	01·2	+0·15	−3·6
1893	362	1965	Oct.	13·52157	23	22	12·71	−10	26	28·5	+0·09	−3·5
1894	371	1965	July	27·55130	19	26	55·98	−19	23	24·7	+0·02	−2·2
1895	372	1965	June	30·66884	20	06	36·42	−40	20	20·7	+0·10	+1·0
1896	372	1965	July	22·56941	19	44	21·76	−40	17	17·7	0·00	+1·0
1897	376	1965	April	14·61569	14	54	43·60	−27	38	03·0	−0·08	−1·0
1898	376	1965	May	12·53462	14	29	45·75	−26	13	17·5	−0·04	−0·7
1899	396	1965	May	26·63337	16	56	16·56	−22	36	17·7	+0·08	−1·7
1900	403	1965	March	10·56769	11	00	44·96	−09	12	10·0	−0·02	−3·6
1901	403	1965	March	22·56541	10	51	46·88	−07	51	06·5	+0·10	−3·8

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1902	405	1965	March	11·62216	12	36	29·75	—26	55	24·5	—0·05	—1·0
1903	405	1965	April	14·54499	12	14	39·79	—23	34	35·6	+0·06	—1·6
1904	410	1965	June	01·67161	18	26	44·58	—18	40	39·5	+0·05	—2·3
1905	410	1965	June	16·60544	18	16	25·44	—20	32	52·1	0·00	—2·0
1906	410	1965	July	14·56291	17	53	29·54	—24	20	04·4	+0·16	—1·7
1907	413	1965	August	09·61404	22	10	19·24	—37	18	37·4	—0·03	+0·5
1908	413	1965	Sept.	14·58375	21	56	50·73	—45	22	05·5	+0·30	+1·3
1909	420	1965	July	07·63783	20	51	39·13	—09	24	44·1	—0·06	—3·6
1910	420	1965	July	28·60340	20	37	51·31	—09	49	22·8	+0·04	—3·6
1911	426	1965	July	05·63226	19	39	19·44	—33	38	53·0	+0·07	0·0
1912	426	1965	July	28·56241	19	14	47·01	—32	14	03·8	+0·11	—0·4
1913	432	1965	June	09·59187	17	06	26·48	—18	13	34·5	+0·05	—2·4
1914	432	1965	July	01·49470	16	45	29·58	—21	07	57·6	—0·03	—1·9
1915	453	1965	April	22·67120	16	03	11·60	—27	12	23·4	+0·02	—1·0
1916	453	1965	May	05·62472	15	53	09·67	—27	54	39·3	+0·10	—0·9
1917	454	1965	August	31·58508	22	29	43·05	—18	28	01·3	+0·03	—2·3
1918	454	1965	Sept.	20·53674	22	13	15·58	—19	09	45·6	+0·09	—2·3
1919	456	1965	June	03·56132	15	59	34·03	—12	59	10·7	+0·04	—3·1
1920	456	1965	June	09·53533	15	55	25·90	—12	06	37·2	+0·02	—3·2
1921	464	1965	Oct.	21·63270	03	00	43·34	+00	24	33·2	+0·03	—4·9
1922	466	1965	July	01·63494	19	36	37·62	—22	57	31·6	+0·04	—1·7
1923	466	1965	July	22·53741	19	18	28·93	—22	05	24·4	—0·05	—1·8
1924	466	1965	August	03·54674	19	09	13·25	—21	31	55·1	+0·11	—1·9
1925	468	1965	July	28·64286	21	18	05·14	—16	26	44·1	+0·08	—2·6
1926	470	1965	July	07·63783	20	48	32·50	—07	51	52·1	—0·05	—3·8
1927	470	1965	July	28·60340	20	31	07·51	—09	27	25·6	+0·06	—3·6
1928	471	1965	June	07·63402	18	27	54·29	—25	32	21·6	—0·02	—1·3
1929	471	1965	June	10·61779	18	25	26·89	—25	45	35·9	—0·04	—1·2
1930	471	1965	July	01·53892	18	05	42·25	—27	12	38·9	—0·07	—1·0
1931	476	1965	May	05·65640	16	44	36·57	—34	29	06·0	—0·01	+0·1
1932	476	1965	June	01·60208	16	20	08·18	—32	45	04·5	+0·13	—0·2
1933	480	1965	March	25·65862	13	43	48·81	—30	06	09·4	+0·05	—0·7
1934	480	1965	April	27·53179	13	17	59·20	—24	49	07·4	—0·02	—1·3
1935	488	1965	July	22·66852	22	01	09·00	—25	16	10·8	+0·01	—1·3
1936	488	1965	August	23·58496	21	38	06·87	—28	01	20·4	+0·08	—0·9
1937	504	1965	July	26·69810	21	27	39·20	—25	42	55·1	+0·23	—1·5
1938	504	1965	August	31·52119	21	01	35·39	—31	15	26·9	+0·03	—0·4
1939	514	1965	March	25·61738	12	52	48·37	—11	33	59·9	+0·03	—3·3
1940	514	1965	April	22·54536	12	32	38·06	—09	15	09·8	+0·08	—3·6
1941	532	1965	July	26·69810	21	29	08·72	—25	34	11·6	+0·22	—1·5
1942	532	1965	August	09·58700	21	17	23·94	—27	26	39·3	+0·01	—1·0
1943	545	1965	May	12·59338	15	59	00·42	—38	12	47·0	—0·05	+0·7
1944	545	1965	May	31·55385	15	40	48·94	—37	41	09·6	+0·04	+0·6
1945	546	1965	April	20·52822	13	10	41·13	—08	29	40·3	—0·07	—3·7
1946	546	1965	May	03·52798	12	58	27·95	—08	41	37·7	+0·07	—3·7
1947	554	1965	June	10·64923	19	13	22·03	—23	51	40·0	—0·04	—1·5
1948	554	1965	July	07·59608	18	46	58·90	—24	05	38·0	+0·09	—1·5
1949	554	1965	July	15·55519	18	38	33·21	—24	05	11·4	+0·04	—1·5
1950	563	1965	Oct.	12·61324	01	32	03·22	—08	55	54·4	+0·02	—3·7
1951	584	1965	March	11·53542	10	34	40·62	—06	45	19·4	—0·05	—4·0
1952	595	1965	Sept.	23·56858	00	19	53·33	—09	58	11·8	—0·06	—3·6
1953	595	1965	Oct.	21·52284	23	57	11·62	—09	42	08·8	+0·08	—3·6
1954	604	1965	July	27·67228	21	54	38·43	—18	21	28·9	+0·08	—2·4
1955	625	1965	Oct.	20·64252	03	29	57·66	—01	35	09·6	—0·01	—4·7
1956	679	1965	June	03·66400	18	48	03·57	—08	19	52·5	0·00	—3·8
1957	679	1965	July	01·57596	18	21	45·08	—11	47	56·6	+0·02	—3·3
1958	680	1965	April	29·62348	14	15	58·34	—11	51	31·6	+0·16	—3·4
1959	680	1965	May	04·56788	14	10	39·59	—12	06	04·3	+0·04	—3·2
1960	694	1965	June	03·56132	16	01	29·55	—13	27	35·8	+0·04	—2·9
1961	694	1965	June	09·53533	15	56	00·13	—12	32	43·5	+0·02	—3·2
1962	695	1965	July	07·63783	20	53	23·87	—06	37	52·6	—0·06	—4·0
1963	695	1965	August	09·53578	20	22	25·74	—04	02	53·6	—0·03	—4·4
1964	702	1965	March	04·54312	09	44	40·59	—08	48	51·8	+0·02	—3·7
1965	702	1965	March	10·52083	09	40	12·64	—08	32	53·8	+0·01	—3·7

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1966	722	1965	July	07·67826	20	42	24·35	—29	48	13·2	+0·10	—0·7
1967	783	1965	Sept.	23·60434	01	05	30·30	—06	33	04·2	—0·05	—4·0
1968	783	1965	Oct.	21·55520	00	42	15·12	—10	08	25·4	+0·09	—3·6
1969	796	1965	July	27·63366	21	03	57·95	—54	41	24·1	+0·12	+3·1
1970	796	1965	August	17·58098	20	36	38·12	—54	51	58·2	+0·24	+2·9
1971	814	1965	August	09·64392	22	29	05·97	—40	04	18·7	+0·04	+0·9
1972	910	1965	April	28·64786	15	23	53·12	—17	42	43·2	+0·09	—2·4
1973	910	1965	May	04·61142	15	18	40·57	—17	49	00·1	+0·03	—2·4
1974	914	1965	May	26·69094	17	50	48·01	—22	28	31·4	+0·15	—1·8
1975	914	1965	June	15·65244	17	29	45·67	—15	54	19·1	+0·24	—2·9
1976	980	1965	March	02·67749	12	37	57·44	—27	07	08·2	+0·05	—1·0
1977	980	1965	March	25·58338	12	19	44·57	—26	48	30·4	—0·01	—1·0
1978	1056	1965	July	22·63816	21	07	28·81	—21	07	50·9	+0·04	—1·9
1979	1056	1965	August	03·62604	20	58	07·71	—22	53	03·4	+0·13	—1·7
1980	1127	1965	Sept.	01·66144	00	27	56·95	—16	35	16·0	+0·02	—2·6
1981	1127	1965	Oct.	13·55580	00	02	31·37	—24	14	43·9	+0·11	—1·5
1982	1140	1965	August	31·61726	23	48	37·22	—26	32	46·9	—0·04	—1·1
1983	1140	1965	Sept.	22·58144	23	29	29·31	—28	04	54·9	+0·09	—0·9
1984	1197	1965	April	22·60984	14	32	49·80	—29	19	04·8	+0·03	—0·7
1985	1197	1965	May	03·58760	14	23	55·74	—27	40	34·9	+0·07	—0·9
1986	1319	1965	March	25·61738	12	50	53·81	—10	08	16·5	+0·03	—3·5
1987	1320	1965	May	26·66582	17	18	54·16	—24	06	53·7	+0·14	—1·6
1988	1320	1965	June	01·64008	17	13	03·89	—25	08	57·4	+0·12	—1·4
1989	1366	1965	July	27·59599	20	30	41·40	—35	16	08·5	+0·03	+0·2
1990	1366	1965	August	03·58592	20	23	52·12	—35	25	26·4	+0·09	+0·2
1991	1592	1965	July	06·66194	20	36	21·73	—22	44	59·7	+0·04	—1·7
1992	1592	1965	July	26·57356	20	24	55·74	—27	34	14·6	—0·05	—1·0

TABLE II

No.	Comparison Stars		Dependences			
1812	Yale *11*	5189, 5198, 5206	0·15766	0·49155	0·35079	R
1813	Cape *17*	11708, 11739, 11753	0·22575	0·42887	0·34538	W
1814	Yale *14*	11666, 11677, 11704	0·27846	0·38567	0·33588	S
1815	Cape *19*	8264, 8272, 8283	0·20270	0·29894	0·49836	S
1816	Cape *19*	8148, 8169, 8175	0·49353	0·26521	0·24126	S
1817	Yale *12* I	6141, 6143, 6168	0·23622	0·39361	0·37017	R
1818	Yale *12* I	6029, 6040, 6047	0·37531	0·40346	0·22122	S
1819	Yale *12* I	7047, 7048, 7079	0·34115	0·31370	0·34515	W
1820	Yale *12* I	6975, 6986, 6994	0·27917	0·47153	0·24931	S
1821	Yale *12* II	6833, 6855, 6867	0·46022	0·22454	0·31524	S
1822	Yale *16*	4952, 4966, 4983	0·24152	0·47884	0·27964	W
1823	Yale *17*	4920, 4922, 4931	0·16693	0·18664	0·64643	W
1824	Yale *14*	13123, 13132, 13174	0·37165	0·17597	0·45238	S
1825	Yale *20*	389, 411, *22* 545	0·24287	0·46144	0·29569	W
1826	Yale *12* I	4317, 4335, 4341	0·29154	0·40851	0·29994	W
1827	Yale *12* I	4222, 4226, 4243	0·42690	0·30325	0·26985	S
1828	Yale *17*	4598, 4612, 4619	0·30106	0·32649	0·37246	W
1829	Yale *17*	4541, 4543, 4554	0·23590	0·46770	0·29640	W
1830	Yale *12* II	5724, 5735, 5742	0·48612	0·28487	0·22901	W
1831	Yale *12* II	5613, 5622, 5637	0·15259	0·60601	0·24140	W
1832	Yale *11*	5822, 5826, 5835	0·39537	0·33913	0·26550	R
1833	Yale *11*	5786, 5793, 5811	0·47280	0·19510	0·33210	S
1834	Yale *17*	4825, 4827, 4839	0·30178	0·39386	0·30436	S
1835	Yale *14*	12993, 12994, 13025	0·55314	0·19624	0·25062	S
1836	Yale *14*	12752, 12774, 12789	0·36176	0·28312	0·35512	S
1837	Yale *20*	776, 781, 787	0·34768	0·44129	0·21103	W
1838	Cord. D	11401, 11433, 11441	0·50270	0·34088	0·15642	R

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1839	Yale *16* 4682, 4690, *11* 4685	0·25302	0·44827	0·29871	W
1840	Yale *11* 4580, 4582, 4601	0·44619	0·37780	0·17601	W
1841	Yale *12* I 6440, 6455, 6470	0·24779	0·42044	0·33177	S
1842	Yale *12* I 6286, 6307, 6313	0·25335	0·28457	0·46208	W
1843	Yale *17* 8085, 8088, 8097	0·33337	0·27364	0·39299	R
1844	Yale *11* 4302, *12* I 4320, 4332	0·37909	0·25612	0·36480	W
1845	Yale *16* 4207, 4215, 4231	0·40593	0·29874	0·29533	W
1846	Yale *12* II 9728, 9749, 9752	0·32342	0·25254	0·42404	W
1847	Yale *13* I 9632, 9638, 9651	0·44344	0·33031	0·22625	W
1848	Yale *11* 5198, 5206, 5216	0·30080	0·32632	0·37288	R
1849	Yale *13* II 15087, 15121, 15122	0·37020	0·37977	0·25003	R
1850	Yale *13* II 14964, 14967, 14999	0·31306	0·38459	0·30235	R
1851	Yale *16* 4599, 4612, 4619	0·37589	0·36980	0·25431	R
1852	Yale *16* 4548, 4562, *17* 4582	0·37226	0·28849	0·33924	R
1853	Yale *11* 4991, 5009, 5022	0·35835	0·30486	0·33679	S
1854	Yale *11* 4979, 4991, *16* 5012	0·33641	0·40088	0·26271	W
1855	Yale *16* 4632, 4637, 4642	0·32329	0·45380	0·22291	W
1856	Yale *16* 4564, 4578, 4586	0·31531	0·28306	0·40163	W
1857	Yale *11* 530, 552, 553	0·49377	0·21050	0·29574	R
1858	Yale *11* 509, 516, 526	0·35725	0·17598	0·46677	S
1859	Yale *11* 8108, 8124, 8133	0·16782	0·38322	0·44896	S
1860	Yale *11* 4894, 4912, *16* 4924	0·43714	0·26321	0·29965	W
1861	Yale *16* 7971, *11* 7873, 7875	0·28162	0·24212	0·47625	W
1862	Yale *14* 11119, 11122, 11153	0·43723	0·30240	0·26037	S
1863	Yale *14* 11073, 11089, 11100	0·21543	0·35034	0·43423	W
1864	Yale *14* 10835, 10866, 10869	0·35199	0·28184	0·36617	W
1865	Yale *11* 5809, 5818, 5828	0·34159	0·22158	0·43683	R
1866	Yale *11* 5725, 5734, 5738	0·27826	0·35399	0·36776	R
1867	Cape *18* 7835, 7842, 7855	0·33742	0·53942	0·12317	W
1868	Cape *18* 7764, 7812, *17* 8185	0·27079	0·34930	0·37991	R
1869	Yale *17* 4825, 4839, 4852	0·28066	0·32704	0·39230	S
1870	Yale *11* 177, 184, 196	0·27689	0·33994	0·38317	W
1871	Yale *11* 104, 122, 124	0·20332	0·54149	0·25519	W
1872	Yale *11* 4922, 4937, 4944	0·17213	0·33654	0·49133	R
1873	Yale *12* I 5159, 5172, 5177	0·23915	0·42958	0·33127	S
1874	Yale *12* I 5135, 5141, 5142	0·10025	0·51987	0·37988	W
1875	Yale *11* 27, 43, 44	0·47555	0·32887	0·19558	R
1876	Yale *11* 6424, 6450, 6452	0·15112	0·52057	0·32831	R
1877	Yale *14* 14556, 14585, 14604	0·37646	0·12250	0·50104	R
1878	Yale *14* 14496, 14497, 14526	0·27056	0·39954	0·32990	W
1879	Yale *11* 7146, 7156, 7164	0·40276	0·23444	0·36280	S
1880	Yale *12* I 7570, *11* 7093, 7127	0·28397	0·34527	0·37076	W
1881	Yale *12* I 8561, 8575, 8597	0·23790	0·37383	0·38826	R
1882	Cape *18* 10667, 10676, 10689	0·29489	0·34822	0·35690	S
1883	Yale *13* II 13282, 13284, 13323	0·38701	0·25328	0·35971	S
1884	Yale *14* 10919, 10942, 10956	0·26710	0·38490	0·34800	R
1885	Yale *14* 10691, 10713, 10725	0·28102	0·43699	0·28199	S
1886	Yale *11* 4922, 4944, 4947	0·29607	0·34006	0·36387	R
1887	Yale *16* 5292, 5310, 5311	0·27175	0·27565	0·45260	R
1888	Yale *16* 5240, 5250, *17* 5265	0·32909	0·47703	0·19388	W
1889	Yale *14* 11078, 11107, 11108	0·18247	0·38667	0·43087	R
1890	Yale *14* 11008, 11015, 11031	0·31502	0·40185	0·28314	W
1891	Yale *14* 10787, 10821, *13* I 6256	0·40638	0·42254	0·17108	W
1892	Yale *11* 8261, 8268, 8270	0·21431	0·45515	0·33054	W
1893	Yale *11* 8167, 8182, 8189	0·35228	0·28471	0·36301	W
1894	Yale *12* II 8328, 8334, 8359	0·32326	0·39628	0·28046	S
1895	Cord. D 14650, 14667, 14693	0·22450	0·30830	0·46720	R
1896	Cord. D 14446, 14476, 14482	0·24506	0·47781	0·27713	R
1897	Yale *13* II 9401, 9412, 9433	0·19885	0·53227	0·26888	W
1898	Yale *14* 10466, 10478, 10495	0·21696	0·47516	0·30788	R
1899	Yale *14* 11714, 11756, 11762	0·42615	0·29201	0·28184	S
1900	Yale *16* 4169, 4179, 4183	0·22970	0·31809	0·45221	R
1901	Yale *16* 4118, 4132, 4137	0·21050	0·37942	0·41008	W
1902	Yale *14* 9471, 9500, 9513	0·23787	0·33272	0·42941	R
1903	Yale *14* 9272, 9295, 9305	0·38752	0·26315	0·34933	W
1904	Yale *12* II 7719, 7722, 7738	0·32397	0·37788	0·29815	W

Table II—*continued*

No.	Comparison Stars	Dependences			
1905	Yale *13* I 7599, 7637, 7650	0·52126	0·26264	0·21610	S
1906	Yale *14* 12264, 12284, 12300	0·39000	0·23440	0·37560	W
1907	Cape *18* 11361, 11381, 11407	0·19433	0·35750	0·44817	R
1908	Cape Z. 19650, Cord. D 15674, 15711	0·22935	0·36124	0·40941	W
1909	Yale *16* 7473, 7488, 7506	0·15544	0·67154	0·17302	S
1910	Yale *11* 7311, 7314, 7318	0·28905	0·19184	0·51910	S
1911	Cape *17* 10711, 10756, 10760	0·43223	0·26052	0·30725	S
1912	Cape *17* 10504, 10509, 10543	0·30151	0·42921	0·26928	S
1913	Yale *12* II 6984, *12* I 6129, 6147	0·40073	0·17192	0·42734	R
1914	Yale *13* I 6846, 6853, 6877	0·27020	0·60243	0·12737	R
1915	Yale *14* 11309, 11321, *13* II 10092	0·35341	0·32927	0·31732	R
1916	Yale *13* II 9983, 9988, 10015	0·44467	0·26456	0·29077	W
1917	Yale *12* II 9530, 9543, 9552	0·42744	0·31721	0·25536	R
1918	Yale *12* II 9444, 9468, *13* I 9466	0·26600	0·28499	0·44900	R
1919	Yale *11* 5548, 5556, 5567	0·54676	0·16098	0·29226	W
1920	Yale *11* 5519, 5544, 5552	0·41422	0·20712	0·37866	R
1921	Yale *21* 639, 642, 657	0·21498	0·42211	0·36291	R
1922	Yale *14* 13670, 13687, 13721	0·31482	0·40580	0·27938	R
1923	Yale *14* 13455, 13482, 13487	0·50152	0·22451	0·27397	R
1924	Yale *13* I 8130, 8162, *14* 13333	0·26206	0·39471	0·34323	W
1925	Yale *12* I 8021, 8048, 8052	0·32137	0·15295	0·52568	S
1926	Yale *16* 7459, 7464, 7471	0·26689	0·47666	0·25645	S
1927	Yale *16* 7301, 7304, 7325	0·37950	0·23748	0·38302	S
1928	Yale *14* 12802, 12816, 12879	0·38289	0·25288	0·36423	R
1929	Yale *14* 12774, 12802, 12816	0·28967	0·35503	0·35530	R
1930	Yale *13* II 11669, 11719, *14* 12505	0·24732	0·27708	0·47560	R
1931	Cape *17* 8762, 8784, 8795	0·20389	0·31201	0·48410	W
1932	Cape *17* 8519, 8522, 8570	0·31475	0·46949	0·21576	W
1933	Yale *13* II 8711, 8735, 8736	0·50754	0·24234	0·25012	W
1934	Yale *14* 9837, 9852, 9869	0·23659	0·29643	0·46698	S
1935	Yale *14* 15058, 15061, 15094	0·34973	0·56740	0·08288	R
1936	Yale *13* II 14169, 14209, 14217	0·39177	0·35790	0·25034	W
1937	Yale *14* 14788, 14791, 14822	0·41914	0·31718	0·26368	S
1938	Cape *17* 11497, 11503, 11529	0·26261	0·34487	0·39252	R
1939	Yale *11* 4637, 4646, 4652	0·29961	0·20777	0·49262	W
1940	Yale *16* 4594, 4602, 4605	0·65715	0·15380	0·18905	R
1941	Yale *14* 14788, 14791, 14822	0·20484	0·18935	0·60581	S
1942	Yale *13* II 13992, 14029, 14035	0·29068	0·42240	0·28693	R
1943	Cape *18* 7932, 7933, 7955	0·14072	0·56245	0·29684	R
1944	Cape *18* 7743, 7766, 7770	0·28759	0·47476	0·23764	W
1945	Yale *16* 4733, 4750, 4760	0·47566	0·22666	0·29767	R
1946	Yale *16* 4687, 4696, 4701	0·27545	0·30491	0·41964	W
1947	Yale *14* 13392, 13397, 13424	0·45453	0·25869	0·28678	R
1948	Yale *14* 13053, 13064, 13107	0·25793	0·41798	0·32410	S
1949	Yale *14* 12961, 12966, 12991	0·33320	0·36767	0·29912	W
1950	Yale *16* 311, 314, 327	0·11674	0·34681	0·53645	W
1951	Yale *16* 4022, 4033, 4047	0·26501	0·32091	0·41409	R
1952	Yale *11* 54, 57, 79	0·18688	0·69623	0·11689	R
1953	Yale *11* 8309, 8318, 8326	0·37324	0·25712	0·36964	R
1954	Yale *12* II 9350, 9367, 9379	0·45938	0·17210	0·36853	S
1955	Yale *17* 843, 863, *21* 760	0·25622	0·41246	0·33131	R
1956	Yale *16* 6369, 6382, 6395	0·39398	0·29703	0·30899	W
1957	Yale *11* 6263, 6290, 6300	0·26352	0·45308	0·28341	R
1958	Yale *11* 5028, 5035, 5044	0·34193	0·47108	0·18699	S
1959	Yale *11* 5007, 5009, 5021	0·45417	0·20302	0·34281	W
1960	Yale *11* 5556, 5567, 5572	0·37802	0·39170	0·23028	W
1961	Yale *11* 5519, 5544, 5552	0·27201	0·59610	0·13189	R
1962	Yale *16* 7501, 7503, 7514	0·32001	0·47463	0·20536	S
1963	Yale *17* 7037, 7050, 7058	0·27293	0·30075	0·42631	R
1964	Yale *16* 3789, 3795, 3813	0·44519	0·24782	0·30699	W
1965	Yale *16* 3762, 3778, 3784	0·28799	0·47033	0·24168	R
1966	Yale *13* II 13612, 13660, 13685	0·29457	0·13097	0·57446	S
1967	Yale *16* 222, 223, 239	0·47564	0·08436	0·44000	R
1968	Yale *11* 135, 140, 150	0·20700	0·51000	0·28300	R
1969	Cape *19* 8241, 8256, 8277	0·53461	0·24211	0·22329	S
1970	Cape *19* 8101, 8136, 8138	0·30918	0·39782	0·29300	S

TABLE II—*continued*

No.	Comparison Stars	Dependences			
1971	Cord. D 15931, 15950, 15962	0·26358	0·41969	0·31673	R
1972	Yale *12* I 5652, 5671, 5673	0·26079	0·43968	0·29953	S
1973	Yale *12* I 5629, 5639, 5641	0·29219	0·42891	0·27890	W
1974	Yale *14* 12236, 12247, 12273	0·35066	0·31247	0·33687	S
1975	Yale *12* I 6279, 6282, 6306	0·33084	0·24881	0·42036	S
1976	Yale *13* II 8120, *14* 9506, 9538	0·26152	0·36471	0·37377	W
1977	Yale *14* 9325, 9333, 9367	0·30004	0·38215	0·31781	W
1978	Yale *13* I 9061, 9073, 9083	0·20307	0·32586	0·47107	R
1979	Yale *14* 14534, 14541, 14549	0·36990	0·34153	0·28857	W
1980	Yale *12* II 126, 138, 139	0·23436	0·33157	0·43406	R
1981	Yale *14* 15965, 7, 8	0·37854	0·31398	0·30747	W
1982	Yale *14* 15864, 15893, *13* II 15087	0·27944	0·46746	0·25310	R
1983	Yale *13* II 14946, 14967, 14973	0·29904	0·42542	0·27554	R
1984	Yale *13* II 9188, 9211, 9213	0·31986	0·26873	0·41142	R
1985	Yale *13* II 9104, 9113, 9137	0·32529	0·22128	0·45343	W
1986	Yale *16* 4660, 4663, 4674	0·43338	0·31822	0·24839	W
1987	Yale *14* 11968, 11991, 12000	0·39459	0·33203	0·27339	S
1988	Yale *14* 11910, 11912, 11947	0·28017	0·40682	0·31301	W
1989	Cape *18* 10631, 10671, *17* 11226	0·27545	0·19739	0·52717	S
1990	Cape *18* 10580, 10604, 10627	0·25177	0·45520	0·29303	W
1991	Yale *14* 14319, 14324, 14353	0·28243	0·44789	0·26967	S
1992	Yale *13* II 13447, 13463, 13484	0·12131	0·48226	0·39644	S

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The Time Spent by Neutrons Inside a Narrow Resonance

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Abstract—It is shown that if a resonance has width less than or equal to $\min_i E_u(1-\alpha_i)$, where E_u is the upper cut-off energy, and α_i is as usually defined, then an explicit closed expression may be determined for the moment-generating function of the time spent by neutrons in the resonance. This expression is derivable from the expression for the slowing-down density. The same method may be applied to wider resonances.

The time scale of the slowing-down process of neutrons in infinite homogeneous reactors has been discussed and investigated by various authors (e.g. Tackacs (1956), Weinberg and Wigner (1958), Wilkins (1966)).

However, it does not appear to have been noticed that when the slowing-down density is known exactly for arbitrary cross-sections, then the moment-generating function of the slowing down time may be determined explicitly. In particular, an explicit expression may be derived for the moment-generating function of the time spent by a neutron inside a " Spinney-type " resonance, i.e. a resonance with a width less than or equal to

$$\min_i E_u(1-\alpha_i)$$

where E_u is the upper cut-off energy of the resonance, α_i is defined by

$$\alpha_i=\left(\frac{1-A_i}{1+A_i}\right)^2,$$

and A_i is the mass of the i-th species in the mixture.

In what follows, $q(E_1,E_2)$ will denote the slowing-down density at energy E_2 due to a normalized mono-energetic source at $E_1(E_1>E_2)$, $h(E)$ will denote the probability that a neutron of energy E is not absorbed at that energy (so that if no species of infinite mass are present, $h(E)$ is the ratio of the total macroscopic scattering cross-section to the total macroscopic cross-section), and $f(E_1,E_2)\Delta E_2$ will denote the probability that a neutron is scattered into the elementary energy range $(E_2,E_2+\Delta E_2)$ after a scattering collision at energy E_1.

Then $q(E_1,E_2)$ is given by

$$q(E_1,E_2)=h(E_1)\left\{\int_0^{E_2} f(E_1,E)\mathrm{d}E+\int_{E_2}^{E_1} f(E_1,E)q(E,E_2)\mathrm{d}E\right\}.$$

Suppose that to each neutron in a non-absorbing system there is attached a weight W which has the initial value 1, and which changes by a factor $W(E)$ when the neutron is scattered from energy E to a lower energy. It is easy to see that if we take

$$W(E)=h(E),$$

then the average value $<W>$ of W, with which neutrons pass energy E_2 after having started from E_1, is just $q(E_1,E_2)$ when absorption is occurring. (See Richtmyer *et al.* (1958).) Hence $<W>$ is given by the same equation as $q(E_1,E_2)$ but with $W(E)$ substituted for $h(E)$.

Let $g(s,E)$ denote the moment-generating function of the time spent by a neutron in a non-absorbing system at energy E. If it is given that the neutron had collisions at energies

$E'_1, \ldots E'_n (E'_1 = E_1)$, and only at those energies, before passing E_2, then conditionally upon such a given sequence of energies, the moment-generating function of the slowing down time t is just

$$\prod_1^n g(s, E'_i).$$

Also conditionally upon such a sequence, the average value of W would be

$$\prod_1^n w(E_i),$$

and in the particular case where $w(E) = h(E)$, would be

$$\prod_1^n h(E'_i).$$

It follows immediately that determining the moment-generating function $G(s, E_1, E_2)$ of t in a non-absorbing system is formally the same as determining $q(E_1, E_2)$ in an absorbing system with $h(E) = g(s, E)$. In particular, when a solution for $q(E_1, E_2)$ exists for arbitrary cross-sections an explicit expression for $G(s, E_1, E_2)$ may be determined in the non-absorbing case merely by substituting $g(s, E)$ for $h(E)$.

For the case where it is desired to determine $G(s, E_1, E_2)$ in an absorbing system, note that the probability density of a sequence $E'_1, \ldots E'_n$, conditional upon slowing-down to energies less than E_2, is

$$\prod_1^{n-1} f(E'_i, E'_{i+1}) \prod_1^n h(E'_i) \int_0^{E_2} f(E'_n, E) \mathrm{d}E / q(E_1, E_2)$$

while in the non-absorbing case, it is just

$$\prod_1^{n-1} f(E'_i, E'_{i+1}) \int_0^{E_2} f(E'_n, E) \mathrm{d}E.$$

It follows that to determine the moment-generating function of t for the absorbing case, $g(s, E)\ h(E)$ must be substituted for $h(E)$ in $q(E_1, E_2)$, and then (to normalize) the resulting expression must be divided by $q(E_1, E_2)$.

The width of a Spinney-type resonance is less than or equal to $E_u(1 - \max_i \alpha_i)$. The collision density inside the resonance is

$$F(E) = A(E) + \int_E^{E_u} h(E') C(E') \exp \left\{ \int_E^{E'} h(E'') B(E'') \mathrm{d}E'' \right\} \mathrm{d}E'.$$

In the last equation $A(E)$ is the density of collisions due to neutrons having their first collision in the resonance, so that in the asymptotic region

$$A(E) = (\bar{\xi} E)^{-1} \sum_1^n \bar{s}_i (1 - \alpha_i)^{-1} (-\alpha_i + E/E_u).$$

where $\bar{\xi}$ has its usual meaning, and $\bar{s}_i$ is the ratio at energies above E_u of the macroscopic scattering cross-section of the i-th species to the total macroscopic scattering cross-section. (The corresponding ratio inside the resonance will be denoted by $s_i(E)$.) Also,

$$B(E) = \sum_1^n s_i(E)(1 - \alpha_i)^{-1}/E,$$

$$= f(E, E'), \qquad E \geq E' \geq \max_i \alpha_i E.$$

while $C(E) = A(E) B(E)$.

Next, the slowing-down density at any energy E is given by

$$h(E_1) - \int_E^{E_1} F(E')(1 - h(E')) \mathrm{d}E'.$$

Hence if E now denotes the lower cut-off of the Spinney resonance, the slowing-down density there is

$$q=1-\int_E^{E_u}[1-h(x)]\left[A(x)+\int_x^{E_u}h(y)C(y)\exp\left\{\int_x^y h(v)B(v)\mathrm{d}v\right\}\mathrm{d}y\right]\mathrm{d}x.$$

The time spent diffusing at a particular energy E has moment generating function

$$g(s,E)=(1-s/\sqrt{2mE\Sigma^2(E)})^{-1}$$

where m^{-1} is the neutron mass and $\Sigma(E)$ is the total macroscopic cross section at energy E. Finally, then, the moment-generating function $G(s)$ of the time spent in the resonance is given by

$$G(s)=\left\{1-\int_E^{E_u}[1-g(s,x)h(x)]\left[A(x)+\int_x^{E_u}g(s,y)h(y)C(y)\exp\left\{\int_x^y g(s,v)h(v)B(v)\mathrm{d}v\right\}\mathrm{d}y\right]\mathrm{d}x\right\}/\mathrm{q}.$$

The same approach may be used for any resonance (since it is always possible to give an exact explicit expression for q), but naturally the moment-generating function becomes more complex the wider the resonance. Only in hydrogen is a simple result obtained, and this may be obtained from the last equation by taking $n=1$ and $\alpha_1=0$.

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The Gravity Terms in the Water Entry Problem

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1. Introduction

Mackie [3], when considering the water entry problem of a thin wedge into an incompressible fluid, remarked that it did not seem easy to obtain the equation for the displacement of the free surface due to the penetration of a thin sharp body except when gravity terms are neglected. A formal power series, of the equation he obtained, did not lead to a valid expansion and, moreover, indicated that the water level rose further due to the gravity terms. An asymptotic expansion using the method of stationary phase valid for large values of $\frac{gt^2}{x}$ is possible (where t is the time elapsed after the initial entry and x is the horizontal distance from the wavemaker), but this is not helpful for the case requiring a fixed x and small t.

In a subsequent paper [4], Mackie investigated the asymptotic form of the splash profile. Basically, the investigation was concerned with the equation of the free surface assuming small values of the ratio $\frac{Ut}{x}$, where U was the (constant) velocity of entry of a thin symmetric body into the water.

In the following, a more general form of the equation of the free surface is obtained as an expansion in powers of g. The asymptotic results of Mackie are then found to be a special case of the more general result.

2. Summary of Applicable Results for the Two-Dimensional Wavemaker

Using the notation and results of Mackie [3], the mean free surface is taken as $y=0$ with the y-axis pointing vertically downwards. The water is assumed to be of infinite depth and the velocity on $x=0$ is given as $U(y,t)$. Considering only the motion of the water to the right of the wavemaker ($x>0$), we have, if the equation of the free surface is $y=\eta(x,t)$,

$$\bar{\eta}(\lambda,t)=-\int_0^t \tilde{U}(\lambda,\tau)\cos\{\sqrt{\lambda g}(t-\tau)\}d\tau, \qquad (1)$$

where $\bar{\eta}(\lambda,t)$ is the Fourier cosine transform of $\eta(x,t)$ defined by

$$\bar{\eta}(\lambda,t)=\int_0^\infty \eta(x,t)\cos\lambda x dx, \qquad (2)$$

and $\tilde{U}(\lambda,t)$ is the Laplace transform of $U(y,t)$ defined by

$$\tilde{U}(\lambda,t)=\int_0^\infty U(\alpha,t)e^{-\lambda\alpha}d\alpha. \qquad (3)$$

In particular, if a thin wedge of angle 2ε is suddenly plunged with constant speed U along the y-axis into the water, which is at rest, (3) becomes

$$\tilde{U}(\lambda,t)=\frac{\varepsilon U}{\lambda}(1-e^{-\lambda Ut})$$

and, hence from (1),

$$\bar{\eta}(\lambda,t)=\frac{-\varepsilon U}{\lambda}\int_0 (1-e^{-\lambda U\tau})\cos\{\sqrt{\lambda g}(t-\tau)\}d\tau$$

$$=\frac{-\varepsilon U^2}{\sqrt{\lambda g}}\int_0^t e^{-\lambda U(t-\tau)}\sin(\sqrt{\lambda g}\tau)d\tau \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

on changing the variable and integrating by parts. Equation (4), on using the inversion theorem for the Fourier cosine transformation, yields the equation of the free surface in the form

$$\eta(x,t)=\frac{-2\varepsilon U^2}{\pi\sqrt{g}}\int_0^\infty \frac{\cos\lambda x}{\sqrt{\lambda}}\int_0^t e^{-\lambda U(t-\tau)}\sin(\sqrt{\lambda g}\tau)d\tau d\lambda. \quad \ldots\ldots\ldots \quad (5)$$

3. The Equation of the Free Surface y=η(x,t)

First, we may write

$$\eta(x,t)=\frac{-2\varepsilon U^2}{\pi\sqrt{g}}\int_0^t\int_0^\infty \frac{\cos\lambda x}{\sqrt{\lambda}}\sin(\sqrt{\lambda g}\tau)e^{-\lambda U(t-\tau)}d\lambda d\tau. \quad \ldots\ldots\ldots\ldots \quad (6)$$

Now, consider the integral

$$I=\int_0^\infty \cos a\lambda \sin b\sqrt{\lambda}\, e^{-c\lambda}\frac{d\lambda}{\sqrt{\lambda}}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

A change of variable, viz. $\lambda=p^2$, and the result (e.g. Erdelyi [2], p. 73)

$$\int_0^\infty e^{-\alpha x^2}\sin xy dx=-\frac{i}{2}\frac{\sqrt{\pi}}{\alpha}\exp\left(\frac{-y^2}{4\alpha^2}\right)\operatorname{erf}\left(\frac{iy}{2\alpha}\right),\ \text{Re}(\alpha)>0,$$

allow us to write

$$I=-i\left\{\frac{1}{\sqrt{c-ia}}\exp\left[\frac{-b^2}{4(c-ia)}\right]\operatorname{erf}\left[\frac{ib}{2\sqrt{c-ia}}\right]+\frac{1}{\sqrt{c+ia}}\exp\left[\frac{-b^2}{4(c+ia)}\right]\operatorname{erf}\left[\frac{ib}{2\sqrt{c+ia}}\right]\right\}. \quad (8)$$

With the definitions and notation of Erdelyi [1*b*], p. 147, we have

$$\operatorname{erf}(iz)=ie^{z^2}\sum_{m=0}^\infty \frac{(-1)^m z^{2m+1}}{(3/2)_m},$$

where $(3/2)_m=\Gamma(3/2+m)\Big/\Gamma(3/2)$, for all z.

Thus,

$$e^{-z^2}\operatorname{erf}(iz)=i\sum_{m=0}^\infty \frac{(-1)^m z^{2m+1}}{(3/2)_m}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Hence, by (8) and (9),

$$I=\sum_{m=0}^\infty \frac{(-1)^m b^{2m+1}}{(3/2)_m 2^{2m+1}(c-ia)^{m+1}}+\sum_{m=0}^\infty \frac{(-1)^m b^{2m+1}}{(3/2)_m 2^{2m+1}(c+ia)^{m+1}}. \quad \ldots\ldots\ldots \quad (10)$$

Equations (6), (7) and (10) give, on interchanging the order of summation and integration,

$$\eta(x,t)=\frac{-2\varepsilon U^2}{\pi}\sum_{m=0}^\infty\int_0^t \frac{(-1)^m g^m \tau^{2m+1}}{(3/2)_m 2^{2m+1}}\left\{\frac{1}{[U(t-\tau)-ix]^{m+1}}+\frac{1}{[U(t-\tau)+ix]^{m+1}}\right\}d\tau. \quad \ldots \quad (11)$$

The integrals occurring in (11) can be evaluated in the following way. Let

$$\int_0^t \frac{\tau^{2m+1}\mathrm{d}\tau}{[U(t-\tau)-z]^{m+1}}=J, \text{ say.} \qquad (12)$$

The change of variable $t-\tau=tT$ allows us to write

$$J=\left(\frac{-t^2}{z}\right)^{m+1}\int_0^1 (1-T)^{2m+1}(1-Zt)^{-m-1}\mathrm{d}T$$

where $Z=\frac{Ut}{z}$. Thus, provided $|\arg(1-Z)|<\pi$ [Erdelyi [1*a*], p. 114],

$$J=\left(\frac{-t^2}{z}\right)^{m+1}\frac{1}{2m+2}\ {}_2F_1\,(1,\ m+1\ ;\ 2m+3\ ;\ Z) \qquad (13)$$

where ${}_2F_1\,(1,\ m+1\ ;\ 2m+3\ ;\ Z)$ is the hypergeometric function.

From (11), (12) and (13) we find, for the equation of the free surface,

$$\eta(x,t)=\frac{-2\varepsilon tU}{\pi}\sum_{m=0}^{\infty}\frac{Z^{m+1}}{(3/2)_m(m+1)2^{2m+2}}\left(\frac{-gt}{U}\right)^m\{{}_2F_1\,(1,\ m+1\ ;\ 2m+3\ ;\ -Z)$$

$$-(-1)^m{}_2F_1\,(1,\ m+1\ ;\ 2m+3\ ;\ Z)\}. \qquad (14)$$

where $Z=\frac{Ut}{z}=\frac{iUt}{x}$. Equation (14) is the general form of the equation of the free surface as a power series in g.

4. $\eta(x,t)$ in Terms of Elementary Functions

The hypergeometric functions occurring in (14) can be expressed in terms of the derivatives of the logarithmic function. To this end we use the result (Erdelyi [1*a*], p. 69)

$${}_2F_1(n+1,\ i+n+1\ ;\ k+i+n+2\ ;\ Z)$$

$$=\frac{(k+i+n+1)!(-1)^i}{k!n!(i+n)!(k+i)!}\frac{\mathrm{d}^{i+n}}{\mathrm{d}Z^{i+n}}\left\{(1-Z)^{k+i}\frac{\mathrm{d}^k}{\mathrm{d}Z^k}\,{}_2F_1\,(1,1\ ;\ 2\ ;\ Z)\right\} \quad k,\ i,\ n=0,\ 1,\ 2,\ \ldots,$$

which, on setting $k=m+1$, $i=m$, $n=0$, gives

$${}_2F_1(1,\ m+1\ ;\ 2m+3\ ;\ Z)=\frac{2(-1)^m}{(m!)^2}\frac{\mathrm{d}^m}{\mathrm{d}Z^m}\left\{(1-Z)^{2m+1}\frac{\mathrm{d}^{m+1}}{\mathrm{d}Z^{m+1}}({}_2F_1\,(1,\ 1\ ;\ 2\ ;\ Z)\right\}$$

and where, in fact, $F(1,1\ ;\ 2\ ;\ Z)=-\frac{1}{Z}\log(1-Z)$.

Obviously,

$$F\,(1,\ m+1\ ;\ 2m+3\ ;\ -Z)=\frac{-2(-1)^m}{(m!)^2}\frac{\mathrm{d}^m}{\mathrm{d}Z^m}\left\{(1+Z)^{2m+1}\frac{\mathrm{d}^{m+1}}{\mathrm{d}Z^{m+1}}\left(\frac{1}{Z}\log(1+Z)\right)\right\}.$$

Therefore, the equation of the free surface becomes, from (14),

$$\eta(x,t)=\frac{\varepsilon tU}{\pi}\sum_{m=0}^{\infty}\frac{Z^{m+1}}{(3/2)_m(m+1)!m!2^{2m}}\left(\frac{gt}{U}\right)^m$$

$$\times\left\{\frac{\mathrm{d}^m}{\mathrm{d}Z^m}\left[(1+Z)^{2m+1}\frac{\mathrm{d}^{m+1}}{\mathrm{d}Z^{m+1}}\left(\frac{1}{Z}\log(1+Z)\right)\right.\right.$$

$$\left.\left.-(-1)^m(1-Z)^{2m+1}\frac{\mathrm{d}^{m+1}}{\mathrm{d}Z^{m+1}}\left(\frac{1}{Z}\log(1-Z)\right)\right]\right\} \quad \ldots\ldots\ldots\ldots\ldots (15)$$

where $Z=\frac{iUt}{x}$.

5. Particular Results

(i) For small g, equation (15) gives, after some manipulation,

$$\eta(x,t)=\frac{\varepsilon}{\pi}\left\{2Ut-2x\tan^{-1}\left(\frac{Ut}{x}\right)-Ut\log\left(1+\frac{U^2t^2}{x^2}\right)\right\}$$

$$+\frac{\varepsilon t^2 g}{2\pi}\left\{3+\frac{x^2}{U^2t^2}\left(1-\frac{U^2t^2}{x^2}\right)\log\left(1+\frac{U^2t^2}{x^2}\right)\right.$$

$$\left.-4\frac{x}{Ut}\tan^{-1}\left(\frac{Ut}{x}\right)\right\}+0(g^2). \quad \ldots\ldots\ldots\ldots\ldots (16)$$

(ii) Mackie [4] obtained the asymptotic form of $\eta(x,t)$ in two ways. He found the displacement at a given position for small t and also the displacement at a given time for large values of x. Obviously, both these cases are contained in the assumption that $\frac{Ut}{x}$ is small.

Making this assumption, a result in agreement with those of Mackie can be obtained from either equation (14) or equation (15). In particular, for both g and $\frac{Ut}{x}$ small, equation (16) gives immediately

$$\frac{\eta}{x}=\frac{-\varepsilon}{3\pi}\left(\frac{Ut}{x}\right)^3\left(1+\frac{gt}{4U}\right)+0\left(\frac{Ut}{x}\right)^5$$

which agrees with Mackie's result.

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The Development of Geophysics in Australia*

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Introduction

The science of Geophysics is very wide-ranging. It is concerned with the study of our planet by physical methods and consequently incorporates topics ranging from those dealing with the interior regions—seismology, tectonophysics and geothermy—through topics concerned with surface phenomena—geodesy, physical oceanography, hydrology, glaciology and exploration geophysics—to studies of the atmosphere and neighbouring "space"—meteorology, upper atmosphere physics and solar-terrestrial relationships. The global scientific and technological effort devoted to these many aspects is now stupendous, although the name "geophysics", with its connotation of a common basis of interest among all the branches, is not yet one hundred years old.

The explosion in geophysical activity had its origins in the great technological advances that resulted from the World War II effort and was much intensified by the International Geophysical Year program of 1957–1958. It is pleasing to be able to say that Australia has played and is playing a small but significant role in this world-wide activity. The work of such authorities as K. E. Bullen, F.R.S., and D. F. Martyn, F.R.S., for example, is too well known to require elaboration.

Summaries of recent progress in geophysical research will be found in publications by Jaeger and Thyer (1960—solid earth), Doyle and Underwood (1965—seismological stations), Thyer (1963—prospecting), Anon. (1965—space research), Radok (1963—glaciology), the Bureau of Meteorology (Anon., 1958, and serial publications of the Bureau), the Commonwealth Scientific and Industrial Research Organization (Annual Reports—meteorological physics, upper atmosphere physics, and oceanography).

Participation in the rush of progress brings the danger that the work of the pioneers will be forgotten. Much that was done in the past suffered from inadequate instruments, insufficient density of observations or unavailability of mathematical theory and techniques of analysis, and consequently must be tackled afresh. But there are some significant instances where the validity of the work remains unaffected by the passage of time—notably in geomagnetism and meteorology. The results in these branches are the more important because they relate to transient phenomena. The quality of the data which we have inherited is an enduring memorial to the devoted labours of such men as Sir John Franklin, G. B. Neumayer and H. C. Russell and their contemporaries.

In this address, therefore, I have endeavoured to review the development of Australian geophysics since the earliest settlement to about 1950, and in so doing to pay a humble tribute to the pioneers who often laboured under difficulties which to-day we find hard to conceive. Attached to this review are an appendix on geophysical activity by Australian observatories and a bibliography of the published work, made as complete as I can manage, for each branch up to just after the stage at which it became firmly established, only selected items published thereafter being included.

A salient feature which will be apparent as the story unfolds is that much of the geophysical work consisted of observation—for sophisticated analysis and theoretical geophysics have only developed here in the last three or four decades (and then rather unevenly).

A Beginning

Because Australia was discovered, explored and settled so much later than other regions of the world it is not surprising that serious scientific investigations proceeded concurrently

* Presidential Address delivered before the Royal Society of New South Wales, April 6th, 1966.

with geographical exploration. Thus Tasman, Dampier, Cook and their successors systematically determined magnetic declinations and to a lesser extent, other magnetic elements, and made meteorological observations. Their magnetic results are of uncertain reliability, however, because proper precautions were not always taken against disturbances of the compasses by iron objects. Cook, for example, on the 1776-80 voyage kept the keys of the leg-irons in his binnacle ! The problem of sources of error in marine magnetic observations was largely settled by Flinders (1814, Appendix II), although his recommendations were not always followed. Flinders also gave examples of geologically caused local anomalies (*op. cit.*, pp. 526–528).

Obvious checks on the early data are for internal consistency of a single series and consistency between series in near locations. In general Cook's observations along the eastern coast of Australia seem reliable, with the outstanding and unfortunate exception of that in Botany Bay, which has an unexplained error of 3°. The value obtained at sea off Narrabeen is preferable for determining the secular variation at Sydney.

The first measurements of magnetic intensity in the Australian region were made by de Rossel who accompanied d'Entrecasteaux on his expedition in search of La Perouse. The quantity observed was the period of oscillation of a dip needle in the magnetic meridian. De Rossel made two measurements, in 1792 and 1793, at Recherche Bay, south of Hobart. Although they were almost certainly disturbed by the magnetic effects of the dolerite outcropping in the region they demonstrated unequivocally, when compared with those obtained at Amboina, that the intensity was least near the equator and increased towards the southern pole as it was already known to do toward the northern pole.

Despite their large standard errors the early observations were, and are, extremely valuable and were utilized between 1702 and 1840 in compilations of geomagnetic data by Halley, Wilcke, Churchman, Duperrey, Hansteen, Barlow (1883) and Sabine (1838, 1840). Each of these included Australia, although the more exact left the actual land mass blank recognizing the lack of inland magnetic information. This became available later as the surveyor-explorers (Oxley, Mitchell, Sturt, etc.) probed the interior of the continent.

Syntheses of meteorology were not as readily made as of magnetism due to the short term of the observations.

In the later part of the eighteenth century interest in the precise size and shape of the earth had developed, and was stimulated by the endeavours of the " Commission générale des poids et mésures " to establish the metric units. As a result pendulum observations of the force of gravity were progressively established over the globe, since, by means of Clairaut's theorem, a good approximation to the earth's polar flattening could be obtained from them. Thus, when he undertook his scientific circumnavigation, L. S. de Freycinet swung pendulums in Sydney during his visit in 1819 (de Freycinet, 1826). This was the first of four determinations of gravity to be made there in a space of ten years, after which no further observations were prosecuted until 1882.

During the voyage de Freycinet also obtained extensive magnetic data which he published in 1842. These data are important because they supply the first extensive determinations of magnetic intensity in the region, made possible by the development by Humboldt of a more satisfactory method of measurement than that used by de Rossel.

Brisbane and the Parramatta Observatory

The foundation of continuing research in the physical sciences in Australia was presaged by the arrival in Sydney of Sir Thomas Brisbane in 1821 to take up his appointment as colonial governor. For Brisbane was a scientist as well as a soldier, and, in spite of the refusal of the authorities to assist, he set up at his own expense an astronomical and geophysical observatory in the grounds of the then Government House at Parramatta. As assistants he employed C. C. L. Rümker and J. Dunlop.

Brisbane brought to Australia a Kater pendulum which he and Rümker had swung before leaving London. Brisbane and Dunlop swung it in the new observatory and thereby established the difference in gravity between London and Parramatta. The results were transmitted to Kater who published them (1823) before de Freycinet, with a vast quantity of data to organize, was able to publish his pendulum observations of 1819.

The program of Brisbane's observatory included regular meteorological observations—the first such to be made systematically in the continent, apart from the brief period covered by Dawes at Sydney Cove. During the period in which he was in charge of the observatory Dunlop unofficially adopted as one of his titles that of "Imperial Meteorologist". Regrettably there survive only the results for part of 1822, all of 1823, part of 1824, one year undated (1827 ?) and occasional readings in 1838 (Russell, 1871, p. 1).

Brisbane left the colony in December 1825 and his observatory was purchased by the government. Rümker was appointed director and, in 1828, using as a base the same pier as that used by Brisbane and Dunlop, he swung a Fortin pendulum in an attempt to determine the *absolute* value of gravity. The result (Rümker, 1829*a*, 1829*b*) was approximately $0 \cdot 2$ cm. sec.$^{-2}$ in error—a scarcely surprising discrepancy considering the technical difficulties of the experiment (which have not yet been satisfactorily overcome). Rümker also made a small number of magnetic measurements (1829*c*).

In the same period another French scientific expedition visited Sydney and swung pendulums to establish the gravity difference from Paris (Duperrey, 1829).

For their work, Brisbane, Rümker and Dunlop were each awarded the gold medal of the Royal Astronomical Society, Brisbane being described by Sir William Herschel as the founder of Australian science. Provided that by science, *physical* science is understood, I would enthusiastically agree with this assessment.

Franklin and the 'Hobarton' Observatory

By the late 1830's international research in geomagnetism was well advanced and C. F. Gauss had completed his epoch-making analysis of the earth's field. However, the southern hemisphere, especially Antarctica, remained poorly known magnetically. In order to remedy this deficiency in knowledge the British Association in 1838 recommended to the British Government that an expedition be sent specifically to investigate terrestrial magnetism in high southern latitudes. The expedition was mounted under the command of J. C. Ross and F. R. M. Crozier. Ross was highly qualified for his task, having already carried out extensive magnetic surveys in the Arctic regions.

To cooperate with the expedition four observatories were established under the general control of Major E. Sabine, R.A. Along with three other observatories set up by the East India Company, the Ross Expedition and Sabine's observatories all participated in the first international cooperative geophysical program, organized by the Magnetische Verein, and took simultaneous observations on pre-arranged 'term-days'. Sabine's observatories were erected at Hobart and Toronto (approximating the regions of greatest known magnetic intensity), on St. Helena (minimum intensity) and at the Cape of Good Hope (where the secular variation was of special interest).

At Hobart the observatory was constructed in 1840 under the personal supervision of the Governor, Sir John Franklin. It was a substantial building; but through the labours of two hundred convicts it was completed in only nine days. Franklin named it "Rossbank" and placed his nephew, Lieut. Henry Kay, R.N., who had arrived with the Ross expedition, in charge. The Royal Society of Tasmania possesses a painting of the observatory.

The instruments were described by Kay (1842) and comprised a declinometer, inclinometer and horizontal and vertical variometers. Systematic meteorological recordings and astronomical observations for time were also made. The heavy program of observations, especially on the pre-arranged term-days, required a team of observers and Franklin enlisted the aid of local residents—who could refuse the Governor ? On these days, when observations had to be taken every two and a half minutes for twenty-four hours, Franklin himself stood a watch of twelve hours, responsibility for the remainder being shared by Lieut. Kay, J. P. Gell, headmaster of the Queen's School, Dr. Adam Turnbull, Clerk of the Councils, F. H. Henslow, private secretary to the Governor, Lieut. Bagot, the Governor's A.D.C., and four others. How these persons must have wished for the invention of self-recording magnetographs !

The Hobart observatory and the Ross-Crozier expedition achieved a large volume of results of the highest importance. Ross and Franklin both returned to Britain in 1843, but the magnetic and meteorological observations at Hobart continued under Kay until 1854, Results were published by Ross (1847), Kay (1849/53, 1850) and Sabine (1843, 1857*a*, 1866. 1868). Analyses of the diurnal variation were published by Sabine (1857*b*) and Heimbrod (1904, 1905). Easily the most significant discovery was that of the parallel variation of intensity of magnetic disturbance and sunspot number (Sabine, 1851/52).

Feeling the need for a wider spread of meteorological observations than could be provided by the one observing station at Parramatta Observatory (which was by then badly rundown), the Colonial Government of New South Wales in 1840 appointed trained convicts as meteorological observers at South Head (Sydney), Port Macquarie and Port Phillip. The observations at Port Macquarie were continued to 1849 (but are stated to be unreliable) and those at South Head were continued until 1855, after which they were executed privately by Jevons until the new colonial astronomer, Rev. W. E. Scott, commenced observations in 1858. The results of a station at Port Stephens for the period 1843–1847 were reported by King (1849). The work at Port Phillip was continued until the separation of Victoria from New South Wales in 1851. Observations were resumed in 1853, at a new observatory established at Williamstown by the Victorian Government; they were continued until the observatory was closed in 1863 (Davy, 1855). The meteorological work of the Hobart magnetic observatory ceased in 1854.

Evidence for the eastward progress over Australia of the main weather and barometrical systems was recognized by Gregory (1860) in an analysis of observations at Adelaide, Melbourne, Sydney and Moreton Bay (Brisbane).

Meanwhile, the explorers continued to contribute magnetic observations from remote parts of the country, although in the case of Strzelecki an accident to his equipment resulted in erroneous readings for the second half of his journey through the Snowy Mountains and Gippsland (Strzelecki, 1845, pp. 47–50).

In this period, also, there were published the first formal reports of earth tremors (Milligan, 1842; Corbett, 1854, 1855); but geological study of the country was at such an elementary stage that analysis of the relationship of the tremors to crustal structure was impossible.

Transformation and Rejuvenation

We have now reached that fascinating period of Australian history—the eighteen fifties and sixties—in which there occurred events both general and academic that were seminal to the development of the country and of science in particular. The gold discoveries brought about fundamental changes in the whole character of the community. At first the effects of the discoveries were essentially disruptive, but there gradually developed a community environment that was essentially stable and prosperous. Urban growth proceeded apace, many new industries were established, railways were commenced and underground mining of gold and other minerals became necessary as the surface supplies were worked out. Thus was generated a demand for technical resources, information and training that early embroiled the newly founded universities at Sydney (1851) and Melbourne (1854) in disputes over the extent to which they should provide courses in the useful arts. Also, the great increase in shipping movements both necessitated and justified the provision of accurate time by an astronomical observatory and the maintenance of a reliable meteorological service.

It is one of the intriguing coincidences of history that this swift metamorphosis of the pattern of life in eastern Australia should have occurred as science in the western world was entering a new phase of consolidation and growth. Sherwood Taylor has described the years 1800–1850 as "the great period of new beginnings in science . . . in those years the civilized world convinced itself of the value of science as a means of explaining the physical world and as a means of getting things done" (Taylor, 1951, p. 117). It was therefore almost a *sine qua non* of the emerging community of feeling and spirit of independence in Australia that scientific endeavour *should* be promoted as a hallmark of a sophisticated and established society—*sidere mens eadem mutato!**

Todd, Scott and Neumayer

The new era was ushered in by the arrival in Adelaide, in November, 1855, of Charles Todd to take up his appointment as Superintendent of Telegraphs and Astronomal Observer for South Australia. By the following year he had commenced meteorological observations in Adelaide. Progressively he established outstations, using the telegraphic network under his supervision for communicating the results to Adelaide.

In New South Wales, following the closure of the Parramatta Observatory in 1847, there were, as we have seen, only fitful attempts to maintain meteorological observations, although protracted discussions took place on the establishment of a new observatory. No action was taken until, due to the substantial encouragement of the Governor, Sir William Denison, it was decided to set up an observatory on "Fort Phillip". The Rev. W. Scott was appointed as astronomer and arrived in 1856. Apart from his astronomical duties he was involved in the

* The motto of the University of Sydney, generally translated "The sky may be changed but the spirit is the same".

establishment of a proper meteorological service, towards which end he distributed twelve sets of instruments to New South Wales country centres, and Brisbane, Rockhampton and Gabo Island. Scott also initiated regular tidal and sea-temperature observations in Sydney Harbour (1860). He planned magnetic observations but these were not commenced until his successor, G. R. Smalley, had taken up residence. Scott resigned in 1862.

In this same period the Williamstown observatory under R. L. J. Ellery was, as we have already noted, recording climatic phenomena. However, the Victorian program was much expanded following the arrival in the colony in January 1857, of Georg Balthasar Neumayer. Neumayer was born in Bavaria on 21 June, 1826 ; at 23 he graduated in physics from the Technische Hochschule of Munich. In 1850 and again in 1855–1856 he worked in Munich with the noted geomagnetician Lamont. From 1850 to 1852 he went to sea and took his master's ticket. In 1852 he landed in Sydney and succumbed to the attraction of the goldfields. Unsuccessful, he proceeded to the magnetic observatory in Hobart and worked there for a time under Kay. Realizing that, with the closure of the observatory in 1854, there would be left a serious gap in the world network of magnetic observatories and furthermore that there was much useful research which could be done in magnetism and meteorology in the southern hemisphere, he applied on his return to Germany to the Duke of Bavaria for finance to purchase instruments with a view to establishing a geophysical observatory in Australia. His request was successful and he brought equipment to the value of £2,000 to Melbourne. On arrival there he was appointed Government Meteorologist and Director of the Magnetic Survey of Victoria. Negotiations with the Victorian Government resulted in his being given the use of the former signal station, which he called the Flagstaff Observatory. The site is now Flagstaff Gardens. He was not altogether pleased with it because testing showed that the magnetic field in the vicinity was irregular due to the presence of unevenly weathered basalt beneath the soil. He expressed a preference for a site on the south side of the Yarra, in the vicinity of Government House, but this was not granted. His reasons for the preference (less magnetic disturbance of geological and industrial origin) were perfectly valid, and were ultimately vindicated when the activities at Williamstown and Flagstaff were united at Melbourne Observatory.

Neumayer quickly joined in the scientific life of Melbourne. He was admitted to membership of the Philosophical Institute of Victoria (predecessor of the Royal Society) in April 1857, and the following month gave an address on " The theory of terrestrial magnetism and the newest steps taken for its advancement and completion ".

Regular hourly measurements of the magnetic and meteorological elements were commenced during March–May 1858, and continued without interruption until the end of February 1863. At any one time two or three assistants were employed to maintain the exacting schedule of observations. W. J. Wills worked there from 1858 to 1860 before joining the ill-fated expedition with Burke. Just how exacting the work was may be judged from Neumayer's description of the observation schedule (1859*a*, p. 101) :

> " At 1 m. 30 s. previous to the full hour the barometer is read. At the hour itself, the instruments for horary variations in terrestrial magnetism. At 1 m. 30 s. after the hour, the dry and wet bulb, black and white bulb, and soil thermometer are read. At 2 m. wind, rain, clouds, etc. At 5 m. the electrical tension of the atmosphere is observed ".

These times were strictly adhered to, night and day ; in six and a half minutes not less than twenty observations were made and recorded, the daily tally being in the vicinity of 550. Nineteen country observing stations were established and their results registered.

In addition, ships' logs were culled for meteorological and oceanographic data relative to the seas surrounding Australia. Aurorae and meteors were also recorded.

In July 1858, members of the Philosophical Institute were invited by Neumayer to visit the observatory. In October the paper mentioned above on the observatory was read before the Institute, and in November a resume of the meteorology of August 1858, was presented (Neumayer, 1859*b*).

In the operation of the observatory various difficulties were experienced, the most troublesome of which seem to have been vibrations occasioned by major road construction nearby in King Street. Also, the erection of two sawmills in the vicinity affected the absolute values of the magnetic elements.

The results of Neumayer's and his assistants' labours at the observatory were published in two large volumes (Neumayer, 1860, 1864) and were analyzed and discussed in a third large volume (Neumayer, 1867). A summary of the climatology of Victoria was prepared for the Victorian Exhibition (Neumayer, 1861).

Neumayer also carried out a magnetic survey of Victoria in which 235 field stations were established (Neumayer, 1869). Since at that time there remained regions of north-eastern Victoria which were but poorly known Neumayer's expeditions also contributed to geographical knowledge and the opening-up of the country.

In 1863, Neumayer visited Hobart to obtain new values for the magnetic elements at the old observatory site in order to determine the secular variation there and compare it with that observed in Melbourne.

Recognizing the need for a measurement of gravity at Melbourne for geodetic purposes, Neumayer swung pendulums in a house in Domain Road, Melbourne, in an attempt to obtain both absolute and relative values (Neumayer, 1865). The results were not written up for many years (Neumayer, 1901, 1902).

By his energetic labours Neumayer made an extremely important contribution to Australian science and to geophysics in general. His initiative in establishing and operating the magnetic observatory on Flagstaff Hill led to a continuing interest in and support of geomagnetic observation by successive Victorian governments and resulted ultimately in the foundation of the present magnetic observatory at Toolangi. Neumayer left Australia in 1864 and returned to Germany where, at the expense of the British Government, he worked up his results for publication. In 1872 he was appointed hydrographer to the German Navy and in 1876 director of the Deutsche Seewarte. In his spare time he continued to work on geomagnetism and published a set of global magnetic charts (epoch, 1885) and analyses of the secular variation at several locations, including Melbourne (Neumayer, 1891; see below). He died on May 24, 1909.

Perhaps as a result of meeting Neumayer or of hearing of his arrival, the Rev. W. B. Clarke contributed a short note to the *Australian Almanac* on magnetic secular variation at Sydney, giving some early measurements (Clarke, 1858).

In 1863 John Tebbutt, an amateur astronomer of note, commenced at his newly-founded observatory at Windsor, N.S.W., meteorological observations which were to extend over 53 years. Tebbutt published his results apparently at his own expense, the first volume on meteorology incorporating the results for 1863–1866 (Tebbutt, 1868). Another amateur astronomer, F. Abbott, in Tasmania, was favourably placed to observe auroras and submitted a report on one to the British Meteorological Society (Abbott, 1865).

From the inception of his work at the Flagstaff Observatory Neumayer considered that a far more suitable site for his magnetic work lay on the south side of the Yarra River in the vicinity of Government House. Ultimately the Victorian government agreed to erect a new observatory at this spot, and provided at the same time for the amalgamation there of the activities of the Williamstown and Flagstaff observatories. The first magnetic measurements were made at the new site in 1862 and by the time Neumayer returned to Europe in 1864 Ellery had the new observatory well established. The magnetic program then continued, in spite of numerous vicissitudes, for sixty years.

Smalley and Russell

G. R. Smalley, the second Government Astronomer of New South Wales, arrived in the colony in January 1864, supplied by Airy with a list of nineteen objectives, the geophysically significant ones being: (*a*) a trigonometrical survey of New South Wales; (*b*) magnetic observations; (*c*) meteorological observations; and (*d*) recording of the tidal characteristics on the coast (Wood, 1958, pp. 10–11).

In order to commence the survey he established a base line at Lake George in 1867, but in spite of much effort had not quite completed its measurement at the time of his death two years later. He had hoped to include a measurement of an arc of meridian in the ultimate survey. In the observation of the magnetic elements at field stations in New South Wales he achieved much, although the results have never been published. He also established a non-magnetic hut in the northern part of the Sydney Observatory grounds (1866) and made periodical measurements there. Smalley expanded the meteorological work started by Scott and initiated the measurement of earth temperature twenty feet below the surface at the Observatory (Smalley, 1869*a*, 1869*b*). Finally, Airy's recommendation concerning tidal measurement was largely fulfilled by the establishment of automatic recording of tidal variations at Fort Denison (an island in Sydney

Harbour) in 1866. Smalley died in 1870 at the early age of 48.

In 1859 Scott had appointed as computer in the Observatory Henry Chamberlaine Russell, one of the early graduates from Sydney University. On Smalley's death Russell was appointed Government Astronomer, in which position he remained for thirty-five years. Throughout this period Russell maintained a large output of scientific work, including over 130 published papers and a large number of original designs for instruments (mostly of the self-recording type). He not only carried out a substantial amount of astronomical work but also achieved much in the field of geophysics. Moreover, he contributed much to the Australian scientific community at large by his work for scientific societies.

In meteorological work Russell was " actuated by a clear vision of the requirements of the country " (Wood, 1958, p. 15), and progressively increased the number of observing stations in the colony (290 in 1881; 1,600 in 1898). In 1877 he arranged with Ellery and Todd to exchange by telegraph data from selected stations, and commenced the publication of a daily weather chart. Russell's published work in meteorology is considerable (see bibliography) and contains repeated references to a nineteen year cycle first proposed by W. B. Clarke in 1846 which Russell considered was evident in the climatic data.

The search for cyclic behaviour in Australian weather forms a persistent theme in meteorological publications. It is natural that there should be such an interest for the economic consequences of the extreme variability of the climate of most areas of the continent are considerable. Papers by Russell (1877, 1897), Lockyer (1909), Keele (1910), Quayle (1910, 1925, 1938), Kidson (1925), Treloar (1934), Cornish (1936), Loewe and Radok (1948), Foley (1957), Radok (1958) and Fitzgerald (1964) are but a few of the many written on this subject; that by Loewe and Radok establishes by thorough statistical analysis the lack of any regular component of variation other than the annual wave. Dr. C. H. B. Priestley of the C.S.I.R.O. Division of Meteorological Physics is at present investigating correlations between climate and the sea temperatures around Australia.

Russell also wrote briefly on the artificial modification of the weather (1883*a*), a branch of geophysical technology that is receiving considerable attention at present.

Russell continued the work on geomagnetism and tides commenced by Smalley. In 1872 he published a paper on the magnetic secular variation at Sydney which combined data previously assembled by Clarke (1858) with the measurements at the Observatory from 1859. He gathered data on auroras observed in 1896–1897 (Russell, 1898*c*).

Russell's close attention to meteorological problems led him to assemble hydrological data for Lake George and the Murray and Darling Rivers (Russell, 1880*b*, 1886*a*, 1887*a*, 1887*b*). To explain the very small proportion of the rainfall on the Darling River catchment that flows downstream at Bourke he suggested that much of the water is absorbed and passes underground at depth (Russell, 1880*b*, 1890). Although his conclusions were incorrect in detail, in part due to his lack of understanding of the geological and petrophysical factors involved in the storage and movement of underground water, his observation led to the discovery and exploitation of the vast reserves of water held in the Great Artesian Basin. Another consequence of this work was a fierce controversy amongst geologists of the day about the origin of the artesian water (see a summary by Pittman, 1914). Pittman's assessment of Russell's contribution thus: " The finding of the first artesian flow in New South Wales was the direct result of experiments induced by Russell's reasoning, and great credit is undoubtedly due to him for this notwithstanding that he was unaware of the construction of the (artesian) basin and that his estimate of the relative run-off of the two rivers (Murray and Darling) was somewhat inaccurate " (1914, p. 7).

In the year of his appointment as Government Astronomer, Russell established a tide gauge at Newcastle and later gradually expanded the work to other ports. In his Presidential Address to the Royal Society of New South Wales in 1886 he lists mean sea levels at Sydney for the years 1873–1884. In the same work he describes a bonus result of his recording of changes in level in Lake George—the recognition of seiches in the lake when the water was impelled by winds from appropriate directions. Russell's results will be found quoted in Proudman's well known textbook on Dynamical Oceanography. Russell also gathered a large amount of data concerning ocean surface currents around Australia (1894, 1896, 1898*a*, 1899).

Disturbances in the orientation of his telescopes caused Russell to take an interest in tides of the solid earth and their detection (1886*b*, 1889*b*). He unsuccessfully investigated the possibility of using Lake George as a kind of giant spirit level which would respond to the tidal distortion of the earth. He was also led to obtain a Ewing seismograph with which the shorter period movements might be detected (see further remarks below), and analyzed the tidal records 1872–1885 for abnormal disturbances (Russell, 1886*b*, 1898*b*). The latter analysis yielded a long table in which the effects of atmospheric pressure on sea level and tsunamis generated by teleseisms are recorded. I can find no correlation of events in Russell's compilation with any known local tremors in this period.

In 1899 the introduction of electric traction on the tramways in Sydney rendered the Observatory site unsuitable for further magnetic measurements and after an interval the work was transferred to the branch observatory at Red Hill*, apparently as a result of Hecker's visit to Sydney to conduct gravity measurements. Intermittent observations were continued there by James Short until 1926 (Appendix I).

Although I have here been concerned to point out some aspects of Russell's geophysical researches, it would be an injustice to him if I did not recognize that his achievements in astronomy were commensurate with those in geophysics, as will be clear from a perusal of Dr. Harley Wood's excellent history of Sydney Observatory (Wood, 1958). A contemporary of Russell in Sydney's scientific community was Professor Archibald Liversidge, whose special interests concerned chemistry and mineralogy. These two men achieved so much in their respective special fields and jointly for science in general (both were awarded the F.R.S., both strongly supported the Royal Society of New South Wales and were co-founders of the Australasian Association for the Advancement of Science) that their relationships with one another and their influence on their younger contemporaries would make a most interesting study.

The Growth and Consolidation of Meteorological Research, 1876–1907

Systematic meteorology spread but slowly to the smaller colonies. In Western Australia it was not established until 1876, when a meteorological branch was added to the Surveyor-General's department (Scott, 1876). From 1877 to 1896 the observer was M. A. C. Fraser; by 1895 fifteen stations were reporting. In 1896 an astronomical observatory was established in Perth under W. E. Cooke and the meteorological department transferred to it (Cooke, 1901). In South Australia (including the Northern Territory), Victoria and New South Wales, the work initiated by Todd, Ellery and Scott, respectively, continued (Todd, 1871, 1894; Russell, 1889*a*), that in Adelaide being transferred in 1874 to the newly founded observatory. In Tasmania observations, which had lapsed in 1854 on the closure of Franklin's Rossbank observatory, were recommenced in 1882. In Queensland, although Brisbane and Rockhampton had been equipped with instruments by Scott in 1857, systematic widespread observations were not commenced until 1887 under the superintendence of C. L. Wragge.

Ellery (1866, 1878) and Stirling (1885) discussed observations made in Victoria.

In 1892 the Hon. Ralph Abercromby donated £100 to the Royal Society of New South Wales to establish the "Abercromby Fund . . . . to be offered as prizes for competitive essays on various phases of Australian weather". In 1896 an award was made to H. A. Hunt, meteorological assistant to H. C. Russell at Sydney Observatory. Meteorology was developing beyond pure observation into analysis and theory; papers by Hepworth (1893) and Hunt (1894, 1895) are evidence of this process, which it was Abercromby's intention to encourage.

At the federation of the Australian colonies in 1901 it was provided in the Act of Constitution that the administration of astronomical and meteorological activities should pass to the control of the federal government. A publication by the geographer J. W. Gregory (1904) included an appeal for a "united meteorological service". Conferences in 1905 and 1906 resulted in the Commonwealth taking over meteorology but not astronomy, the Bureau of Meteorology being instituted in January 1907 under the directorship of H. A. Hunt, who had been in charge of the state bureau for New South Wales from 1901. Since 1907 meteorological research in Australia has expanded tremendously, largely within the Bureau of Meteorology (Anon., 1958). From its inception the Bureau has had its headquarters in Melbourne and as a result has catalyzed the development of teaching and research in meteorology at the University of Melbourne and the Royal Melbourne Institute

*About 12 miles north-west of Sydney Observatory, at the intersection of Beecroft and Pennant Hills Roads, Pennant Hills; closed 1931.

of Technology. Analytic publications of the Bureau of Meteorology include the " Bulletin ", " Australian Meteorological Magazine " and " Meteorological Studies ". Of many syntheses of Australian climate and meteorology published since 1907 those by Hunt (1908, periodically revised) and Taylor (1920) may be mentioned.

The Birth and First Growth of Australian Seismology, 1882–1910

Australians, living in a land of very low seismicity, might be excused for a lack of interest in earthquake phenomena in the nineteenth century. It is clear, however, that as inquiry into seismological problems increased in depth in the northern hemisphere, there were scientists in Australia who followed this progress with interest. We have already noted the early records of an earth tremor in Flinders Island, Bass Strait, by Milligan (1842) and in Tasmania by Corbett (1854, 1855). Ellery (1874) discussed the Gippsland tremor of 1869. The Rev. W. B. Clarke in 1868 essayed an analysis of " the causes and phenomena of earthquakes, especially in relation to Australia " (Clarke, 1869) but the time was not ripe for such bold ventures into the realm of the unknown processes which occur in the earth. Very nearly a century later no finality has been reached on this subject !

The first instrumental seismology was conducted by A. B. Biggs, an amateur astronomer in Launceston, Tasmania. Biggs constructed his own instruments in 1882 and made a series of recordings from 1883 to 1885. The instruments and results were described in the Papers and Proceedings of the Royal Society of Tasmania (Biggs, 1885). Macroseismic observations of Tasmanian tremors in the period 1883–1885 were published by Shortt (1885, 1886) and Griffiths (1886). In 1888 Russell acquired a Ewing seismograph for Sydney Observatory and in the same period Ellery acquired a Gray - Milne instrument for Melbourne Observatory. All these seismometers registered the horizontal component of motion. The Ewing instrument came into the possession of Sydney University and was kept at different times in the Geology and Physics schools. In 1957 I was informed, much to my regret, that this historically interesting instrument was disposed of in 1953 or 1954 during the renovation of the Physics School.

The formation in 1888* of the Australasian Association for the Advancement of Science brought scientists from New Zealand into closer contact with their Australian fellows. At its third meeting the A.A.A.S. formed a committee on seismological phenomena in Australasia, the main purpose of which was to collect macroseismic data on earth tremors and quakes. New Zealand, being a moderately seismic area and having a close interest in the work of the committee, supplied its first secretary, G. Hogben. Hogben arranged for the systematic collection of reports of tremors in New Zealand and eastern and South Australia. The data were tabulated in successive reports of the Seismological Committee to the parent body (Hogben, 1893, 1894, 1895, 1898 ; Baracchi, 1903*a* ; Baracchi and Hogben, 1905) and constitute an invaluable record. At the time the Committee was established R. M. Johnston put forward some observations on the causes of epeirogenic crustal movements (Johnston, 1892). Uncritical and essentially valueless assemblies of the data for New South Wales were made by H. A. Hunt and reproduced by Taylor (1910, 1911 (?)). Meanwhile progress in seismology overseas, especially as a result of the work of Milne in Japan, had led to the design of better instruments with higher sensitivity. The first of the second generation of seismographs to be installed in Australia was a Milne brought into operation at Perth Observatory by W. E. Cooke on October 1, 1900. Six months later Pietro Baracchi established a similar instrument at Melbourne Observatory. The reports of the Seismological Committee of the British Association for the Advancement of Science at this period reflect the excitement felt by the members as the installation of instruments in countries widely distributed over the earth progressed steadily. Registrations at the early Australian stations were reported by the B.A. committee.

Russell also, in 1901, obtained a Milne instrument, but it was not operated owing to heavy blasting work in cutting Hickson Road below the Observatory. The San Francisco earthquake of 1906 revived interest in seismological recording and Lenehan, Russell's successor, commenced registrations on May 17, thirty days after the great earthquake.

In 1903 H. I. Jensen investigated a possible correlation between sunspots, volcanic and seismic phenomena and climate (Jensen, 1904).

An extremely important event in the development of Australian seismology occurred largely as the result of a break-down in the health of a Jesuit missionary in China, Father E. F. Pigot. Edward Francis Pigot was born in

* Coincidentally the first year in which the term ' geophysics ' is known to have been used.

Dundrum, Ireland, 18 September, 1858. He took degrees in arts and medicine and after several years' work in a Dublin hospital entered the Jesuit order. He was appointed to Riverview College, Sydney, as science master in 1892 and in 1899 went as a missonary to China. Not long after arrival there his health broke down and he was attached to an observatory near Shanghai where he was able to pursue an interest in astronomy aroused by Sir Robert Ball, whose lectures he had attended as a student at Dublin. He returned to Riverview College in 1905 and proceeded to assemble astronomical and seismological equipment for an observatory in the college grounds. Seismography commenced in March 1909, when the horizontal-component Wiechert instrument was commissioned. This was followed in April by a Wiechert vertical-component seismometer, the first seismograph in Australia to record the vertical component of motion. Pigot's account of the new installation, published in 1910, is a modest record of a very fine achievement. In June 1910 two horizontal-component Mainka seismographs with smoked paper recording were commissioned. Pigot devoted the remainder of his life to the observatory, developing the astronomical activities with success equal to that which crowned his efforts in seismology. The observatory quickly acquired a world-wide reputation for the quality of its work—a reputation which it deservedly retains to this day. Father Pigot died in Sydney on 22 May, 1929. Father William J. O'Leary was appointed from Rathfarnham, Ireland, as his successor.

The last development in this first flush of growth in Australian seismology occurred in about July 1909, when the fourth Milne instrument to come to Australia commenced recording at Adelaide Observatory, under the superintendence of G. F. Dodwell, government astronomer. Dodwell also compiled and published an important catalogue of South Australian earthquakes to 1908 (Dodwell, 1910).

From the foregoing account it will be seen that of the five seismographic stations established in the first decade of this century, the Riverview installation was the largest, most versatile and most sensitive. All of the Milne instruments at the government observatories were set up to record the East-West component of horizontal motion and consequently were comparatively insensitive to the steeply emergent compressional waves from teleseisms. Although changes and improvements were effected at all the observatories over the years, the general situation remained static for twenty-eight years until the foundation of the station at Brisbane by the Geology Department, University of Queensland (Pigot and Cotton, 1921).

Geodesy—the Second Phase, 1880–1938

By the publication of the Indian spheroid by Everest in 1830, the Russian spheroid by Bessel in 1841 and the subsequent great labours of Clarke over four decades, international scientific geodesy achieved very substantial progress to which Australia regrettably made no contribution. No survey of truly geodetic quality was completed in the period (Smalley's 1868 base-line at Lake George remained unused), and no results of gravity observations were published (Neumayer's 1863 results were not published until 1901). By the 1880's international geodesy had reached a stage of stocktaking accompanied by filling-in of gaps in data. Australia represented such a gap and endeavours were at last made to remedy the deficiency.

In 1882 Pritchett and Smith of the U.S. Coast and Geodetic Survey, visited Sydney with Kater pendulums and made gravity measurements (Smith, 1885). Geodetic surveys were commenced in Victoria and New South Wales, progress in the latter being described by Furber in 1898. Unfortunately the base measurements of the Victorian work were made with wooden poles and the ultimate accuracy was below acceptable standards. Kater pendulums on loan from England were swung in Melbourne and Sydney in 1893–1894 by Baracchi and Love (Baracchi, 1894; Love, 1894*a*, 1895) and by von Elblein, of the Austro-Hungarian Navy. At Baracchi's instigation the Royal Society of Victoria established a gravity survey committee to organize extensive gravity measurements in Australia (Love, 1894*b*). Unfortunately, little more was achieved than the pendulum work in Melbourne and Sydney, but Ellery and Threlfall were stimulated to develop improved instruments for gravity measurement.

Threlfall was Professor of Physics at Sydney University and had been conducting research into the elastic properties of fused quartz. His assistant was J. A. Pollock. Together they developed an instrument which may be described as a torsion gravity meter, one of the earliest practical gravity meters invented (Threlfall and Pollock, 1899). Differences in gravitational force between localities were detected by the differing angular deflection of a light boom attached to a taut horizontal quartz thread stretched along a horizontal tube 60 cm. long. The angular displacement of the boom against the restoring torque of the quartz thread was determined by a null-setting method using a sextant adapted for the purpose. The instrument was mounted on a strong tripod when a reading was taken. When packed the weight of the instrument and appliances was 226 lb. Each observation required about three hours, of which unpacking and packing occupied one hour and a half. The gravity meter was used successfully in calibration readings between Sydney, Melbourne and Hobart and field readings at Hornsby, Springwood and Armidale in New South Wales. The observations at Springwood were made in the cellar of the Oriental Hotel and all went well until a beer-keg rolled against the tripod knocking the instrument to the floor! Repeat readings made on the return to Sydney showed that the shock had induced a permanent set in the quartz-thread but no substantial damage was done. (Such shock-induced "tares" in reading, as they are called, are not unfamiliar in the operation of modern gravity meters). An unsuccessful attempt was made to detect tidal variations of gravity (Russell, 1892, p. 34).

Threlfall returned to England in 1898 and was succeeded as Professor of Physics by Pollock. No opportunity arose for Pollock to continue work on the instrument and it was stored in the Physics Laboratory until 1923, when, on Pollock's death, the director of research at the Admiralty, Sir Frank Smith, suggested that the instrument be brought to England. It was received by Threlfall in the National Physical Laboratory in September 1923. Extensive repairs and modifications had to be carried out to render it again usable after a quarter of a century of storage. It was used in a series of observations at Teddington, Kew and Oldbury in 1927–1928 and 1930–1931 (Threlfall and Dawson, 1932).

The instrument is now preserved in the Science Museum, London. It was the progenitor of the Mott-Smith gravity meter and is related to the modern Worden meter. The inventor of this instrument, Mr. Sam Worden of Texas, told me in 1954 that he was amazed that Threlfall and Pollock's instrument had worked as well as it did (standard error of ± 8 mgal) considering the difficulties he met in perfecting his own gravity meter (standard error $\pm 0{\cdot}02$ mgal).

While Threlfall and Pollock were developing their instrument a succession of European workers—Budik, Hecker and Alessio—visited Australia with pendulum sets, mainly at the instigation of the Internationale Erdmessung. Neumayer published the results of his 1863 observations in Melbourne (1901, 1902) and L. C. Bernacchi, a member of the National Antarctic Expedition, made observations at Melbourne with von Sterneck pendulums from the Potsdam Geodetic Institute (Bernacchi, 1908; Chree, 1908).

The data from this period were collated and revised by Helmert (1901) and Borass (1911, 1914).

Although by the turn of the century there remained large land areas for which no gravity values were available, a deficiency of far greater significance lay in the lack of data for the seventy per cent of the globe covered by the seas. Pendulums could not be used due to the irregular motion of a ship at sea. O. Hecker surmounted this problem by means of a static gravity device which measured the difference between the atmospheric pressure indicated by a mercury barometer and by the boiling-point of water. Clearly, a major source of error in this method is the pumping of the mercury due to the motion of the ship. Nevertheless, in spite of the large random errors inherent in his results, Hecker was able to show in a series of cruises that gravity was approximately normal in the ocean basins (*i.e.* free-air anomalies averaged zero value) (Hecker, 1908).

Progress in the geodetic survey of New South Wales remained slow and the other states showed no willingness to commence similar work. Certainly, no heed was paid to W. E. Cooke, then Western Australian Government Astronomer, when in 1907 he advocated a geodetic survey of the continent (Cooke, 1908*a*). To the British Association, meeting in Australia, Furber was able to report some progress in the New South Wales survey (Furber, 1915), and further limited progress was described at the meetings of the Pan Pacific Science Congress in Australia (Chesterman, 1924; Furber, 1924). Nevertheless, the section of the Congress on Geodesy and Geophysics resolved "that a geodetic survey of Australia is an urgent necessity, alike on national, economic and scientific grounds" (Proceedings, vol. 1, p. 36). This advice fell on very deaf governmental ears.

The New South Wales survey petered out after covering only about a quarter to a third of the State. Slight geodetic survey activity thereafter was maintained solely by the Royal Australian Survey Corps. The parlous situation of geodesy was described in all its shameful details by Miller (1934) who also pointed to inadequacies of the New South Wales work that was completed.

Gravity measurements had also almost ceased. Pendulums were swung in Melbourne by Wright in 1913 (Wright, 1921).

Hecker's pioneer attempts to measure gravity at sea were followed up by W. G. Duffield (1917, 1924) who essayed several determinations in Australian waters. The barometric method was, however, essentially imprecise and Duffield's and Hecker's results are now only of historic interest. Duffield confessed himself "not entirely satisfied" with his own results. In 1921 Adelaide Observatory acquired a set of 2-second and ½-second invar pendulums for gravity work (Annual Report, 1921), however I have been unable to find any record of any observations. In 1922 Love discussed past land gravity measurements, apparently unaware of Borrass' earlier detailed reviews (Borrass, 1911, 1914).

In 1935 F. A. Vening Meinesz, in the course of his epic program of gravity expeditions at sea, visited Western Australia, making a measurement at Fremantle with his submarine pendulum apparatus and measurements at Perth and six inland stations with Holweck Lejay pendulum apparatus (Vening Meinesz, 1941; 1948, pp. 127–128, 218–221). In 1937 C. Kerr Grant, then geophysicist at the Adelaide Observatory, obtained on loan two sets of Cambridge ½-second pendulums previously used in Africa and England. To October, 1938, when the pendulums were recalled to Cambridge, 87 stations were occupied; the results, unfortunately, were not published. Thus closed the second stage of Australian geodesy. The record of achievement, especially in geodetic survey, was indeed a sorry one.

Activity in Other Branches at the Turn of the Century

Although in this period the expansion of meteorological, seismological and geodetic studies constitute the dominant theme, less obtrusive but significant progress was achieved in/other branches of geophysics, and the birth of research in aeronomy was heralded.

Physical oceanography.—A turning-point in the development of the whole of marine science was the great circumnavigating expedition under Murray in *H.M.S. Challenger*, 1873–1876. As a result of visits to Australian waters important data were obtained and local interest in the subject was stimulated. Buchanan (1884) reported on the density distribution, and extensive measurements of other physical parameters of sea water were obtained and are recorded in the reports of the expedition. A summary of the results in the south-western Pacific by Sir John Murray was published (Murray, 1905). Working locally, Ellery (1869), Fowler (1898, 1901), Russell (1894, 1896, 1898*a*, 1898*b*, 1899) and Halligan (1921*a*, 1921*b*, 1924 and 1930) synthesized data on the surface properties, surface circulation and sea-level variations of non-tidal origin, but thereafter activity appears to have petered out. E. C. Andrews, reporting to the fourth Pan Pacific Science Congress as chairman of the "Australian Oceanographic Committee", had little that was new to contribute (Andrews, 1930). Foreign expeditions continued to visit Australian waters and important syntheses of data for both the Pacific and Indian Oceans were published by Schott (1935) and Thomsen (1935). In the same period Deacon in *R.R.S. Discovery II* carried out systematic studies of the circum-Antarctic waters (Deacon, 1937*a*, *b*).

Recordings of the tides along the Australian coast commenced, as we have seen, by Ellery and Scott in the middle of the nineteenth century, were submitted to the United States Coast and Geodetic Survey for analysis in the 1890's so that the accuracy of tidal predictions might be improved. Tidal observations on the coasts of South Australia, the Northern Territory and Western Australia were initiated after 1880. Analyses of the principal components for Port Adelaide were published by Chapman (1893) and Chapman and Inglis (1894). Errors in Chapman's earlier analysis were noted by Chapman and Inglis (1898). At the turn of the century R. A. Harris, of the U.S.C.G.S., published a series of exhaustive memoirs on tides, in one of which he gave the results of analyses of tidal components for Sydney, Melbourne, Adelaide and Fremantle, a map of cotidal lines and range of spring tides, and charts of tidal currents in south-eastern Australia and the entrance to Port Phillip (Harris, 1901, pp. 674–675, Plates 25, 34, 35). Chapman and Inglis reported on the tides of Port Darwin in 1903. The issue of tidal predictions for Western Australia was commenced by Perth Observatory in 1913. General reports on tidal recording and analysis were published by Chapman (1921) and Halligan (1924). Chapman recorded that automatic tide gauges were operating as follows: New South Wales, seven; South Australia, five; Western Australia, four; Queensland, four; Tasmania, two; Victoria, one. The data from Queensland and Tasmania had not been analyzed and no predictions were being issued there.

Geomagnetism.—In the course of the oceanographic work, magnetic observations were made on *H.M.S. Challenger*, the results of which were reported by Creak (1888) and Maclear *et alii* (1882). In 1885 Harris described the secular variation of declination in South Australia, and in 1888–1891 C. C. Farr determined the magnetic elements at Sydney University (Farr, 1892). Neumayer, working entirely in his spare time, continued to make substantial contributions to the subject, and in a general discussion of considerable importance (Neumayer, 1891) he summarized the secular variation at Melbourne over the period 1858–1884 (pp. 7, 10, 13) by quadratic functions:

$$D = -8^\circ 19{\cdot}74' - 1{\cdot}1800\ (t\text{-}t_0) + 0{\cdot}020\ (t\text{-}t_0)^2$$
$$I = -67^\circ 06{\cdot}0' + 0{\cdot}08'\ (t\text{-}t_0) + 0{\cdot}008'\ (t\text{-}t_0)^2$$
$$H = 23{,}630 - 6\ (t\text{-}t_0) + 0\ (t\text{-}t_0)^2 \text{ gamma.}$$

Standard errors of the coefficients are not given.

Surveying vessels periodically visited Australian waters and made routine magnetic observations. In 1890–1891, in the course of such work mainly along the coast of Western Australia, *H.M.S. Penguin* examined at Port Walcott a magnetic anomaly the existence of which had been reported by Staff-Cdr. Coghlan five years previously. So detailed a survey of the anomalous area was carried out (Creak, 1896) I shall have cause to refer to it again in the section on geophysical exploration. In 1895 the " Missions magnetiques du Bureau des Longitudes " were active in the Australian region (David, 1896).

In 1898 the A.A.A.S., at its Sydney conference, created a committee for the purpose of promoting the study of terrestrial magnetism in the Australian colonies. The main practical results achieved were (i) the New Zealand government was persuaded to establish a permanent observatory at Christchurch; (ii) the Victorian government was persuaded to make a financial allocation to enable Baracchi to employ assistants at Melbourne Observatory to reduce the accumulated magnetic records; and (iii) a magnetic survey of Tasmania was instituted (Hogg, 1902; McAulay and Hogg, 1903). (Note that Hogg's historical review in his 1902 paper ignores the work of de Rossel, Fitzroy, Franklin and Wickham prior to 1839).

An isolated contribution to the theory of the origin of the earth's field was made in 1900 by William Sutherland (described by Blainey as a " sensitive and lonely scholar "—Centenary History of Melbourne University, p. 44). Sutherland's hypothesis was that the earth carries an electrostatic field in its rotation. The obliquity of the magnetic field he ascribed to asymmetric magnetic permeability of the earth which also caused the induction of earth currents, the secular variation of whose tracks was the cause of the magnetic secular variation. Since it has been conclusively shown that the main geomagnetic field is internal in origin theories dependent on external electrostatic fields are unacceptable.

Tectonophysics.—The inward increase of temperature was investigated at the Balmain Colliery, Sydney and a gold mine at Bendigo, Victoria, by Rae *et al.* (1899) and Jenkins (1903) respectively. In 1914 Statham discussed " pressure in relation to the solid components of the earth's crust " but his ideas were astray. In the period 1914 to 1922, L. A. Cotton of Sydney University operated a Heidelberg horizontal pendulum at Burrunjuck Dam, near Yass, New South Wales, hoping to record the deflections of the crust as the dam filled with water (Cotton, 1915, 1921). The crustal deflection was obscured by the larger-magnitude effects of the diurnal insolation and the inadequacy of the pendulum and recording system. However, several small earth tremors were recorded; it was impossible to determine whether these may have been triggered by the water load because their precise location was unknown.

Aeronomy.—Early signs of interest in this subject appear from papers by Russell (1898*c*) on auroras and by J. A. Pollock (1909, 1910) (preceded only by records of atmospheric electricity by Neumayer from 1859 to 1862—Neumayer, 1867, pp. 70–83). However, two decades were to pass before intensive research commenced in this field.

Magnetic and Atmospheric Research by the Carnegie Institution of Washington; Watheroo Observatory

In 1905 the Carnegie Institution of Washington commenced world-wide research into terrestrial magnetism and Australian geophysics was to benefit greatly from the bold program undertaken by the Institution. In 1906 magnetic observations were made by Carnegie men at the Melbourne and Red Hill observatories (Bauer, 1912, pp. 75, 148).

In about August, 1911, Edward Kidson was placed in charge of C.I.W. magnetic survey work in Australia. At the end of the year he had secured observations at about 35 stations in Victoria, South Australia and New South Wales, including comparisons with the Melbourne Observatory instruments and reoccupations suitable for secular variation analysis. Kidson also visited Hobart and compared and standardized the magnetic instruments (in part supplied by the Carnegie Institution) of Mawson's Australasian Antarctic Expedition. Messrs. E. N. Webb and A. L. Kennedy, magnetic observers for the expedition, were instructed in the use of the instruments and methods of observation. During February to April, 1912, Kidson secured observations at 25 stations in Western Australia. At Mt. Magnet he established five auxiliary stations to investigate in a general way the local disturbance at this locality (due to Pre-Cambrian magnetite-bearing "Banded Iron Formation"; anomalies exceeding 50° in declination, 12° in inclination and 3000γ in horizontal force were found. On May 24, 1912, Kidson set out on his first transcontinental journey, with F. W. Cox as assistant observer, from Oodnadatta, South Australia, then the railway terminus. They proceeded north by a caravan of eight camels arriving at Alice Springs on June 20, Tennant Creek on July 25, and Darwin on September 17. Forty stations were occupied, generally at night to avoid delay. The average daily travel was a mere seventeen miles. Kidson's director at the C.I.W. Department of Terrestrial Magnetism commented (Bauer, 1913, p. 2234): "The successful execution of the work required no little perseverance, endeavour and self-sacrifice". These qualities of persevering in the face of difficulty were also exhibited by Kidson in later journeys along the Canning Stock Route in Western Australia and in South America; indeed they were qualities demanded of most of the magnetic field observers of the Carnegie Institution in the pursuit of its object of a global magnetic survey.

Kidson presented a summary of his results to January 1913, to the A.A.A.S. (Kidson, 1914). The survey continued to the end of 1914 and a second transcontinental trip by camel was completed, on this occasion in Western Australia, from Coolgardie to Wiluna, Hall's Creek (via the Canning Stock Route), and Wyndham (Kidson, 1915, 1922). It is of interest that Mr. J. van der Linden, of the Bureau of Mineral Resources, while carrying out a magnetic resurvey along the Canning Stock Route, discovered a box with C.I.W. markings apparently abandoned by Kidson some fifty years previously. We may also note that in 1914 the earth inductor was first used by the Institution in replacement of the dip circle. Kidson's results were tabulated by Bauer and Fleming (1915) and Bauer *et al.* (1921). A fascinating account of Kidson's varied life as a C.I.W. magnetic observer has been given by his wife (Kidson, 1941); in 1920 he joined the Australian Bureau of Meteorology and later became Director of the New Zealand Meteorological Service.

The Carnegie Institution also actively prosecuted magnetic research at sea, in the course of which the *Carnegie* cruised near the north-eastern coast of New South Wales (cruise IV) and called at Fremantle (cruise VI) (Bauer *et al.*, 1917; Ault and Mauchly, 1926, pp. 95, 109–110, 251).

In 1916 W. C. Parkinson and W. F. Wallis, of the C.I.W. staff, carried out trial surveys in Western Australia for a site suitable for a magnetic observatory to be approximately antipodal to the main C.I.W. observatory in the United States and to compliment that at Melbourne. A site was selected on the flat sandy plain at Watheroo, 120 miles north of Perth and the observatory constructed (Fleming and Wallis, 1920). Magnetic observations were commenced on January 1, 1919, and atmospheric electricity and telluric current observations in 1922. The initial staff included W. F. Wallis and E. Kidson.

The early published work of the observatory included papers on magnetic storms (Wallis, 1919*a*; Kidson, 1920*a*, *b*, 1921*a*; Parkinson, 1921*a*; Wait, 1923*a*, *b*; Johnston, 1925), atmospheric electricity (Kidson, 1921*b*; Wait, 1923*b*; Johnston, 1926), auroral displays (Wait, 1923*b*), telluric currents (Gish, 1923; Gish and Rooney, 1928), and earthquakes registered by the Eschenhagen magnetographs (Wallis, 1919*b*; Kidson, 1920*c*, 1921*b*; Parkinson, 1921*b*; Wait, 1922*a*, *b*, 1923*a*; Johnston, 1925). The work and equipment of the observatory were described at the Pan Pacific Science Congress in Australia by Wait (1924). The accumulated magnetic data of the observatory to mid 1947 were published in three volumes aggregating 1770 pages (Fleming, Johnston, McNish, *et al.*, 1947; Fleming, Johnston, Parkinson, *et al.*, 1947; Parkinson, *et al.*, 1951).

In 1935 ionospheric research was commenced. Publications resulting from this work are noted in a subsequent section.

At the request of the Carnegie Institution Watheroo Observatory was taken over by the

Bureau of Mineral Resources on July 1, 1947. It was closed at the end of 1958 and replaced by the Gnangara observatory near Mundaring, east of Perth, W.A.

C.I.W. parties periodically reoccupied Australian magnetic stations, in order to determine the secular variation and permit revision of world magnetic maps ; in addition, a few new field stations were occupied (Fisk and Sverdrup, 1927 ; Wallis and Green, 1947).

Magnetic Work by Melbourne and Adelaide Observatories, 1912–1943

Stimulated and greatly aided by the Carnegie magnetic parties in Australia, the Melbourne and Adelaide observatories took an increasing interest in terrestrial magnetism during the second decade of this century. After his appointment to the directorship of Melbourne Observatory in 1915, J. M. Baldwin reorganized the magnetic work within the limited means at his disposal, and some reduction of records was completed (Baldwin, 1920). The forthcoming introduction of electric traction on the Melbourne suburban railways made it essential to transfer the magnetic observatory to a suitable site in the country. Toolangi, 33 miles north-east of Melbourne, was chosen and the new observatory commenced operation in 1919 (Baldwin, 1919) at the same time as that at Watheroo. Hourly values for the years 1924 to 1926 only were published by Baldwin (1926, 1927, 1928). In 1935, Major E. H. Booth observed the diurnal variation in Z at his country home " Hills and Dales ", Mittagong, and published a discussion of discordances between his curves and those observed at Toolangi (Booth, 1936). In 1943, the Victorian government transferred the Melbourne observatory organization to the control of the Commonwealth Solar Observatory, Mt. Stromlo, which in 1947, transferred the magnetic and seismological activities of the observatory to the Bureau of Mineral Resources (van der Waal and Brooks, 1951).

In Adelaide, the director of the Observatory, G. F. Dodwell assisted the Carnegie magnetic party (Kidson and Webb) during their work in South Australia. Then, using apparatus borrowed from the Carnegie Institution, Sydney Observatory and Perth Technical College, he carried out a series of magnetic observations in the Musgrave Ranges. Incorporating these results with Kidson's preliminary reductions of his own work, Dodwell published charts of D, H and I for South Australia and Australia (Dodwell, 1915). From this date a variable but useful number of magnetic stations was achieved in most years to 1936 (Dodwell, 1918, 1921, 1934, 1935 ; Wallis and Green, 1947). In 1928, 109 stations were established, principally on Yorke Peninsula and the west side of Spencer Gulf. Some of the later work was directed towards geophysical prospecting (see below).

Later events.—To meet wartime needs, J. M. Rayner compiled declination charts for epoch 1942 (Rayner, 1944) and, in conjunction with R. B. Makinson of Sydney University, made some magnetic determinations. In 1953, the Bureau of Mineral Resources commenced systematic regional surveys throughout Australia which continue to the present time.

Aeronomy

Modern Australian research into atmospheric electricity and the upper atmosphere sprang largely from the practical needs of efficient radio communication over long distances within the continent and with overseas countries. The research became established so rapidly that it is practicable only to mention early publications to avoid overloading the bibliography.

In 1927, the Council for Scientific and Industrial Research formed a Radio Research Board to assist, coordinate and expand radio propagation research already in progress in the Universities of Sydney and Melbourne. The Board resolved that the first problems to be tackled should be fading and atmospherics. This quickly led to fundamental geophysical research of considerable importance, especially in the study of the ionosphere, contributed by A. L. Green, V. A. Bailey and D. F. Martyn, all of whom had come under the influence of E. V. Appleton in the United Kingdom. Progress in the study of the ionosphere was rapid (Green, 1932 ; Bailey and Martyn, 1934 ; Martyn, 1934 et seq.) and soon led to significant discoveries concerning the properties of the upper atmosphere as a whole (Martyn and Pulley, 1936). Systematic observations of atmospherics demonstrated that they almost always arose from thunderstorms and their diurnal and seasonal variation was correlated with the variation of thunderstorm activity (Munro and Huxley, 1932 ; Munro *et al.*, 1935).

In 1930 research into atmospheric electricity and the ionosphere was instituted at the Commonwealth Solar Observatory, Mount Stromlo, Canberra, by C. W. Allen and A. R. Hogg (Allen, 1934, 1939 ; Hogg, 193.*a*, *b*, 1935, 1939). At the Watheroo Observatory ionospheric research was commenced in 1935 (Seaton and Hogg, 1938; Parkinson and Prior, 1939). Research on the upper atmosphere soon elicited the influence of solar disturbance on the ionosphere. The Mount Stromlo observatory having both ionospheric and solar research equipment was favourably placed for investigations into this new borderline field between geophysics and astrophysics, generally called "solar-terrestrial relationships" (Giovanelli, 1938; Higgs and Giovanelli, 1938).

Important research in each of these fields continues to be carried out in Australia, stimulated by the introduction of rocket and satellite techniques.

Geophysical Prospecting

Geophysical methods of prospecting depend for their efficacy on contrasts in properties between juxtaposed rock masses. The magnetic effects of certain rocks were recognized qualitatively before the Christian era and in more recent times were often commented upon by explorers (*e.g.* Flinders, 1814, pp. 526–528). A note on the magnetic properties of the dolerite from Brady's Lookout, Tasmania, was presented by R. C. Gunn to the Royal Society of Van Diemen's Land in April, 1845. The earliest quantitative investigations relating to Australia of which I have found a record were those by A. W. Rücker, Professor of Physics in London. In a letter to Liversidge dated 1887, he requested information that may be available "as to whether rocks in Australia which contain (1) magnetite, (2) iron ore other than magnetite, attract the south-seeking pole of a magnet in their neighbourhood" (Rücker, 1889*a*). The letter was read to a meeting of the Royal Society of New South Wales. A Mr. D. M. Maitland stated that he had found this to be the case when in the Tumut district some years previously. Rücker contributed a note to the first meeting of the A.A.A.S. on the polarity of magnetic rocks in which he recognized the magnetizing effects of lightning strikes (Rücker, 1889*b*). Later he published data on the magnetic susceptibilities of Australian basalts (Rücker, 1894).

The earliest detailed magnetic survey of which I have found a record was that of the entrance roads of Port Walcott, near Roebourne, W.A., carried out by Cdr. Moore in *H.M.S Penguin* in 1890–1891 and reported in "*Nature*", March 19, 1891, and by Ellery (1892). Anomalies in declination, dip and intensity were determined in an area approximately 4 km. by 3 km. Samples from the sea bed and nearby shore were collected and submitted to Rücker for susceptibility determination. All the results were reported by Creak (1896) but a satisfactory explanation of the anomaly was not arrived at until H. P. Woodward geologically surveyed the adjacent land and established that the anomaly lay on strike with a magnetic-bearing jaspilite (Woodward, 1911, p. 19).

The application of geophysical methods to prospecting dates from the closing decades of the last century, and in this country appears to have commenced shortly after 1910—so that here it is little more than fifty years of age. Historical notes have been published previously by Rayner (1932–1933), Booth (1937), and Thyer (1963), each dwelling upon special aspects of the story.

In 1913 the Electrical Prospecting Company of Sweden (ABEM) took out Australian patents 10535 and 11438 and the Schlumberger Company (of France) took out patent 9378 in 1913 and patent 13132 in 1914, all being concerned with electrical prospecting methods.

In 1915 Dodwell noted magnetic anomalies due to basic rocks in the Musgrave Ranges (1915, pp. 69–71). In 1918 Dodwell and Grant carried out a partially successful search for irrigation equipment lost in the Torrens River near Adelaide, using the magnetic method and a Hughes electrical induction balance (Dodwell, 1918, p. 8). Magnetic anomalies associated with mineralization in an area north of Ardrossan (Yorke Peninsula, South Australia) were mentioned by Dodwell (1921, p. 12).

In 1925, in connection with the telluric current work conducted by the Watheroo Observatory, a resistivity depth sounding was executed by Rooney and Gish (1927) in order to determine the vertical distribution of resistivity.

Systematic geophysical surveying for metalliferous deposits appears to have commenced about 1925 or 1926 and official interest in the new technique was aroused. E. C. Andrews, Government Geologist of New South Wales, investigated geophysical methods while overseas in 1927 and reported favourably, recommending the institution of geophysical facilities by the New South Wales Geological Survey (Andrews, 1928). Also an extensive paper was delivered to a meeting of the Institute of Mining and Metallurgy by H. W. Gepp and others in which the prospecting methods were described and their use in Australia advocated (Gepp *et al.*, 1927).

In the same year the South Victoria Prospecting Company conducted an electrical survey of the vicinity of the Monarch mine at the Pinnacles, Broken Hill. In a report quoted by the *Sydney Morning Herald*, April 5, 1927, it was claimed that the survey " had disclosed lode bodies 60 to 80 feet wide, a lode channel up to 300 feet wide and 500 feet in length with a depth of 1,000 feet with increasing richness ". Some indication of the field methods by which these startling discoveries were made may be gained from reports of the Broken Hill mining inspectors and the geologist Kenny (Annual Report of the Department of Mines, N.S.W., for 1927, pp. 47–48 and 130): The electromagnetic system used " apparatus of the simplest kind. Results are obtained direct from portable electrode spears and headphones for listening in . . . If no sound is heard in the phones it is taken that some good conductor has absorbed the current and this is mapped as an ore body ". One is led to wonder how much of the huge " orebody " thus outlined resulted from high contact resistance of the electrodes. Work was also carried out at the Globe mine.

In the mid-twenties metalliferous mining in Australia began to decline and governmental action to stimulate activity especially in gold-mining took the form of both legislation—for example the Precious Metals Prospecting Act of 1926—and negotiations with the United Kingdom concerning new methods of prospecting. Andrews' report previously referred to and the recommendations of H. W. Gepp, chairman of the federal Development and Migration Commission (Gepp, 1928), led to an approach by the Australian government to the Empire Marketing Board in 1927 concerning geophysical surveys. The Board asked the British Committee of Civil Research to appoint a sub-committee to consider the question of geophysical prospecting in the widest sense. In its report the sub-committee commended geophysical methods of prospecting and strongly recommended that an experimental survey be organized to conduct an " extensive trial of the principal methods accompanied by full publication of the scientific information and experience so acquired ". The proposed survey was to last for two years and Australia was suggested as a suitable location.

The Imperial Geophysical Experimental Survey thus created was financed by contributions of £16,000 each by the Empire Marketing Board and the Australian Government, the latter's contribution being appropriated under the Geophysical Survey Act, 1928. The work was controlled by a representative executive consisting of Dr. A. C. D. Rivett, Professor T. H. Laby and Messrs. W. E. Wainwright, E. C. Andrews, L. K. Ward and H. W. Gepp. Operations were directed by Mr. A. B. Broughton Edge (England, a mining engineer) assisted by Dr. E. S. Bieler (Canada) as Deputy Director. The scientific staff comprised the Australians, E. H. Booth, N. B. Lewis, R. L. Aston, E. L. Blazey, and J. M. Rayner (the last seconded by the N.S.W. Geological Survey), together with J. C. Ferguson, S. H. Shaw and J. McG. Bruckshaw from the United Kingdom. Bieler died in Geraldton from pneumonia.

The survey commenced during 1928 and concluded in 1930. A wide variety of methods was used at twenty localities in Australia. While in Australia Edge addressed the Institute of Mining on geophysical prospecting but curiously did not allude (in the printed version, at least) to the work of his organization (Edge, 1928). The results of the survey were compiled and published, together with a discussion of methods, by Edge and Laby (1931).

During 1928, geophysical investigations were carried out at Yerranderie by a Mr. W. H. Frazer, but no results were published (Annual Report, N.S.W. Mines Department, 1928, p. 45). In 1929, Dr. H. Jensen advocated before the Queensland Royal Commission on Mining a geophysical survey of the Mount Morgan field (Sydney Morning Herald, June 28, 1929), but no work was carried out by the I.G.E.S.

In 1930, C. T Tennberg of the A.B.E.M. company addressed the Institute of Mining on modern prospecting (Tennberg, 1930). The paper was followed by an extended discussion (Edge, 1930; Wainwright, 1930). Of the Broken Hill area, Tennberg said (p. 15): " I do not think it will be of much use to look for the Broken Hill ore-body towards the depth by means of geophysics, but there are areas in the vicinity, especially around the Pinnacles Mine, that would be well worth examination . . . . We have the problem of saline ground waters here, but I think that is a difficulty that could be overcome to some extent with modern instruments ". It is interesting to assess this statement in the light of subsequent experience on the field with airborne electromagnetic, AFMAG and induced polarization surveys carried out in the past decade!

In furtherance of its policy of arousing interest in geophysical methods, the Institute of Mining reprinted an American summary of geophysical prospecting originally published in 1929 (McLaughlin, 1930). In 1930 magnetic surveys over basalt-covered deep leads at Gulgong were made by J. M. Rayner, the sole geophysicist in permanent government service in Australia at the time (Rayner, 1931). He addressed the Institution of Surveyors on geophysical methods (1932–1933). In subsequent years Rayner carried out numerous surveys in New South Wales, reports on some of which were published (see bibliography). Also Booth conducted some magnetic surveys in connection with purely academic geological research (Booth and Rayner, 1935; Booth, 1935).

Private electrical surveys are known to have been carried out in the Cobar area in 1931 and in eastern Victoria, at Bethanga, Talgarno and Cassillis, in 1932 (Blazey and Rose, 1933). The A.B.E.M. company was active, mainly in Western Australia. In 1934, Dodwell published a map of magnetic declinations observed in the Kadina copper mining district, South Australia, in the period 1928–1933, to " determine the course of the lode " (Dodwell, 1934, pp. 2, 7).

Another important step towards the firm establishment of geophysical prospecting in Australia was taken by the Federal Parliament in 1934, when, by passing the Northern Australia Survey Act, the Aerial, Geological Survey of Northern Australia was established. The idea of the survey was conceived by H. W. Gepp (Commonwealth Consultant on Development; knighted 1933). The survey was intended to cover approximately 10,000 square miles in mineral-bearing areas, generally north of the 22nd parallel, in each of Queensland, the Northern Territory and Western Australia. Work commenced in 1935 and was originally to run for three years. Extensions prolonged the life of the survey to 1941. The Executive Committee comprised Sir Herbert Gepp, Chairman and Director of Survey, L. C. Ball and F. G. Forman (Government Geologists of Queensland and Western Australia), and P. B. Nye, executive Officer (Government Geologist of Tasmania). The Consultants were W. G. Woolnough (Commonwealth Geological Adviser) and J. M. Rayner (seconded by the New South Wales Geological Survey). The geophysical staff comprised initially two parties: (1) R. F. Thyer, party leader and applied geophysicist, C. A. Jarman, applied geophysicist and B. P. Oakes, trainee geophysicist; (2) E. L. Blazey, party leader and applied geophysicist, L. A. Richardson, applied geophysicist, and J. Daly, trainee geophysicist. L. A. Richardson was subsequently placed in charge of a separate magnetic party. In 1936, C. H. Zelman and J. V. Hocking, trainee geophysicists, were added to the geophysical staff. The total staff reached 67.

The work of the survey covered a large number of mineral prospects. Of 177 reports issued in full or in part in the semi-annual reports of the survey, 42 were geophysical. Some economically significant results were obtained, the most outstanding of which were those at Tennant Creek, N.T., and Dugald River, Queensland (Thyer, 1963, pp. 274–276). The geophysical methods used were described by Horvath (1937) and Rayner *et al.* (1940). The small group of experienced exploration geophysicists existing at the cessation of the survey was largely absorbed into the federal Mineral Resources Survey which was established in 1942, and which in 1946, became the Bureau of Mineral Resources. The professional geophysical staff of the Bureau is at present about 120 persons.*

The application of geophysics to the search for petroleum in Australia occurred later than in mineral exploration, and the standards of he surveys and interpretations left much to be desired. In 1928–1929, at the suggestion of Dr. Jensen, chief geologist of Roma Oil Corporation, Queensland Geophysical Surveys Ltd. arranged with the German Piepmeyer company to carry out geophysical tests. " Details of the work are not available, but it is believed that magnetic, gravity, electrical, seismic and radioactive methods of exploration were used; however, the work was confined to local testing at various places, and no useful results were obtained " (Dooley, 1950, p. 6).

Reporting on his tour of the United States and Argentina, the Geological Adviser to the Commonwealth, Dr. W. G. Woolnough, took a pessimistic view of the value of geophysical methods: " So far as I am aware, in no instance has the result of geophysical work been directly followed by production drilling . . . To summarize . . . it may be said that while such (geophysical) investigations are of great value in indicating areas where geological structure may be of favourable character, they are all, in their present stage of development, very costly, and the indications which they give are very incomplete and indefinite " (Wool-

* Note added in proof: Mr. J. M. Rayner, Director of the Bureau of Mineral Resources since 1958, was honoured by H.M. Queen Elizabeth with the award of *O.B.E.* on 1st January, 1967.

nough, 1931, pp. 36–39). The first claim was incorrect. From 1924 the Nash, Orchard, Anahuac and other fields had been discovered entirely by geophysical means.

In 1932 a magnetic survey was conducted in the Gippsland, Victoria, to locate topographic highs in the basement (Oil Search, Ltd., publication, 1932, quoted by Booth, 1937). From 1939, the Shell company conducted geophysical reconnaissance over about 192,000 square miles in south-eastern Queensland.

The largest single factor inducing extensive geophysical surveys of adequate quality was the passage of the Petroleum Search Subsidy Act by Federal Parliament in 1959.

In retrospect, it seems to me obvious that but for the persistent advocacy of geophysical methods by Sir Herbert Gepp, the search for Australia's mineral resources might have languished at least until the Second World War. Without the nucleus of experienced men derived from the North Australia survey, the creation of the geophysical section of the Bureau of Mineral Resources would have been seriously hampered, and the post-war development of our mineral wealth correspondingly restricted.

Resurgence of Geodesy, Physical Oceanography and Seismology

After the Second World War two important factors combined to stimulate Australian geophysical activity: rapid growth of population, requiring rapid national development; and vastly improved technology inherited from wartime developments.

Geodesy.—The need for an adequate geodetic survey was at long last admitted at government level and in 1946 the National Mapping Office was created from the former Survey branch of the federal Department of the Interior. Even so, by 1952, geodetic survey extended only from the Queensland-New South Wales border clockwise around the coast to Port Augusta, South Australia. By 1961 a transcontinental arc approximating 32° S. was available (Lambert, 1962), and the whole survey is now very near completion, including moreover, a connection with the international network through Indonesia.

After a long interval, geodetic gravity measurements were resumed in 1950 and a pendulum survey of the continent carried out by McCarthy and others (Dooley *et al.*, 1961). Numerous visits were paid by overseas workers effecting gravity connections to the U.S.A. and Europe.

Physical Oceanography.—Until very recently almost the sole research activity in this field was that pursued at the C.S.I.R.O. Division of Fisheries and Oceanography, for many years merely as an adjunct to fisheries investigations. The issue of regular station-lists was commenced in 1951, and research expanded steadily. Important papers on the structure and circulation of the Tasman Sea and Indian Ocean have since been published by Rochford (1957, 1959), Wyrtki (1960) and Hamon (1961). Observations on the surface layers of Antarctic waters have been conducted by members of the Australian National Antarctic Research Expeditions (*e.g.* Loewe, 1950, 1957).

Seismology.—The paucity of seismographic stations in Australia between the wars rendered it impossible to locate by normal instrumental methods the epicentres of any but the largest Australian earthquakes. Discussions of the macroseismic effects of a few earthquakes were published (Hedley, 1925; Holmes, 1933; Bryan and Whitehouse, 1938; Gaskin, 1947; Jones, 1948) and a general synthesis of Australian seismicity was compiled by Burke-Gaffney (1952).

New seismographic stations were established in 1937 at Brisbane by the Geology Department, University of Queensland (Bryan, 1938), and at Rabaul, New Britain, by the New Guinea Administration. Substantial development of the Australian network did not, however, commence until 1957 (Doyle and Underwood, 1965).

De Jersey, in 1946, discussed the seismological evidence for crustal thickness in the south-west Pacific region. The first analysis of seismic travel times in Australia (with revision of a number of epicentres) was published by Bolt (1959).

Theoretical seismology received some attention from L. A. Cotton, who investigated earthquake frequency in relation to tides of the solid earth (Cotton, 1919–1922), but received a great boost in 1940 when K. E. Bullen came to Australia to join the staff of the University of Melbourne. In that year were published the standard tables of body-wave travel-times compiled by H. Jeffreys and himself. Professor Bullen's subsequent contributions to seismology and the study of the interior of the earth and inner planets have received international acclaim.

The analysis of microseismic levels in relation to storms attracted interest for a short period. Data from Riverview Observatory were incorporated into a general analysis by Lee (1934).

More recently the relation of microseismic activity to cyclones in the Coral Sea was studied by Upton (1956, 1960).

The Teaching of Geophysics

Australian University courses paid scant attention to Geophysics until the great development of mineral and petroleum exploration throughout the continent after the Second World War brought about a demand for geologists with some knowledge of geophysics and later a demand for geophysicists. Physics departments proved reluctant to admit any geophysical material into their third-year courses (where it would have been of greatest value in interesting physics graduates in a geophysical career), and several departments of geology took over the responsibility.

Thus, apart from the series of sixteen lectures, four demonstrations and three field days in Geophysical Prospecting given in 1931 by Booth under the auspices of the Extension Board of Sydney University, a University undergraduate geophysics course was not established until 1950. The lecturer was Dr. H. I. S. Thirlaway, a graduate of the Cambridge Department of Geodesy and Geophysics, who was specifically appointed by the University of Sydney to develop teaching and research in geophysics, both fundamental and applied, as a member of the Geology Department. He remained only a year, but successfully pioneered both teaching and research which have since spread to seven other Australian universities.

Epilogue

The development of geophysics in Australia was a microcosm of progress on the wider, international scene. Throughout most of the period the number of participants in any field was small, as were the financial resources available. Much of the progress achieved resulted from personal energy, devotion and leadership, coupled, of course, with the necessary skills and intellectual qualities. In this context, I see the work of such men as Brisbane, Franklin, Neumayer, Ellery, Russell, Dodwell, Piggot and Booth as of paramount significance.

Acknowledgements

In the preparation of a compilation such as that essayed here, one must necessarily depend on the assistance of one's seniors in elucidating the details of events which are not clear in the printed record. I wish especially to acknowledge fruitful conversations with Mr. J. Bayliss, Dr. W. R. Browne, the late Dr. G. Builder, Professor K. E. Bullen, the late Father T. N. Burke-Gaffney, the late Father A. Fynn, Mr. B. V. Hamon, Mr. C. Kerr Grant, Mr. J. M. Rayner, Mr. P. F. Rheinberger, Mr. L. A. Richardson, Mr. R. F. Thyer and Dr. H. W. Wood.

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Appendix

Observatory Geophysics in Australia, 1821–1957

Observatory[1]		Period of Operation (Intermittent Operation shown between brackets)				
Location	Owner	Meteorology[2]	Seismology	Geo-magnetism	Iono-sphere	Other[3] Aeronomy
Parramatta, N.S.W.	Brisbane; N.S.W. Govt.	1821–1827; 1832–1838	—	(1821–1828)	—	—
Hobart, Tas.	U.K. Govt.; Tas. Govt.	1847–1854; 1882–1911	—	1840–1854	—	—
Williamstown, Vict.	Vict. Govt.	1853–1863		—	—	—
Windsor, N.S.W.	Tebbutt	1863–1915	—	—	—	—
Flagstaff, Melb., Vict	Neumayer	1857–1862	—	1858–1862	—	Au 1859–1862 AE 1858–1862
Sydney, N.S.W.	N.S.W. Govt.	1858–	(1888–1906) 1906–1948	1865–1899 see Red Hill	—	—
Melbourne, Vict.	Vict. Govt., Aust. C.S.O., Aust. B.M.R.	1863–	1902–1962	1862–1922 see Toolangi	—	—
Adelaide, S. Aust.	S.A. Govt., Adel. Univ.	1874–	1909–1950 1958–	(1914–1937)[4]	—	—
Perth, W. Aust.	W. Aust. Govt.	1896–	1901–1964	—	—	—
Red Hill, N.S.W.	N.S.W. Govt.	—	—	(1905–1907) 1908–1926	—	—
Riverview, N.S.W.	Jesuit Order	1931–	1909–	—	—	—
Mt. Stromlo, A.C.T.	Aust. C.S.O., Aust. Nat. Univ.	(1911–1913)	1958– (designated as "Canberra")	—	1930–	AE 1925–
Watheroo, W. Aust.	Carnegie Inst., Aust. B.M.R.	1919–1958	—	1919–1958	1935–1958	AE: 1922–1958 TC 1923–1958
Toolangi, Vict.	Vict. Govt., Aust. C.S.O.; Aust. B.M.R.	—	1962–	1919–	—	—
Brisbane Qld.	Univ. Qld.	—	1937–1951; 1953–[5]	—	—	—
Rabaul, N. Britain	New Guinea Admin.	—	1940–1942; 1954–	—	—	—
Heard Island	Aust. N.A.R.E.	1948–1954	1951–1954	1947, 1950 1952–1954	—	Au: 1947–1954
Macquarie Island[6]	Aust. N.A.R.E.	1948–	1951–	1948, 1951–	1950–1956	Au: 1950–
Camden, N.S.W.	C.S.I.R.O.	—	—	—	1952–	1952–
Mawson, Antarctica	Aust. N.A.R.E.	1954–	1956–	1955–	1955–	Au: 1954–
Gnangara, W. Aust.	Aust. B.M.R.	—	—	1957–	—	—
Darwin, N. Terr.	Aust. B.M.R.	—	1961–	1957–1958	1957–1958	—
Port Moresby, Papua	Aust. B.M.R.	—	1957–	1958–	—	—

[1] Names shown in italics represent observatories established primarily for geophysical research. Abbreviations: C.S.O., Commonwealth Solar Observatory; B.M.R., Bureau of Mineral Resources, Geology and Geophysics; C.I.W., Carnegie Institution of Washington, Department of Terrestrial Magnetism; N.A.R.E., National Antarctic Research Expeditions.

[2] Meteorological activities of the State observatories taken over in 1908 by Bureau of Meteorology.

[3] Au, auroral observations; AE, atmospheric electricity; TC, telluric currents.

[4] Proposed to be transferred in 1938 to a site at the Waite Agricultural Institute; there is no record of any observations there.

[5] Transferred to Mount Nebo in 1963.

[6] Observations also conducted for short periods in earlier years by polar expeditions.

Appendix

Observatory Geophysics in Australia, 1821–1957

Observatory[1]		Period of Operation (Intermittent Operation shown between brackets)				
Location	Owner	Meteorology[2]	Seismology	Geo-magnetism	Iono-sphere	Other[3] Aeronomy
Parramatta, N.S.W.	Brisbane ; N.S.W. Govt.	1821–1827 ; 1832–1838	—	(1821–1828)	—	—
Hobart, Tas.	U.K. Govt. ; Tas. Govt.	1847–1854 ; 1882–1911	—	1840–1854	—	—
Williamstown, Vict.	Vict. Govt.	1853–1863	—	—	—	—
Windsor, N.S.W.	Tebbutt	1863–1915	—	—	—	—
Flagstaff, Melb., Vict.	Neumayer	1857–1862	—	1858–1862	—	Au: 1859–1862 AE: 1858–1862
Sydney, N.S.W.	N.S.W. Govt.	1858–	(1888–1906) 1906–1948	1865–1899 see Red Hill	—	—
Melbourne, Vict.	Vict. Govt., Aust. C.S.O., Aust. B.M.R.	1863–	1902–1962	1862–1922 see Toolangi	—	—
Adelaide, S. Aust.	S.A. Govt., Adel. Univ.	1874–	1909–1950 1958–	(1914–1937)[4]	—	—
Perth, W. Aust.	W. Aust. Govt.	1896–	1901–1964	—	—	—
Red Hill, N.S.W.	N.S.W. Govt.	—	—	(1905–1907) 1908–1926	—	—
Riverview, N.S.W.	Jesuit Order	1931–	1909–	—	—	—
Mt. Stromlo, A.C.T.	Aust. C.S.O., Aust. Nat. Univ.	(1911–1913)	1958– (designated as "Canberra")	—	1930–	AE: 1925–
Watheroo, W. Aust.	Carnegie Inst., Aust. B.M.R.	1919–1958	—	1919–1958	1935–1958	AE: 1922–1958 TC: 1923–1958
Toolangi, Vict.	Vict. Govt., Aust. C.S.O. ; Aust. B.M.R.	—	1962–	1919–	—	—
Brisbane Qld.	Univ. Qld.	—	1937–1951 ; 1953–[5]	—	—	—
Rabaul, N. Britain	New Guinea Admin.	—	1940–1942 ; 1954–	—	—	—
Heard Island	Aust. N.A.R.E.	1948–1954	1951–1954	1947, 1950 1952–1954	—	Au: 1947–1954
Macquarie Island[6]	Aust. N.A.R.E.	1948–	1951–	1948, 1951–	1950–1956	Au: 1950–
Camden, N.S.W.	C.S.I.R.O.	—	—	—	1952–	1952–
Mawson, Antarctica	Aust. N.A.R.E.	1954–	1956–	1955–	1955–	Au: 1954–

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Triassic Plant Microfossils from a Shale within the Wollar Sandstone, N.S.W.

R. Helby

Abstract—Fifteen species of microspores and pollen from a sample taken within the Wollar Sandstone, N.S.W. are described, seven as new species. A new species of megaspore is also described. Age relationships of the microflora are briefly discussed and it is proposed that the sample is of upper Scythian or lower Anisian age.

Zusammenfassung—Fünfzehn Arten von Mikrosporen und Pollen aus einer Probe des Wollar Sandstone, N.S.W. werden beschrieben, davon sieben als neue Arten. Eine neue Megasporen Art wird ebenfalls beschrieben. Altersbeziehungen der Mikroflora werden kurz diskutiert und ein Oberskyth oder Unteranisisches Alter wird vorgeschlagen.

Introduction

The Wollar Sandstone, first described by Dulhunty (1937), is predominantly an arenaceous unit, probably non-marine, conformably overlying the Lithgow Coal Measures of the Goulburn and north-western Hunter valleys. It is conformably overlain by the carbonaceous shales and arenites of the Comiala Shale. It consists of a lower conglomeratic and shaly unit up to 400 ft. thick. This lower unit is characterized by a prominent conglomerate band with abundant green pebbles at the base, overlain by interbedded, red and green shales and siltstones. The shale and siltstone beds of this lower unit often contain abundant plant microfossils. The overlying unit consists of massive sandstone beds, with a few shale partings in the lower portion, increasing in content of mottled red shale and claystone in the upper part of the section.

Areally, the Wollar Sandstone extends from Uarbry in the north-west, along the Goulburn River valley to the south and to Murrurundi in the north-east. Surface mapping suggests that the Wollar Sandstone is at least partially correlatable with the Narrabeen Group in the north-western part of the Sydney Basin, but in view of the present information it is not possible to determine the relationship more exactly. As the Wollar Sandstone is one of the few units showing stratigraphic continuity with the sediments of the southern edge of the Great Artesian Basin and the northern edge of the Sydney Basin, its study will be advantageous in determining time relations between the two basins.

Techniques

The process of separation of the microfossils consisted of gently boiling the carbonate free, crushed sediment in commercial hydrofluoric acid (50–70%), washing in heated 10% hydrochloric acid, washing in warmed water and several washings in alcohol. The remaining organic and mineral residues were separated in a bromoform-alcohol mixture (S.G. 2·1), the organic residue being washed in alcohol and then in water. The residue was then mounted, unstained, in glycerine jelly.

Single specimen mounts were prepared by severing a small, usually rectangular piece of glycerine jelly containing the desired specimen from a rigidly set glycerine jelly smear of the preparation. The severed piece of glycerine jelly was transferred to a glass slide, melted and a cover slip applied.

Sample Material and Storage

Only one sample was examined during this study, being the only sample in a number of samples from the area to yield spores and pollen of this age. The sample was obtained from a small shale band intercepted in a seismic shot hole, L. H. Smart Exploration Ltd. S.P.A. 7 (150° 28′ 30″ E. 32° 14′ 15″ N). Unfortunately only a small amount of the sample was collected, sufficient for a single treatment. Slide numbers quoted in the text refer to slides lodged in the palynological collection of the Department of Geology and Geophysics, University of Sydney. Numerals following the slide numbers refer to the stage locations of individual specimens on Leitz Ortholux microscope No. 491309.

Systematic Palynology

The systematic framework initiated by Potonié and Kremp (1954) and subsequently modified by these authors and others, is followed. Morphological terminology follows Dettmann (1963), except where other authorities are cited.

Systematic Descriptions

Anteturma SPORITES H. Potonié 1893
Turma TRILETES Reinsch 1881

Genus RETUSOTRILETES Naumova 1953

Type species *Retusotriletes simplex* Naumova 1953 ; Upper Terrestrial Beds, Kaluga district, U.S.S.R. ; Middle Devonian.

Retusotriletes praetexta sp. nov.
Pl. 1, figs. 10, 11.

Holotype. S.U.D.G. 1/SS 2, 28·1 120·0. Amb convex triangular (Pl. 1, fig. 10). Laesurae lipped. Exhibits curvaturae perfectae (Potonié and Kremp, 1955, pp. 12–13). Sculpture similarly developed on either face, thickly set granula.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Microspore, trilete, exhibiting curvaturae perfectae. Laesurae extend about three quarters radius, lipped, straight although distorted in some specimens (Pl. 1, fig. 11), occasionally accompanied by folds. Exine appears to be about 2 microns thick, covered with thickly set granula, individual elements being well rounded, 1–1·5 microns high, about 1·5 microns basal diameter.

Dimensions. 30 (34) 42 microns 10 specimens measured.

Comparisons

Retusotriletes praetexta sp. nov. differs from *R. domanicus* Naumova 1953 in size. It is differentiated from the specimen illustrated by Naumova as *Retusotriletes famenensis* (1953, Pl. 16, fig. 44) by its more thickly set sculpture. *Retusotriletes clipeata* sp. nov. is differentiated by its very much finer sculpture. Retusotriletes bears some resemblance in both size and form to microspores separated from fertile remains of *Osmundopsis plectophora* Harris (1931, Pl. 12, fig. 7) and *Todites hartzi* Harris (1931, Pl. 10, fig. 3).

Known stratigraphic range

Only known occurrence in the Wollar Sandstone, upper portion.

Retusotriletes clipeata sp. nov.
Pl. 1, fig. 3

Holotype. S.U.D.G. 1/SS 7, 27·4 125·2. Amb almost circular (Pl. 1, fig. 3). Maximum diameter 37 microns. Laesurae lipped. Exhibits curvaturae perfectae, contact faces reaching almost to the equator. Central, circular, raised portion of the exine on the proximal surface.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Microspore, trilete, exhibiting curvaturae perfectae. Laesurae extend almost two thirds radius, slightly sinuous in vicinity of proximal pole. Exine thin, covered with small granula, less than 1 micron basal diameter. Circular, slightly raised portion of the exine, in the vicinity of the proximal pole, exhibits a thickening of the sculpture. Contact faces usually extend to the equator.

Dimensions. 33 (39) 42 microns. 10 specimens measured.

Comparisons

Retusotriletes clipeata sp. nov. is distinguished from *R. praetexta* sp. nov. by the nature and size of the sculpture. *Retusotriletes mesozoicus* Klaus 1960 has smaller contact faces and lacks a definite sculpture.

Known stratigraphic range.

Only known occurrence in the Wollar Sandstone, upper portion.

Retusotriletes sp.
Pl. 1, fig. 2

Description of specimens

Microspore, trilete, exhibiting curvaturae imperfectae (Potonié and Kremp, 1955, p. 13). Amb circular with well developed line marking outer edge of contact faces, about 4 microns from the equator. Laesurae straight, lipped, about three quarters radius. Laesurae do not reach the line demarking the edge of the contact faces but are usually joined to it by a barely perceptible raised portion of the exine.

Dimensions. 41–53 microns. 6 specimens measured.

Comparisons

This species is similar in overall organization to *Retusotriletes obliteratus* Tschibrekova (1962, Pl. 3, fig. 8), but of smaller dimensions. It differs similarly from *Polymorphisporites laevigatus* Alpern 1958. It is differentiated from

R. mesozoicus Klaus 1960 by the curvaturae and the thicker exine.

Genus Punctatisporites Ibrahim emend. Potonié and Kremp 1954.

Type species. *Punctatisporites punctatus* Ibrahim 1933; Aegir Seam, Ruhr, West Germany; Upper Carboniferous.

Punctatisporites sp.
Pl. 1, fig. 1

Description of specimens

Microspore, trilete. Amb circular, but often distorted due to folding. Laesurae extend about two thirds radius, lipped often accompanied by folds, up to 4 microns high. Exine about 2 microns thick, punctate (Potonié and Kremp, 1955, pp. 13–14), usually folded.

Dimensions. 65–82 microns. 5 specimens measured.

Comparisons

This species resembles *Punctatisporites gretensis* Balme and Hennelly 1956, but appears to differ by having a thinner exine and a smaller size range (possibly due to the restricted number of specimens measured).

Genus Cyathidites Couper 1953.

Type species. *Cyathidites australis* Couper 1953; Ohika Beds, New Zealand; Jurassic.

Remarks

The major morphological elements of some of the form genera representing triangular, trilete, smooth exine forms are set out on Table 1. All the forms are subject to some morphological overlap by other forms. This is most evident in considering the relationship of *Deltoidospora* Miner 1935 and *Leiotriletes* Naumova emend. Potonié and Kremp 1954. These forms are obviously similar and possibly synonymous. A further difficult association is that of *Alsophilidites* Cookson ex Potonié 1956, *Cardioangulina* Maljavikina emend. Potonié 1960 and *Cyathidites* Couper 1953. As the only morphological differences between the three forms are slight variations in the length of the laesurae it is difficult to justify retention of the three genera. Dettmann (1963, p. 22) has suggested that these genera are synonymous, indicating that *Cyathidites* Couper 1953 had priority as the other genera were not validated until 1956 and 1960 respectively.

Cyathidites breviradiatus sp. nov.
Pl. 1, fig. 4

Holotype. S.U.D.G. 1/SS 24, 21·4 122·0. Amb concave triangular, apices broad, well rounded. Laesurae distinct, less than half radius, lipped, almost straight but slightly sinuous in the vicinity of the proximal pole. Maximum dimensions, sides to apices, 39 microns.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Microspore, trilete, amb mostly markedly concave triangular, apices broad, well rounded. Laesurae usually lipped, less than half radius. Exine about 2 microns thick, smooth or faintly punctate. Tendency for the exine to tear away from the proximal pole, parallel to the sides, tearing along the laesurae.

Dimensions. 36 (40) 42. 10 specimens measured.

Comparisons

Cyathidites breviradiatus sp. nov. differs from previously described species of *Cyathidites* by having shorter laesurae. It is morphologically similar to the megaspore *Nemejcisporites nemejci* (Kalibova) Potonié and Kremp 1955, differing in size. *Cyathidites breviradiatus* sp. nov. is distinguished from *Leiotriletes sphaerotriangulatus* (Loose) Potonié and Kremp 1954 by the more concave shape and shorter laesurae. A similar form occurring in the upper Bulgo Sandstone and lower part of the Bald Hill Claystone to the south of Sydney, is slightly smaller, but otherwise morphologically indistinguishable.

Known stratigraphic range

Wollar Sandstone, upper portion and upper Narrabeen Group.

Genus Granulatisporites Ibrahim emend. Potonié and Kremp 1954.

Type species. *Granulatisporites granulatus* Ibrahim 1933; Aegir Seam, Ruhr, West Germany; Upper Carboniferous.

Granulatisporites sp. cf. *G. trisinus*
Balme and Hennelly 1956
Pl. 1, figs. 12, 13

Description of specimens

Microspore, trilete, amb triangular, sides straight or slightly convex, apices rounded. Laesurae usually straight but accompanied by folds, rather than lipped which assume sinuous paths, reaching almost to the equator. Exine about 2 microns thick, covered with granula,

TABLE 1

	Cyathidites Couper (1953)	*Cyathidites* This paper	*Concavisporites* Pflug (1952)	*Deltoidospora* Miner (1935)	*Gleicheniidites* Ross (1949)	*Alsophilidites* Cookson (1947)	*Leiotriletes* Naumova emend. Potonié & Kremp (1954)
Shape							
Length of Laesurae	2/3 +	1/2 +	?	2/3 +	1/1	1/1	1/2 +
Exine	Psilate	Psilate to finely punctate	Mostly psilate	Psilate	Psilate	Psilate	Psilate to finely reticulate
Shape of Sides	Always concave	Always concave	Always concave	Slightly concave or slightly convex	Slightly concave	Slightly concave	Concave or convex
Additional Features			Kyrtome developed				

1–1·5 microns in basal diameter, 1 micron high, 1·5 microns apart but irregularly spaced.

Dimensions. 62–79 microns. 4 specimens measured.

Comparisons

These specimens differ from *Granulatisporites trisinus* Balme and Hennelly 1956 of the underlying Lithgow Coal Measures only by their slightly more prominent sculpture. They are distinctly excluded from the genus *Microfoveolatispora* Bharadwaj 1960, despite Bharadwaj's proposition of designating *G. trisinus* Balme and Hennelly 1956 to his new genus (Bharadwaj, 1960, p. 82), by the very distinct granula. The possibility of these forms resulting from reworking of older sediments has been considered, but the problem is difficult to resolve in view of the excellent preservation and the absence of other forms characteristic of the Permian Lithgow Coal Measures.

Granulatisporites sp.
Pl. 1, fig. 6

Description of specimens

Microspores, trilete, amb triangular, sides convex, apices rounded. Laesurae slightly sinuous near the proximal pole, raised, lipped, reaching almost to the equator. Exine 3 microns thick, covered with irregularly shaped granula, 0·5–1 micron apart.

Dimensions. 31–35 microns. 4 specimens measured.

Comparisons

This species is not unlike *Granulatisporites parvus* (Ibrahim) Potonié and Kremp 1955, although it has slightly larger sculptural elements.

Genus OSMUNDACIDITES Couper 1953.

Type species. *Osmundacidites wellmanii* Couper 1953; Ohika Beds, New Zealand; Jurassic.

Remarks

Osmundacidites as defined by Couper (1953) is at least partly synonymous with *Cyclogranisporites* Potonié and Kremp 1954. Balme (1963) has briefly discussed the merits of retention of *Osmundacidites*, mentioning the diversity of the sculpture as a possible means of delineating the two genera. The forms encountered in the Wollar Sandstone are characterized by this diversity of sculpture, even on single specimens.

Osmundacidites sp. cf. *O. wellmanii*
Couper 1953
Pl. 1, figs. 7–9

Description of specimens

Microspore, trilete, amb circular but often irregular due to sculpture or folding. Laesurae straight, extending about two thirds radius, path frequently interrupted by sculptural elements. Exine about 2 microns thick, covered with scattered coni (the term coni is used here in the sense of Potonié and Kremp 1955, p. 14) and granula, which are often irregular, thickly set on the distal surface, thinning on the proximal surface approaching the laesurae, although scarcely diminishing in size. Granula (often irregular verrucae) 1·5 microns high, 2 microns basal diameter, occasionally pointed to form spinulae. Folding of the exine is quite common.

Dimensions. 34–62 microns. 50 specimens measured.

Comparisons

Osmundacidites sp. cf. *O. wellmanii* is distinguished from *Osmundacidites wellmanii* Couper 1953 only by the slightly shorter laesurae. It is slightly smaller than *Osmundacidites senectus* Balme 1963 and is larger and has slightly longer laesurae than *O. alpinus* Klaus 1960. *Osmundacidites parvus* de Jersey 1960 is slightly smaller, has longer laesurae and more regular sculptural elements than *Osmundacidites* sp. cf. *O. wellmanii*.

Known stratigraphic range

Osmundacidites wellmanii Couper 1953 occurs abundantly throughout Mesozoic sediments.

Genus KRAEUSELISPORITES Leschik emend. Jansonius 1962.

Type species. *Kraeuselisporites dentatus* Leschik 1955; Schilfsandstein (Reed Sandstone), Switzerland; Upper Triassic.

Kraeuselisporites differens sp. nov.
Pl. 2, figs. 23–27

Holotype. S.U.D.G. 1/SS 6. Amb almost circular (Pl. 2, figs. 24, 25), diameter 56 microns. Exoexine markedly thickened and detached from intexine in equatorial regions. Distal and equatorial sculpture consists of irregular spinae and coni, proximal surface showing development of low well rounded rugulae in equatorial regions, less well developed towards the proximal pole. Laesurae extend to the inner margin of the lateral equatorial exoexine, slightly sinuous.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Microspore, trilete. Amb circular to rounded triangular. Zona always well developed although it has not been possible to detect the extent of exoexinal detachment in distal or proximal regions. Laesurae slightly sinuous, lipped, extending to the inner margin of the zona. Sculptural elements often absent from proximal face although low rugulae sometimes occur. Distal and equatorial sculpture strongly developed, consisting of closely packed coni and verrucae with irregular bases, coalescing in basal portions to show a rugulate pattern in low focus. Coni 1 5–4·5 microns in length, 1–3 microns basal diameter. Some specimens, including the holotype (Pl. 2, fig. 24), show weakly defined markings suggesting an extension of the laesurae across the zona.

Dimensions. Total diameter 39 (46·5) 56 microns. Width of zona 3·5 (4·5) 7 microns. 16 specimens measured.

Comparisons

Kraeuselisporites differens sp. nov. differs from *K. cooksonae* (Klaus) Dettmann 1963, *K. cuspidus* Balme 1963 and *K. major* (Cookson and Dettmann) Dettmann 1963 in size. *Kraeuselisporites linearis* (Cookson and Dettmann) Dettmann 1963 (which appears to be very similar to the specimen illustrated as *Cirratriradiates splendens*, Balme and Hennelly 1956, Pl. 5, fig. 7) and *K. saeptatus* Balme 1963 have a different sculpture from *K. differens* sp. nov. It appears that a gradation exists between those specimens resembling *K. spinosus* Jansonius 1962 and the more typical specimens of *K. differens* sp. nov. as illustrated. It would be possible to regard the end members of this gradation as *K.* sp. cf. *K. spinosus*. *K. differens* sp. nov. differs from the species of *Kraeuselisporites* described by Leschik (1955) in the density and type of sculpture and generally well marked laesurae. Although very similar *K. apiculatus* Jansonius 1962 may be differentiated by its more regular sculptural elements and slightly larger size.

Known stratigraphic range

Only known occurrence in Wollar Sandstone, upper portion.

Turma Monoletes Ibrahim 1933

Genus Polypodiisporites Potonié and Gelletich ex Potonié 1956.

Type species. *Polypodiisporites favus* (Potonié) Potonié and Gelletich 1933 ; Geiseltal Seam, Geisel Valley, Germany ; Middle Eocene.

Polypodiisporites ipsviciensis (de Jersey) Playford and Dettmann 1965
Pl. 1, fig. 4

Description of specimens

Microspores monlete. Amb circular to oval, irregular due to sculpture. Laesurae indistinct, usually obscured by sculpture. Exine about 1·5 microns thick, covered with irregular verrucae, sometimes surmounted by spinae, bases coalescing to give rugulate pattern in low focus. Verrucae 2 microns high, up to 2·5 microns basal diameter. Spinae and occasional coni 1·5 microns high, basal diameter up to 1·5 microns.

Dimensions. 23 (26) 31 microns. 10 specimens measured.

Remarks

As mentioned by de Jersey (1962), a large proportion of the specimens examined appeared alete. However, several specimens do exhibit a monolete mark, confirming the identification as *Polypodiisporites ipsviciensis*.

Known stratigraphic range

Polypodiisporites ipsviciensis first appears in the upper part of the Narrabeen Group in N.S.W., extending into the Lower Jurassic. It is found extensively throughout Middle and Upper Triassic sediments in eastern Australia.

Genus Aratrisporites Leschik emend. Playford and Dettmann 1965.

Type species. *Aratrisporites parvispinosus* Leschik 1955 ; Seam 2, Schilfsandstein (Reed Sandstone), Neuewelt, Switzerland ; Upper Triassic.

Aratrisporites goulburniensis sp. nov.
Pl. 1, figs. 14–16

Holotype. S.U.D.G. 1/SS 12. Amb disrupted oval (Pl. 1, fig. 14), overall length (Measurement A) 38 microns. Laesura distinctly lipped, slightly sinuous, extend into detached exoexine. Exine granulate between coni and spinae, sculptural elements well developed distally and equatorially, diminishing on proximal surface.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Microspore, usually cavate, monolete. Amb oval generally conforming to margin of intexine. Laesura seldom straight, usually lipped, 1–2 microns wide, slightly raised and may extend into the exoexine laterally. Intexine possibly attached to exoexine on proximal surface, at

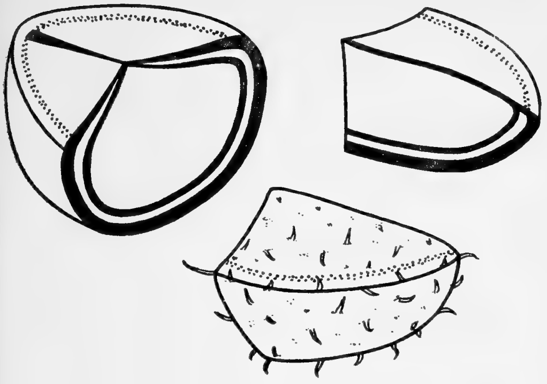

Fig. 1*a*
Shows exploded view of internal structure of *Aratrisporites*.

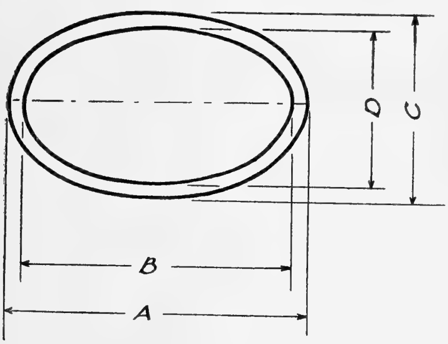

Fig. 1*b*
Shows measurement plan of *Aratrisporites*
A.—Overall length of grain exclusive of sculptural elements.
B.—Maximum length of detached intexine.
C.—Maximum breadth of grain exclusive of sculptural elements.
D.—Maximum breadth of detached intexine.

least in the vicinity of the laesura. Exoexine thickens distally, bearing well scattered spinae and coni up to 5 microns long and 3 microns at the base.

Dimensions. see text fig. 1.
A. 33 (37) 40 microns B. 27 (29) 31 microns
C. 28 (29) 31 microns D. 21 (23) 27 microns
10 specimens measured.

Comparisons

Aratrisporites goulburniensis sp. nov. although superficially similar to *A. flexibilis* Playford and Dettmann 1965 differs in size, being smaller and has somewhat more massive and thickly set sculptural elements. It is readily distinguished from other previously published species by its massive sculptural elements and dense exine.

Known stratigraphic range

Only known from the Wollar Sandstone, upper portion.

Aratrisporites wollariensis sp. nov.
Pl. 1, figs. 17–19

Holotype. S.U.D.G. 1/SS 10, 12·2 120·7. Amb almost oval (Pl. 1, fig. 17), overall length (Measurement A) 34 microns. Cavate nature of exoexine illustrated by folded intexine. Spinae and coni on exoexine about 1 micron basal diameter, 1 micron high, often surmounted by hairlike projections about 2 microns long, 1/5 microns wide.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Microspore, sometimes cavate, monolete. Amb usually oval, often pointed at lateral extremities. Exoexine about, not always visibly detached from intexine. Laesura does not always extend to the lateral edge of the intexine and is usually sinuous. Laesura normally lipped, thickenings up to 1 micron in width, the entire proximal face in vicinity of the laesura being arched. Many specimens are observed compressed in a plane slightly oblique to the proximo-distal plane, exhibiting the original boat like shape. Very commonly the intexine is folded. The exoexine, which thins noticeably in the vicinity of the laesura, is covered with fine spinae, coni and granula, most thickly set in the equatorial regions.

Dimensions. See text fig. 1.
A. 28 (33) 42 microns B. 24 (28) 35 microns
C. 22 (27) 30 microns D. 19 (23) 25 microns
50 specimens measured.

Comparisons

Aratrisporites wollariensis sp. nov. is easily distinguished from *A. goulburniensis* sp. nov. by the size of its sculptural elements. *Aratrisporites granulatus* (Klaus) Playford and Dettmann 1965 as described by Klaus (1960) is slightly larger and has a granulate sculpture. *Aratrisporites paraspinosus* Klaus 1960 is slightly larger and has more prominent sculpture. *Aratrisporites wollariensis* sp. nov. differs from *A. corylisеminis* Klaus 1960 in size and nature of the sculpture although the specimen illustrated by Playford and Dettmann (1965, Pl. 15, fig. 41) as *A. coryliseminis* appears somewhat similar. Those specimens of *Aratrisporites wollariensis* sp. nov. which are not evidently cavate could be assigned to *Punctatosporites* Ibrahim 1933.

Remarks

Aratrisporites wollariensis sp. nov. is the dominant form (66%) occurring in the sample. Several almost complete microsporangia, yielding this species, were encountered in the preparation residue, some being stuck to clumps of *Nathorstisporites pulcherrima* sp. nov. It is possible that these two forms are associated in a strobilis of the *Lycostrobus* Nathorst type.

Known stratigraphic range

Known from the upper portion of the Wollar Sandstone, very abundant in the Collaroy Claystone, also encountered in Hawkesbury Sandstone.

Aratrisporites sp.
Pl. 2, fig. 20

Description of specimens

Microspores, cavate, monolete. Amb oval. Laesura almost straight, extending almost to the outer edge of the lateral exoexine. Exoexine usually quite transparent, bearing spinae up to 4 microns long, $\frac{1}{2}$ micron wide. Sculptural elements thin out and diminish in size on the proximal face. Intexine often folded.

Dimensions. See text fig. 1.
A. 30 microns, B. 25 microns, C. 24 microns, D. 18 microns. 1 specimen measured.

Comparisons

This species differs from *Aratrisporites goulburniensis* sp. nov. and *A. wollariensis* sp. nov. by the size and type of sculptural elements. It is smaller than *Aratrisporites fimbriatus* (Klaus) Playford and Dettmann 1965 and has a thinner exoexine. It is not possible to distinguish this specimen from microspores of *Cylostrobus* Helby and Martin 1965, several specimens of which are illustrated (Pl. 2, figs 21, 22).

Known stratigraphic range

A single specimen has been encountered in the upper portion of the Wollar Sandstone. It is one of the dominant forms in the upper part of the Collaroy Claystone and Gosford Formation to the immediate north of Sydney. It is also encountered in the Hawkesbury Sandstone.

Anteturma POLLENITES R. Potonié 1931
Turma SACCITES Erdtman 1947

Genus ALISPORITES Daugherty 1941.

Type species. *Alisporites opii* Daugherty 1941 ; Chinle Formation ; Arizona, U.S.A. ; Upper Triassic.

Remarks

Considerable confusion exists at present concerning the taxonomy of fossil bisaccate pollen, in particular those forms morphologically similar to *Alisporites* Daugherty 1941. The original inadequate description of *Alisporites opii* Daugherty 1941 has led to a long history of reinterpretation of *Alisporites*. (Potonié and Kremp 1956, Rouse 1959, de Jersey 1962, Jansonius 1962 and Maedler 1964). Examination of material from the Chinle Formation suggests that the holotype may not be characteristic of the population concerned so that re-examination of the original material, if possible, is warranted. I regard *Alisporites* to be confined to forms displaying a distal colpus (anacolpate, Erdtman and Straka 1961), synonymous with *Sulcatisporites* Leschik 1955 and *Pteruchipollenites* Couper 1958.

Alisporites townrovii sp. nov.
Pl. 2, figs. 29–32, 34, 35

Holotype. S.U.D.G. 1/SS 13, 21·4 120·0. Specimen compressed laterally (Pl. 2, fig. 34). Overall length 99 microns. Corpus distinctly broader than deep, reticulation strongly developed. Colpus distinct, lipped, reaching almost to the proximal cap. Small exoexine " bridge " crosses colpus.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Pollen, bisaccate, anacolpate. Amb haploxylonoid (Pl. 2, fig. 28), sacci offset and converging distally. Corpus normally longer than broad, ranging to the reverse ; as deep as long, but varying ; sacci as deep as corpus. Colpus distinct and lipped, lips 1–2 microns wide, usually extending almost to the proximal surface. A distal exoexine " bridge " often crosses the colpus. In most cases this structure springs from the area of detachment of the saccus exoexine from the intexine. Reticulation strongly developed on sacci and corpus, sacci lumina 1–2 microns in diameter, muri about 1 micron thick. Corpus lumina 1–2 microns diameter, muri about $\frac{1}{2}$ micron thick.

Dimensions. See text fig. 2.

L.C. 30 (49) 63 microns, B.C. 28 (43) 56 microns, D.C. 39 (50) 56 microns, L.S. 30 (47) 64 microns, B.S. 31(35) 45 microns, D.S. 40 (44) 55 microns, O.L. 55 (80) 110 microns. 50 specimens measured in polar view.

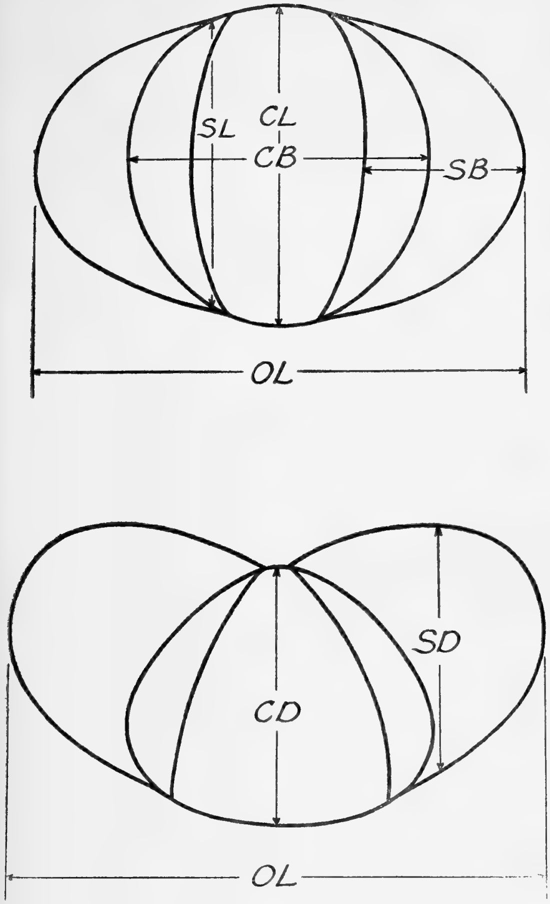

Fig. 2

Shows measurement plan of *Alisporites towrovii* sp. nov.

C.B.—Corpus breadth
C.L.—Corpus length
C.D.—Corpus depth
O.L.—Overall length
S.B.—Saccus breadth
S.L.—Saccus length
S.D.—Saccus depth

Comparisons

Alisporites townrovii sp. nov. differs from *Pteruchipollenites thomasii* Couper 1958 in that it has a strongly lipped colpus, very strongly developed sculpture and often shows a" bridge " over the colpus. It differs from *Alisporitis australis* de Jersey 1962 and *Pityosporites nigracristatus* Hennelly 1958 in similar fashion. A structure similar to the distal " bridge " of *Alisporites townrovii* is exhibited by specimens of *Alisporites* occurring in Middle and Upper Triassic sediments of eastern Australia. This structure appears to be proximally situated, reminiscent of the structure described by Klaus for *Chordasporites* Klaus 1960.

Known stratigraphic range

Known only from the Wollar Sandstone, upper portion.

Genus Platysaccus Naumova emend. Potonié and Klaus 1954.

Type species. *Platysaccus papilionis* Potonié and Klaus 1954 ; Cristiana horizon, Salzberg Hallstatt, Austria ; Permian—Triassic.

Remarks

The emendation of the genus *Platysaccus* Naumova 1937 by Potonié and Klaus 1954, although valid, appears to me to have strayed somewhat from the original concept of Naumova, which although not well described in words, is illustrated by sketches of three species. *Cuneatisporites* Leschik 1955 is very similar to *Platysaccus* as emended by Potonié and Klaus and *Platysaccus* as illustrated by Naumova (1937, fig. 1). However, the holotype of *Cuneatisporites radialis* Leschik 1955 displays a weakly developed, small trilete mark on the proximal surface of the corpus.

? *Platysaccus* sp.
Pl. 2, fig. 33, text fig. 3

Description of specimens

Pollen, bisaccate, anacolpate (only seen in one specimen). Overall shape strongly diploxylonoid, sacci converging slightly in distal direction. Corpus usually rounded or slightly longer than broad. Depth of corpus not determined. Colpus appears to extend full length of corpus, not noticeably lipped (text fig. 3). Saccus sculpture distinctly reticulate,

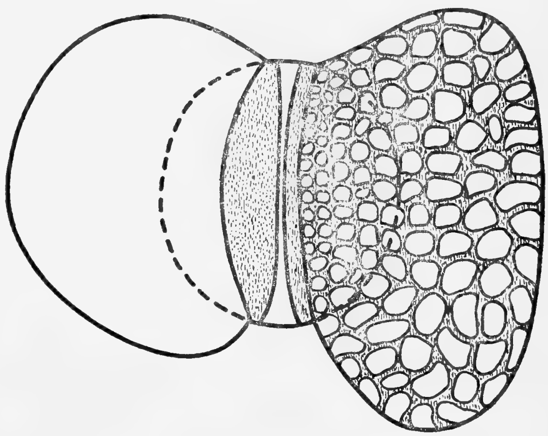

Fig. 3

Shows a sketch of the distal view of a colpate specimen of ? *Platysaccus* (S.U.D.G. 1/Y 39.0 119.5) exhibiting area of attached exoexine and intexine (stippled area) in relation to sacci colpus.

lumina 2·5–4 microns diameter, muri slightly less than 1 micron. Corpus either faintly reticulate with very fine muri becoming smooth in the vicinity of the colpus, or smooth.

Dimensions

L.C. 29, 30, 36 microns, B.C. 31, 27, 30 microns, L.S. 54, 46, 60 microns, B.S. 40, 32, 42 microns, O.L. 85, 68, 90 microns. 3 specimens measured. Specimen showing colpus located S.U.D.G. 1/Y 39·0 119·5.

Comparisons

The presence of the colpus in one of the specimens, suggests similarity to *Alisporites* specimens which occur in the assemblage. The specimens differ from *Platysaccus papilionis* Potonié and Klaus 1954 by lacking radially stretched lumina. They are similar to *Platysaccus queenslandi* de Jersey 1962, distinguished only by the occurrence of the colpus on a single specimen.

MEGASPORE

Anteturma SPORITES H. Potonié 1893
Turma TRILETES Reinsch 1881

Genus NATHORSTISPORITES Jung 1958.

Type species. *Nathorstisporites hopliticus* Jung 1958 ; *Zamites –Thaumatopteris* Zones, Nuremberg, West Germany ; Lower Jurassic.

Nathorstisporites pulcherrima sp. nov.
Pl. 3, figs. 36–41

Holotype. S.U.D.G. 1/SS 25, 33·7 126·5. Specimen compressed in plane containing the polar axis (Pl. 3, fig. 36), equatorial diameter 530 microns, polar diameter 548 microns. Laesurae reach almost to the equator, accompanied by thickly set capilli. Limit of proximal face shown by line of exoexinous elevation accompanied by spinae. Capilli up to 200 microns in length, 40 microns basal diameter, branch irregularly, branches often joined by thin membranes. Spinae on distal surface up to 100 microns long, 10 microns basal diameter, irregularly spaced, about 50 microns apart.

Type Locality. L. H. Smart Exploration Ltd. S.P.A. 7.

Description of specimens

Megaspores, trilete, circular to rounded triangular in polar view. In equatorial view distal surface is rounded, proximal surface distinctly pyramidal, surfaces usually delineated by exoexine elevation. Laesurae extend about ¾ radius, lipped, lips up to 35 microns wide, often raised, particularly in the vicinity of the proximal pole. Lips surrounded and thickly set with capilli. Capilli up to 200 microns in length, usually thickened and branching towards the top, terminating in blunt, somewhat broadened processes. Individual capilli exhibit a membrane between the branches, or several branches may be joined by membrane. Capilli often packed with small microspores, dominantly *Aratrisporites wollariensis* sp. nov. Spines are irregularly disposed on the distal surface. There are many different forms of elements occurring on the specimens examined, some of which are illustrated on text fig. 4. A mixture of these sculptural elements usually occurs on individual specimens.

FIG. 4
Shows some of the variation of sculptural elements encountered on the distal surface of specimens of *Nathorstisporites pulcherrima* sp. nov.

Dimensions

Oxidized specimens

Equatorial diameter	372–593 microns
Polar diameter	391–548 microns

50 specimens measured

Unoxidized specimens

Equatorial diameter	298–419 microns
Polar diameter	280–372 microns

20 specimens measured.

Comparisons

Nathorstisporites pulcherrima sp. nov. is differentiated from *N. hopliticus* Jung 1958 and *N. reticulatus* Dettmann 1961 by the well developed sculptural elements of the distal surface. It differs from *N. flagellulatus* Dettmann 1961 in size, being smaller, having capilli on the proximal surface in large quantity, and the size and type of sculptural elements on the distal surface.

Known stratigraphic range

Nathorstisporites pulcherrima sp. nov. first appears in the upper part of the Collaroy Claystone, is particularly abundant in this sample from the Wollar Sandstone and occurs extensively in Triassic sediments of the Great Artesian Basin in N.S.W.

Discussion

The percentage distribution of forms in the microflora, based on a count of 1000 specimens is as follows:

Alisporites townrovii	5·0%
Aratrisporites goulburniensis	0·3%
Aratrisporites wollariensis	66·3%
Granulatisporites sp.	0·1%
Kraeuselisporites differens	0·1%
Leiotriletes sp.	0·1%
Osmundacidites sp. cf. *O. senectus*	0·2%
Osmundacidites sp. cf. *O. wellmanii*	14·0%
? *Platysaccus* sp.	0·2%
Polypodiisporites ipsviciensis	0·1%
Punctatisporites sp.	1·1%
Retusotriletes clipeata	0·3%
Retusotriletes praetexta	1·0%
Unidentified specimens	11·2%

The absence of *Taeniaesporites* and *Lundbladispora* forms in this assemblage would suggest that the microflora was younger than that microflora from the Scythian Kockatea Shale of Western Australia (Balme 1963) and its eastern Australian equivalents. The dominance of *Aratrisporites* is to be noted as this genus appears to be an important, biostratigraphic form. In the northern part of the Perth Basin, Western Australia, it is first encountered in the uppermost portion of the Kockatea Shale, presumably uppermost Scythian in age, becoming quite prominent in the overlying Woodada Formation (Mr. B. E. Balme, pers. comm.). In western Europe it is first encountered in probable upper Scythian, attaining some prominence in the Muschelkalk and its equivalents (Dr. W. Klaus and Dr. K. Maedler, pers. comm.). In western Canada it makes its first appearance in the upper portions of the Toad/Grayling Formation, regarded as probable Anisian (Dr. J. Jansonius, pers. comm.). *Aratrisporites* forms (*Zonomonoletes tschalyschevi*) have been reported from the Kracnovetno horizon of the continental Pereborskoi Formation in the northern Urals. Tschalyschev and Varyukhina (1962) regard these occurrences as lower Triassic, assigning them to the Indsky stage.

In the Sydney Basin *Aratrisporites* first appears in the Collaroy Claystone and the uppermost portions of the Bulgo Sandstone of the Narrabeen Group. It attains maximum representation in the microfloras of the uppermost Narrabeen Group, gradually decreasing in prominence throughout the overlying Hawkesbury Sandstone and Wianamatta Shale. In view of this information it is suggested that this microflora encountered in a sample from the Wollar Sandstone is equivalent to the microfloras occurring in the uppermost Narrabeen Group or lower Hawkesbury Sandstone and that it is probably upper Scythian or lower Anisian in age.

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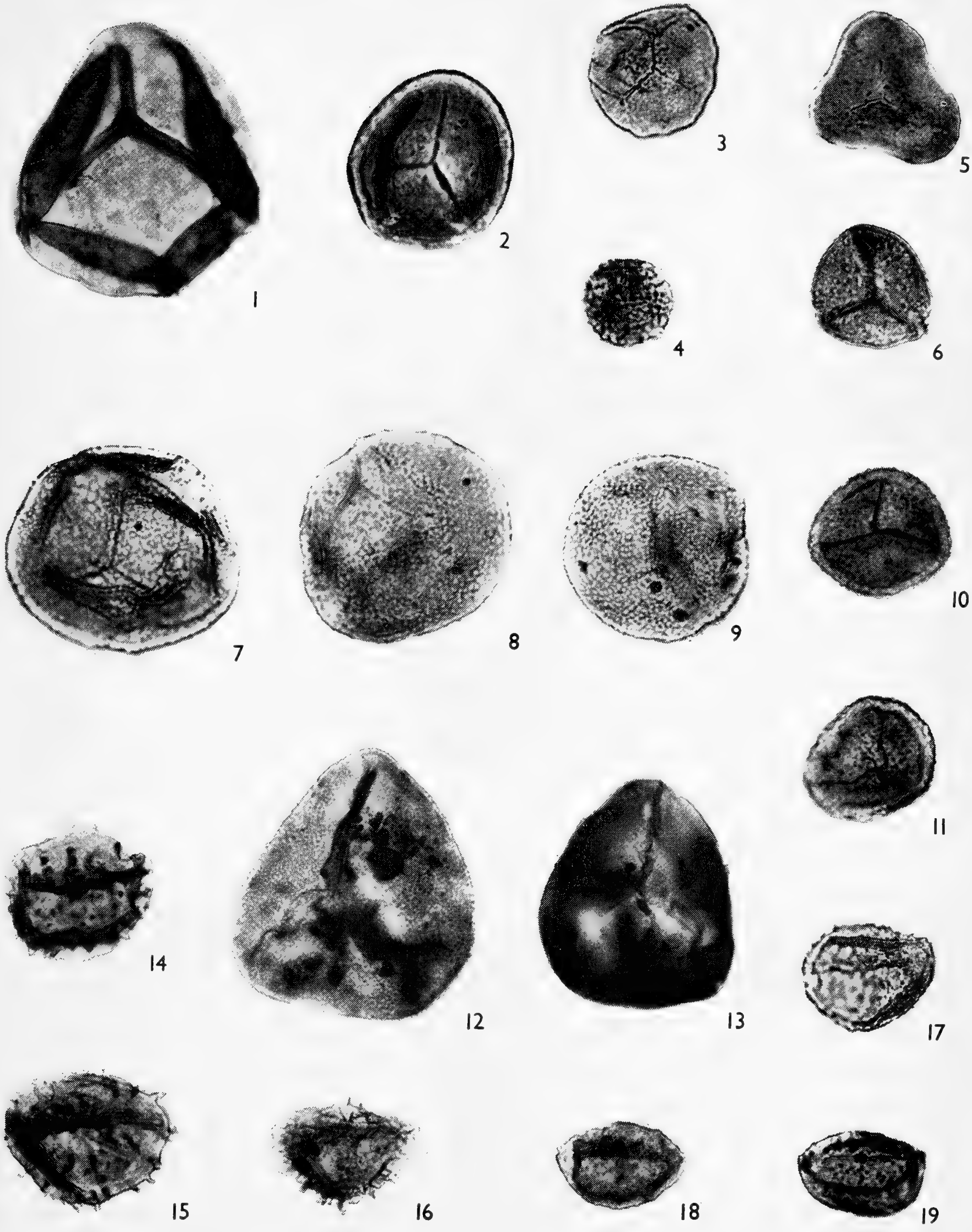
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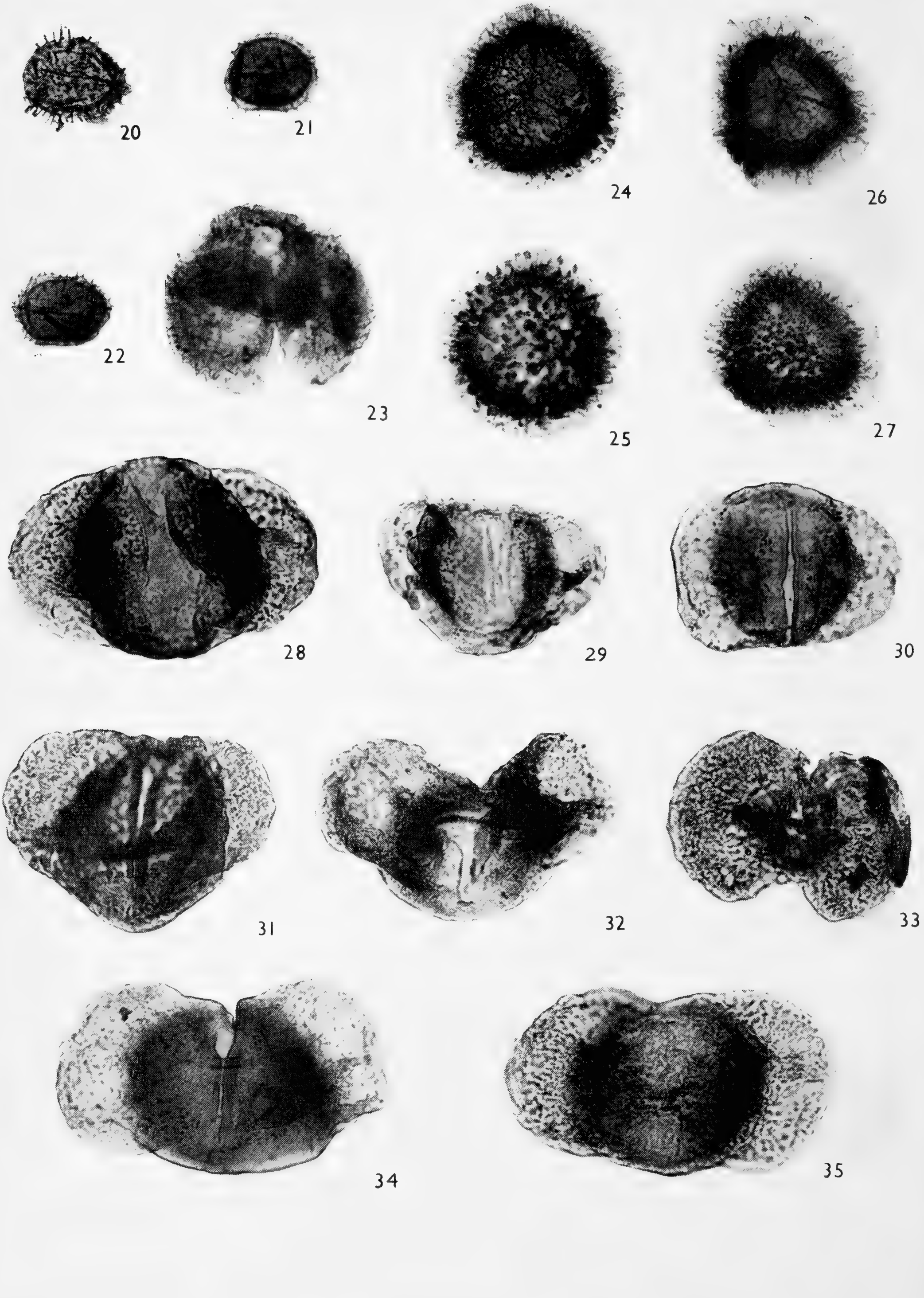
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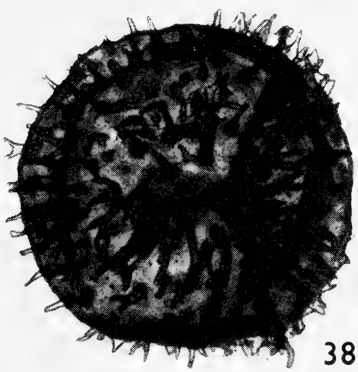

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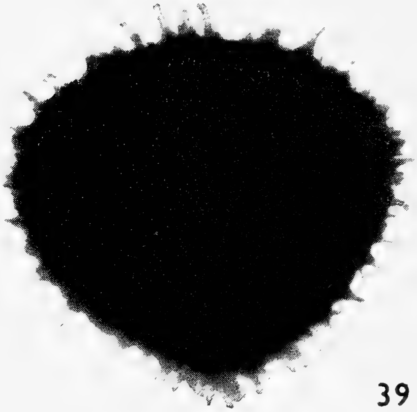

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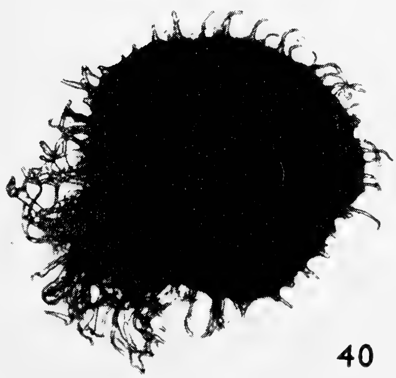

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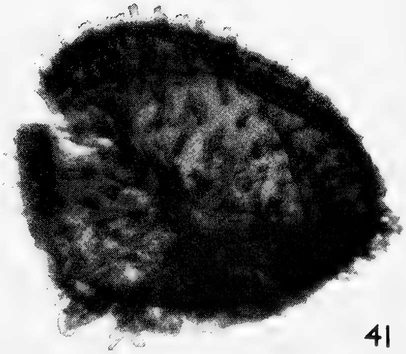

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Explanation of Plates

Plate 1

(Magnification ×500)

Fig. 1. *Punctatisporites* sp. S.U.D.G. 1/SS 17.
Fig. 2. *Retusotriletes* sp. S.U.D.G. 1/SS 8, 23·7 118·3.
Fig. 3. *Retusotriletes clipeata* sp. nov. Holotype. S.U.D.G. 1/SS 7, 27·4 125·2.
Fig. 4. *Polypodiisporites ipsviciensis* Playford and Dettmenn, 1965. S.U.D.G. 1/SS 3, 22·8 117·7.
Fig. 5. *Cyathidites breviradiatus* sp. nov. Holotype. S.U.D.G. 1/SS 24.
Fig. 6. *Granulatisporites* sp. S.U.D.G. 1/Y, 31·0 125·5.
Figs. 7–9. *Osmundacidites* sp. cf. *O. wellmanii* Couper 1953.
Fig. 7: S.U.D.G. 1/1, 29·0 113·9.
Fig. 8: S.U.D.G. 1/SS 21, 18·6 116·5.
Fig. 9: S.U.D.G. 1/SS 22, 27·7 122·9.
Figs. 10–11. *Retusotriletes praetexta* sp. nov.
Fig. 10: Holotype, S.U.D.G. 1/SS 2.
Fig. 11: shows slightly distorted specimen: S.U.D.G. 1/SS 16, 33·3 121·5.
Figs. 12–13. *Granulatisporites* sp. cf. *G. trisinus* Balme and Hennelly, 1956.
Fig. 12: S.U.D.G. 1/SS 1, 24·5 117·7.
Fig. 13: S.U.D.G. 1/SS 1, 24·0 117·9.
Figs. 14–16. *Aratrisporites goulburniensis* sp. nov.
Fig. 14: Holotype, S.U.D.G. 1/SS 12.
Fig. 15: S.U.D.G. 1/SS 23, 35·5 126·4.
Fig. 16: shows end view: S.U.D.G. 1/SS 18, 23·2 122·4.
Figs. 17–19. *Aratrisporites wollariensis* sp. nov.
Fig. 17: Holotype, S.U.D.G. 1/SS 10, 12·2 120·7.
Fig. 18: shows folded intexine: S.U.D.G. 1/SS 5, 35·0 116·1.
Fig. 19: S.U.D.G. 1/2, 34·6 110·0.

Plate 2

(Magnification ×500)

Fig. 20. *Aratrisporites* sp. S.U.D.G. 1/X, 29·2 130·0.
Figs. 21–22. Microspores of *Cylostrobus sydneyensis* Helby and Martin, 1965.
Figs. 23–27. *Kraeuselisporites differens* sp. nov.
Fig. 23: shows partial tetrad: S.U.D.G. 1/1, 42·7 118·4.
Fig. 24: Holotype, proximal focus, S.U.D.G. 1/SS 4.
Fig. 25: Holotype, distal focus.
Fig. 26: proximal focus: S.U.D.G. 1/SS 4.
Fig. 27: distal focus: S.U.D.G. 1/SS 4.
Figs. 28–32. *Alisporites townrovii* sp. nov.
Fig. 28: S.U.D.G. 1/SS 15.
Fig. 29: S.U.D.G. 1/SS 14, 15·7 119·2.
Fig. 30: S.U.D.G. 1/SS 19, 35·4 121·0.
Fig. 31: shows "bridge" in almost equatorial position: S.U.D.G. 1/SS 11, 12·4 114·0.
Fig. 32: shows well developed, distal "bridge": S.U.D.G. 1/2, 21·9 118·9.
Fig. 33. ? *Platysaccus* sp. S.U.D.G. 1/2, 25·2 116·3.
Figs. 34–35. *Alisporites townrovii* sp. nov.
Fig. 34: Holotype, S.U.D.G. 1/SS 13, 21·4 120·0.
Fig. 35: S.U.D.G. 1/SS 9.

Plate 3

Figs. 36–41. *Nathorstisporites pulcherrima* sp. nov. ×100.
Fig. 36: Holotype, S.U.D.G. 1/SS 25, 33·7 126·5.
Fig. 37: shows nature of distal sculptural elements: S.U.D.G. 1/SS 28.
Fig. 38: shows proximal view with laesurae and sculptural elements on exoexinal thickening delineating contact face: S.U.D.G. 1/SS 30.
Fig. 39: Unoxidized specimen in proximal view—distal plane—silhouette: S.U.D.G. 1/SS 29.
Fig. 40: Silhouette, polar plane: S.U.D.G. 1/SS 27.
Fig. 41: S.U.D.G. 1/SS 28.

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The Balickera Section of the Carboniferous Kuttung Facies, New South Wales

J. H. Rattigan

Abstract—Excavations near Balickera, New South Wales displayed a perfectly exposed, thick sequence from which is described rock units and type sections of Carboniferous sediments and volcanic rocks that were formerly assigned to the " Basal ", " Volcanic " and " Glacial Stages " of the " Kuttung Series ". The stratigraphic section includes zeolite facies sediments and volcanic rocks, carbonaceous strata that give the earliest evidence of coal forming conditions in the Hunter Valley, well defined floral zones, and a perfectly exposed succession of volcanic and pyroclastic rocks of a basalt andesite rhyolite association. The section is a critical base for special studies relating to a period when world climate was changing and polar wandering or drift was possibly in progress.

Introduction

An almost perfectly exposed section of the middle to upper Carboniferous sequence formerly known as the " Kuttung Series " has been exposed by works constructed for the Hunter District Water Board's Grahamstown water scheme near Balickera, north of Raymond Terrace, New South Wales. These included about five miles of open excavation and 4,000 feet of tunnelling, much of which was transverse to the strike of Carboniferous strata developed in a relatively steep (30° to 55°) and regularly dipping sequence east of a major tectonic feature, the Williams River Fault (Fig. 1) and forming the western limb of the Medowie Basin.

A very thick and complete section of strata through the greater part of the " Kuttung Series " was revealed on excavation, though water in canals, weathering, formation of batter and lining part of the tunnel have obscured much of the section. The section was measured and sampled during the course of excavation over a period of five years and the perfection of exposures and freshness of samples from Balickera have displayed features hitherto unrevealed in the surface Carboniferous exposures of the Hunter Valley which have been described in the series of papers by Osborne, Browne, David, Sussmilch and Scott reviewed by Voisey (1957), the later studies of Roberts (1961) and unpublished studies by Banks (1946), Brennan (1961), Chesnut (1960), Johnson (1962) and Blayden (1965).

Surface mapping in wide areas of the Lower Hunter region is made difficult by non-exposure of the more easily weathered strata; by faulting; by the variety of igneous and pyroclastic rocks, their lensing and differing modes of weathering from place to place; and by the boulder " float " shed and redistributed from conglomerates of differing ages. The perfection of the Balickera section assists greatly in placing surface exposures elsewhere, in their correct stratigraphic position. Faults were encountered at intervals along the section line but the complete exposure usually revealed where strata were repeated. The observed faults usually had no prominent zone of deformation and similar structures would be very difficult to establish in partly concealed areas.

It is suspected that the section lines of some published sections have been cut by concealed faults. Moreover, emphasis in studies based on surface mapping has been on the strongly outcropping rocks at the expense of the poorly exposed or unexposed, softer rocks which are of great significance in geological study of the region.

The purpose of this paper is to describe the succession and define new units, from the area about a type section in the excellently exposed Balickera excavations.

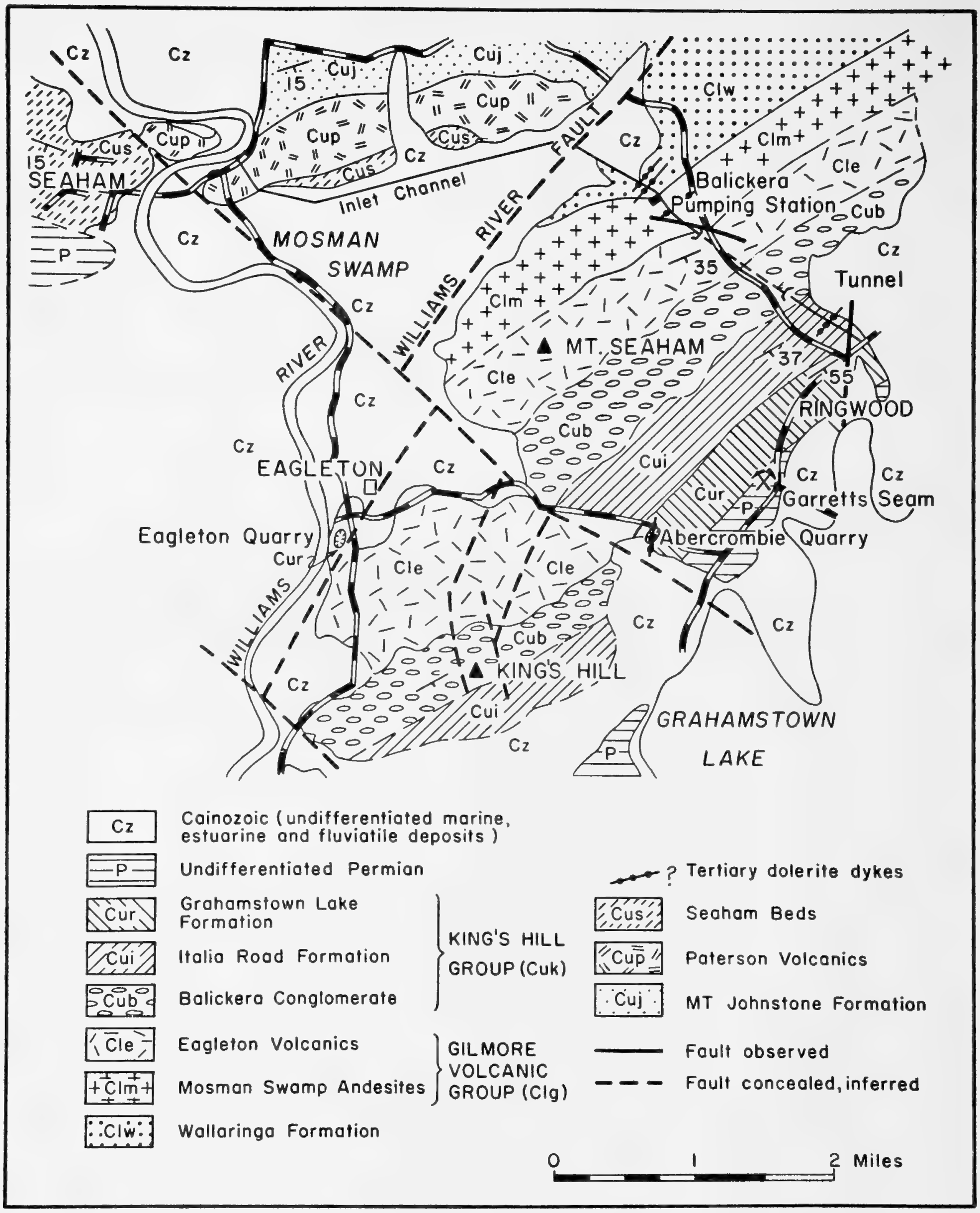

Fig. 1
Geological sketch map of the district about the Balickera excavations, N.S.W.

Stratigraphy

The " Kuttung Series " (Sussmilch and David, 1919) as described and subdivided by Osborne (1922), does not qualify (Voisey, 1957) as a lithological unit and has been replaced by lithological units of differing rank in published (Roberts, 1961) and unpublished studies (Blayden, 1965, Brennan, 1961, Chesnut, 1960 and Johnson, 1962). Engel (1965) proposes to erect a " Kuttung Facies " as virtually synonymous with the " Kuttung Series ". This aids understanding of broader bio-correlation and litho-correlation problems but is not a substitute for lithological subdivision which is necessary for detailed sedimentological study.

In the writer's view the " Kuttung Series " is the Molasse-like facies of the New England Eugeosyncline which succeeds the Flysch-like

" Burindi Series " (Burindi Facies of Engel, 1965) with some interdigitation near the base (part of the Myall Facies of Engel, 1965). The terms Molasse and Flysch are here used in the sense of De Sitter (1956, p. 292).

In the Lower Hunter region Osborne (1922) proposed a three fold " Stage " terminology (Table 1), the subdivisions of which were virtually similar in broader aspect to the units recognized earlier by Sussmilch and David (1919). In more recent literature the broad subdivisions of these workers for the " Kuttung Series " have not been challenged but they have been renamed (Roberts, 1961 and Geological Society of Australia, in press) usually by reference to the original sections and localities without remapping in the " type " areas. These redefined units are not all applicable to the Balickera-Seaham Range area.

The writer considers that Osborne's units as originally defined (1922) for the Lower Hunter region, and not as extended beyond the limits of this district, correspond with valid lithological units of group ranking.

For this reason two groups, corresponding with Osborne's Volcanic and Glacial Stages are proposed, and their component formations in the Balickera area are defined. It is considered that the names of the groups which comprise formations with common lithogenetic characteristics may be applicable widely throughout the Lower and Middle Hunter Valley. Their component formations will vary because of normal lithofacies variation; and particularly with the irregular lateral and vertical occurrence of volcanic and pyroclastic units about volcanic centres. The units named for the Balickera District are shown on Table 1 and their distribution on Fig. 1.

Wallaringa Formation

This unit was defined by Roberts (1961) from the Wallarobba district. The succession between the Williams River Fault and the pumping station at Balickera (Fig. 2) corresponds with the " Basal Stage " beds of the " Kuttung Series " (Osborne, 1922 and Banks, 1946) and is correlated with the Wallaringa Formation. Complete exposure of 860 feet of sediments was revealed in the Balickera excavations (Fig. 2). This may be an almost complete section of the rock unit but the base of the section is concealed by Cainozoic strata near the inferred position of the Williams River Fault.

The perfect exposure in this section does reveal some interesting sedimentological features. The facies is predominantly molasse of the red bed type. Thickly bedded, massive, conglomeratic, coarse lithic arenites, with scour and fill structures and coarse torrential and trough cross lamination, are the most prominent rocks. In this perfectly exposed section cyclical features of sedimentation are revealed in some

TABLE 1

Balickera-Seaham Range (this paper)		Paterson (Geol. Soc. Aust., in press)	Clarencetown-Paterson Osborne (1922)		
Dalwood Group (Permian)		Dalwood Group (Permian)			
King's Hill Group	Grahamstown Lake Formation	Seaham Beds	Kuttung Series	" Main Glacial Beds "	Glacial Stage
	Italia Road Formation	Paterson Volcanics		Paterson Toscanite	
	Balickera Conglomerate	Mt. Johnstone Formation		" Lower Portion "	
Gilmore Volcanic Group	Eagleton Volcanics	Gilmore Volcanics		Volcanic Stage	
	Mosman Swamp Andesites				
Wallaringa Formation		Wallaringa Formation		Basal Stage	

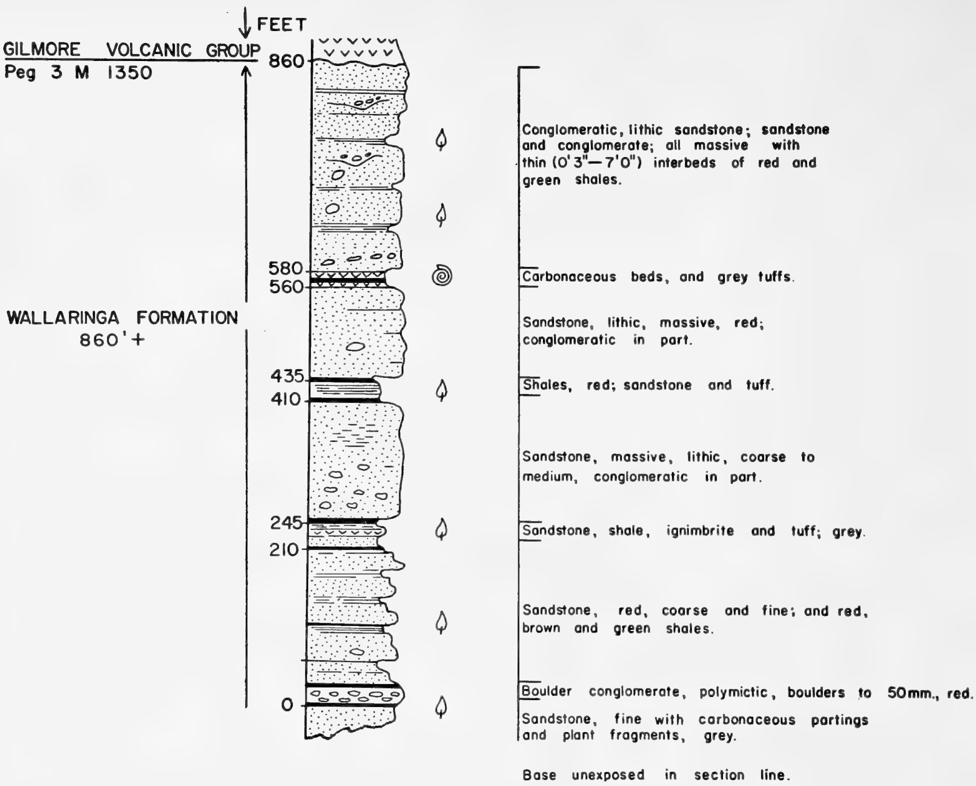

Fig. 2

Measured section through the Wallaringa Formation, at and west of Balickera Pumping Station.

lower units by the repetition of the passage from coarse, poorly sorted arenites, to well sorted fine arenites and red or green shales.

Two thin, grey-coloured units interrupt the normal "red bed" succession and one bed contains poorly preserved fragments of marine fossils (brachiopods) and is succeeded by black, highly carbonaceous beds. The grey colour may be due to intermittent reducing conditions in the original depositing basin but the metamorphic effects of associated ignimbrites may also have contributed to the reduction of iron. Dense, red and grey ignimbrites and graded, ashfall tuff units, composed of crystal, crystal-vitric and bentonite layers, occur at several horizons in the Wallaringa Formation.

The dominant lithotype is a coarse, red, feldspathic, lithic arenite with angular fragments of andesitic and other intermediate volcanic rocks and mineral grains, set in a zeolitic and haematitic paste. Laumontite is prominent in veins. Monolayers of well rounded pebbles, cobbles and boulders occur in some beds and may be the extremities of conglomerate lenses.

Gilmore Volcanic Group

Synonomy: The unit is essentially the Gilmore Volcanics (Roberts, 1961). It corresponds with part of the "Volcanic Stage" (Osborne, 1922) and the Martin's Creek Beds (Sussmilch and David, 1919).

Derivation: Mt. Gilmore (Paterson 832683).

Lithology: Andesitic, dacitic, toscanitic and rhyolitic volcanic and pyroclastic rocks, including pitchstones, ignimbrites and derived bentonites.

Thickness: 2,400 feet at Balickera (Fig. 3); Osborne's Volcanic Stage section at Mt. Gilmore (1922, p. 122) is 2,900 feet but probably includes units correlatable with the Balickera Conglomerate as defined in this paper.

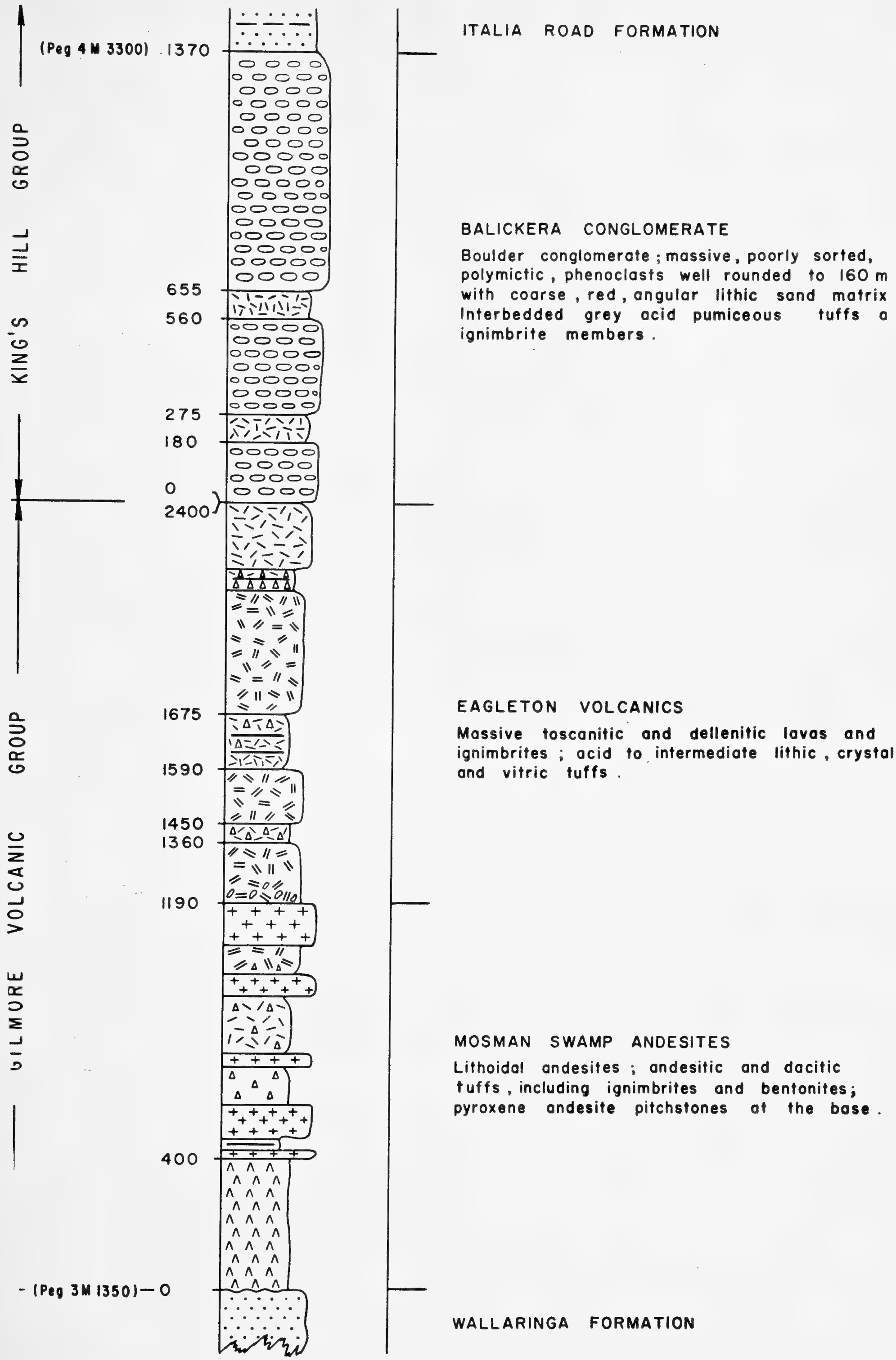

FIG. 3
Measured section through the Gilmore Volcanic Group and Balickera Conglomerate east of Balickera Pumping Station.

Age and Relationship: The unit is almost completely of direct igneous or pyroclastic genesis with the layered rocks deposited in a continental environment. The unit is believed to be the time equivalent of partly marine strata, held to be Visean, in the Bulahdelah area (Engel, 1965). The basal unit was observed to have slight discordance with the Wallaringa Formation in the Balickera Pumping Station excavation but the regional significance of this discordance is unknown. The succession at Balickera is different in many aspects from the neighbouring Mt. Gilmore section of Osborne (1922). The differences are due in no small measure to the better record available through the perfection of exposures available for field study at Balickera.

The group consists of a basal sequence chiefly of intermediate composition, and an upper acid sequence. These sequences are defined as formations.

Mosman's Swamp Andesite

Synonomy: Lower part of the Gilmore Volcanics (Roberts, 1961) and Volcanic Stage of Osborne.

Deviation: Mosman Swamp (Paterson 780610).

Type Section: Easterly from peg 1350, Balickera Pumping Station (Paterson 820620).

Thickness: 1,190 feet at Balickera (Fig. 3).

Relationships and Petrology: The basal member is of porphyritic pyroxene andesitic pitchstone with marked convolute flow structure evident in the face of Balickera Pumping Station excavation. The basal unit possibly flowed over an irregular surface, but the basal contact relationships are partly in doubt because a thin (to nine inches) dolerite sill of later age occurs along the lower surface. The sandstone of the undersurface is baked and discoloured. This flow has been irregularly altered to hard red, haematitic rock and a soft, celadonitized rock possibly by hydrothermal action. Pitchstones dominate in the basal 400 feet and are succeeded by lithoidal andesitic ignimbrites. These are succeeded by green, red, chocolate, yellow, purple and grey layered tuffs (including some altered to bentonite) a coarse, quartz-bearing, crystal tuff, and massive blue-grey, quartz-bearing, andesitic to dacitic ignimbrites with alternations of layered lithic, crystal and vitric tuffs. The sequence is almost completely of direct igneous and pyroclastic origin, little terrigenous detritus is present. Apart from the pitchstones, most rocks in thin section show evidence of an ignimbritic character. Rock fragments, broken crystal grains, shards and deformed shards and flattened pumiceous fragments are common. Vitric material has often devitrified and there are few criteria to distinguish the massive rocks from lavas in hand specimen.

Eagleton Volcanics

Synonymy: Upper part of Gilmore Volcanics (Roberts, 1961).

Derivation: Eagleton (Paterson 778578).

Type Section: Balickera Tunnel (Paterson 825606; Fig. 3).

Lithology: Toscanitic, dellenitic and rhyolitic volcanic and pyroclastic rocks with minor intermediate (andesitic or dacitic) tuffs and volcanic breccias, and tuffaceous sediments.

Thickness: 1,210 feet in type section (Fig. 3).

Relationships and Petrology: The basal unit is a volcanic or pyroclastic rock containing large clasts, some rounded, and has flow or pseudoflow fabric. It weathers to green celadonite and may correspond with a "Green Tuff" of Banks (1946). The unit is dominated by massive, toscanitic and dellenitic rocks (Gilmore-type) which occur between 1,450 feet to 2,130 feet in the section (Fig. 3). These exhibit a variety of fabrics, often clearly ignimbritic, and typically display "phenocrysts" of pink and white feldspar, quartz and mafic components set in a lithoidal, light green or blue-grey matrix. Layered tuffs and tuffaceous sediments occur at intervals in the section. The topmost unit (2,200-2,400 feet, Fig. 3) is a grey, pumiceous, rhyolitic ignimbrite with deformed, pink, pumice fragments and pink feldspars set in a grey, lithoidal matrix.

King's Hill Group

Synonomy: Glacial Stage, Kuttung Series of Osborne (1922), though the base may have been included by Osborne in his Volcanic Stage. Banks (1946) also mapped the base of the unit partly as "Glacial Stage" (at King's Hill) and partly as "Volcanic Stage" (at Balickera).

Derivation: King's Hill (Paterson 792555) where the writer's group corresponds generally with "Glacial Stage" as mapped by Banks.

Lithology: Basal boulder conglomerates, coarse lithic sandstones, fine sandstone, shales, carbonaceous shales and sandstones, coal, varved siltstone, and chert are the dominant sedimentary rock types. Crystal, lithic and vitric tuffs including ignimbrites and the altered products, bentonites, occur throughout the group, generally as thin interbeds.

Thickness: 3,800 feet in the type section at Balickera.

Age and Relationships: There is a slight discordance, possibly of diastem status, with the underlying Gilmore Volcanic Group. The basal conglomerates contain large boulders derived from the underlying acid volcanics as well as those of exotic provenance. The King's Hill Group is divided into several formations as shown in Table 1, and is correlated there with other units in the Hunter Valley. It is a major graded unit comprising a conformable passage from a basal conglomerate formation, through one dominantly composed of sandstone and thence to one dominantly of siltstone. Within the major graded unit there are many second and third order cyclical units.

The huge size and exotic character of some boulders in the conglomerates and the varve-like and diamictic character of the uppermost sediments suggest the group may be glacigene in character. The group is the first in which *Rhacopteris* spp. are found and become prolific in the Hunter Valley. By correlations with marine facies developed laterally (Engel, 1965) the group is believed to be Stephanian in age.

Balickera Conglomerate

Synonomy: It is not clear whether the unit corresponds with the conglomeratic upper part of the "Volcanic Stage" sequence at Mt. Gilmore (Osborne, 1922) or the succeeding basal conglomerate of the "Glacial Stage". Banks (1946) mapped the areas underlain by the unit variously in the "Volcanic Stage" (for example, where the type section is located) and the "Glacial Stage". It corresponds possibly with the lower part of the "Mt. Johnstone Formation" (of Brennan, 1961).

Derivation: Polymictic boulder conglomerate with two prominent members of grey, pumiceous, rhyolitic tuffs and ignimbrites.

Type Section: East Portal, Balickera Tunnel (Paterson 830602).

Thickness: 1,370 feet in the type section. The similarity in character and thickness of ignimbrites within the section (Fig. 3) suggests that some repetition of strata through faulting is possible but no definite faults were mapped.

Age and Relationships: Plant fragments are found in the unit but are indeterminate, though *Lepidodendron* is found below and *Rhacopteris* spp. with *Lepidodendron* above this unit. Lateral correlations with marine strata of the "Myall Facies" of Engel (1965) suggest it is possibly Stephanian. Slight discordance with the underlying tuffs in the type section is possibly due to local cut and fill and may be of diastem status.

The conglomerates are coarse, massive, polymictic rudites with well-rounded phenoclasts (to 160 cm.) of adamellites and diorites, cherts and metamorphic rocks of exotic provenance as well as lavas, ignimbrites, tuffs and sediments which can be related to the underlying section. The matrix contains ill-sorted, angular to sub-rounded lithic fragments and mineral grains, set in a red haematitic and zeolitic paste. Interlayered members of massive, grey tuffs and ignimbrites which contain red pumiceous fragments, flattened and aligned in eutaxitic fabric, have indurated the underlying sediments.

The large size, exotic character and some rare facetting and striation of the phenoclasts suggests the formation may be glacigene. A glacial origin is not however firmly established.

Italia Road Formation

Synonomy: The unit corresponds with part of the "Glacial Stage" of Osborne (1922), but the rocks in areas underlain by it have been represented by Banks (1946) as variously being in the "Volcanic" and "Glacial Stages". The unit corresponds with part of the Mt. Johnstone Formation (Brennan, 1961).

Derivation: The name is derived from the Italia Road which turns off the Pacific Highway at Paterson 837594.

Type Section: The type section (Fig. 4) lies between pegs 4M 3300 and 4M 5190 in the Balickera Outlet Channel which adjoins the Italia Road.

Lithology: The unit comprises coarse to medium, massive lithic arenites with interbeds of fine laminated sandstones, shale, carbonaceous shales and poor coal, and minor mottled and laminated cherts. The deposition is clearly cyclical. Ignimbrites, tuffs and bentonites, are developed throughout the sequence, but usually as thin beds or members (Rattigan, 1965).

Thickness: 1,180 feet in the type section (Fig. 4).

Age and Relationships: The formation contains abundant *Rhacopteris* spp. throughout, associated with *Lepidodendron* sp. in the lower 600 feet, and *Aneimites* sp. (perhaps "*Triphyllopteris*" sp. according to J. F. Rigby) in the

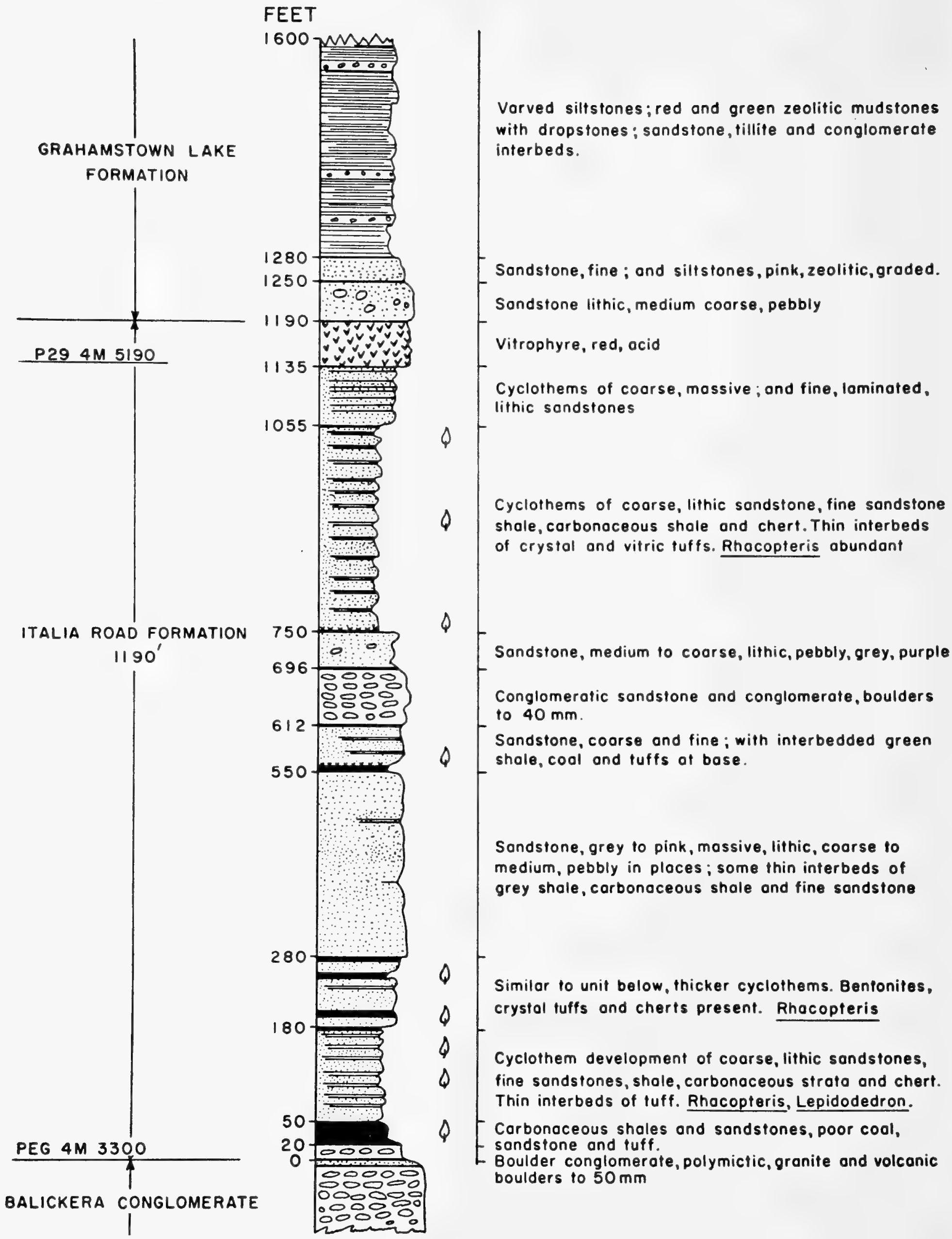

Fig. 4
Measured section east of Balickera Tunnel; the type section of the Italia Road Formation.

upper part of the section. By correlation with the lateral marine " Myall Facies " it is believed to be Stephanian or younger (Engel, 1965, Table 2). The unit is conformable with the underlying Balickera Conglomerate and is succeeded apparently conformably by the Grahamstown Lake Formation. The topmost member of the unit as mapped is a red, vitrophyric ignimbrite which, though it has no macroscopic similarity, is correlatable with the Paterson Volcanics, as the sedimentary members beneath and above this ignimbrite closely resemble those adjoining the Paterson Volcanics in the type area at Paterson. Were better surface exposures available it is probable that the formation would be changed in status as some units in the section appear to occur at corresponding stratigraphic positions throughout the Lower Hunter region. One such unit is the *Rhacopteris* bearing member lying between 750 feet and 1,055 feet in the section (Fig. 4) which corresponds with the " zone which occupies in general a constant stratigraphic level—from 50-300 feet below the Paterson " toscanite " (Osborne, 1922, p. 180).

Most members are clearly cyclical with cyclothems formed of massive, graded, lithic sandstone as the basal cyclothem unit passing upwards into a sorted, cross-laminated sandstone, and thence to shales with carbonaceous beds or poor coal. Pyroclastic material interrupts the normal cyclical deposition at many horizons. Chert which often occurs near the top of cyclothems may result from silica derived as a by-product of the transformation of vitric ash to montmorillonite.

Grahamstown Lake Formation

Synonomy : The unit corresponds at least in part with the " Glacial beds of Seaham and Paterson " of Sussmilch and David (1919), the " Main Glacial Beds " of Osborne (1922, p. 180), the " Glacial Stage " as mapped by Banks (1946) at Balickera.

Derivation : Grahamstown Lake, an artificial reservoir.

Type Section : The type section lies near Paterson 838585, between pegs 5M 0030 and pegs 5M 2400 of the Balickera Outlet Channel near where it enters Grahamstown Lake (Fig. 4).

Lithology : Laminated, red, green and mauve claystones, siltstones, fine sandstones, and varves and massive mudstones with dropstones (diamictites) ; fine to medium, well-sorted or graded, pink, zeolitic sandstones, lithic sandstones and pebble conglomerates. The zeolites clinoptilolite, stilbite and laumontite are common constituents of the pastes of sediments.

Thickness : 1,190 feet in the type section.

Age and Relationships : The unit contains *Rhacopteris* but not in the abundance of the underlying formation. The basal member (60 feet in thickness, Fig. 4) is conglomeratic and possibly corresponds with the " Fluvioglacial conglomerate " which rested on the " Paterson rhyolite " of Sussmilch and David (1919). It is succeeded by pink and green mudstones, varved siltstones and fine, pink, zeolitic sandstones well exposed over 300 stratigraphic feet. Alternating conglomeratic sandstones, mudstones and laminated siltstones succeed. These pass transitionally to massive, fine to medium grained, lithic sandstones which immediately underlie the tuffs and coal of Garrett's Seam (David, 1907, p. 79), which is associated with *Gangamopteris*. These sandstones are taken arbitrarily, following Banks (1946), to be the basal unit of the Permian System. Garrett's Seam was not observed, due to the deepening of Cainozoic superficial strata, in the Balickera canals but was interpreted by projections along strike to lie about 200 feet above the top of the Grahamstown Lake Formation.

Concluding Discussion

The Balickera excavations are of geological interest in providing a base for studies in the stratigraphy, sedimentology, igneous petrology and palaeobotany in the Kuttung Facies. The complete and fresh exposure allowed selection of excellent material for laboratory analysis. The excavations provided exposures in three dimensions for detailed field study of the succession, the scalar and directional properties of sediments and volcanic rocks and the tectonic structures. It is proposed to present the results of specialized studies in subsequent publications.

The section is a critical one in that it provides, in its volcanic and pyroclastic rocks developed throughout the section, an opportunity for thorough absolute age dating and palaeolatitude or palaeoclimatological studies through a period in which world climates changed markedly and possibly polar wandering and drift were in progress.

Many pyroclastic units including those altered to bentonites are isochronous mappable units for intra-regional correlation and thus may provide a key to correlation of contemporaneous continental and marine facies. With proper field and laboratory control bentonites may also be invaluable indices for confirming, by independent geological means, some geophysical concepts of polar wandering and drift (Eaton, 1964).

Acknowledgements

The writer wishes to thank the Hunter District Water Board, and its officers, who at all times gave freely any assistance required in mapping the Balickera Excavations. Staff and students of Newcastle University College also assisted in the investigation at several periods. Floral nomenclature used here follows the preliminary identifications by J. F. Rigby.

This paper was completed during the tenure of a visiting professorship at the University of California at Riverside and thanks are due to the Chairmen of the Department of Geological Sciences for drafting and typing facilities made available for its completion.

M. R. Banks of the University of Tasmania assisted by providing a geological map and sections of the Balickera-Raymond Terrace district which he had geologically mapped while a student at Sydney University. The writer remapped only the northern part of the area covered by Banks whose valuable work was modified in the light of the greater wealth of geological detail now available in excavations and displayed on aerial photographs.

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Report of the Council for the Year Ended 31st March, 1966

Presented at the Annual and General Monthly Meeting of the Society held 6th April, 1966, in accordance with Rule XXVI.

At the end of the period under review the composition of the membership was 348 members, 23 associate members and 9 honorary members; 8 new members (including one associate member who transferred to full membership) were elected and 10 associate members were admitted. Eleven members and one associate member resigned and two names were removed from the list of members under Rule XVIII. We are pleased to announce that Mr. R. S. Rishworth was elected a member in appreciation of his legal advice to the Society.

During the year the following organizations became company members of the Society: Australian Consolidated Industries Ltd., Australian Iron and Steel Pty. Ltd. and Colonial Sugar Refining Co. Ltd.

It is with extreme regret that we announce the loss by death of:

Mr. Robert L. Corbett (elected 1933),
Mr. Thomas J. Holm (elected 1952),
Mr. Charles W. R. Powell (elected 1921),
Mr. George F. Sutherland (elected 1919),
Dr. Harold B. Taylor (elected 1915),
Sir Robert D. Watt (elected 1911).

Nine monthly meetings were held. The abstracts of all addresses have been printed on the notice paper. The proceedings of these will appear later in the issue of the "*Journal and Proceedings*". The members of the Council wish to express their sincere thanks and appreciation to the eight speakers who contributed to the success of these meetings, the average attendance being 46.

The Annual Social Function was held on 24th March at the Sydney University Staff Club and was attended by 56 members and guests.

The Council has approved the following awards:

The Clarke Medal for 1966 to Prof. Dorothy Hill, F.R.S., F.A.A., of the University of Queensland.

The Society's Medal for 1965 to Dr. F. Lions, of the University of Sydney.

The Walter Burfitt Prize and Medal for 1965 to Dr. C. A. Fleming, O.B.E., of the New Zealand Geological Survey.

The James Cook Medal for 1965 to Dr. J. Gunther, C.M.G., O.B.E., Assistant Administrator, Territory of Papua and New Guinea.

The Edgeworth David Medal for 1965 to Prof. J. L. Dillon, of the University of New England.

The Clarke Memorial Lecture for 1965 was delivered by Dr. A. A. Öpik, of the Bureau of Mineral Resources, Canberra, on 30th August. The title of the lecture was "The Early Upper Cambrian Faunal Crisis and its Correlation".

The Pollock Memorial Lecture, sponsored by the University of Sydney and the Society, was delivered by Dr. Fredk. Seitz, President, National Academy of Sciences, U.S.A., on 26th August. The title of the lecture was "Perspectives in Solid State Science".

The Society has again received a grant from the Government of New South Wales, the amount being £750 ($1,500). The Government's interest in the work of the Society is much appreciated.

The Society's financial statement shows a deficit of £186 ($372).

The *New England Branch of the Society* met six times during the year and the proceedings of the Branch follow.

The President represented the Society at the Commemoration of the Landing of Captain Cook at Kurnell; and attended a Conversazione arranged by the Australian Academy of Science and held at the University of New South Wales.

The President attended the Annual Meeting of the Board of Visitors of the Sydney Observatory.

We congratulate Father L. Drake on his appointment as Director of Riverview College Observatory; Dr. M. R. Lemberg, F.R.S., F.A.A., of the Britannica Award for Science and Prof. K. E. Bullen, F.R.S., F.A.A., on the award of the Royal Society of Victoria Research Medal.

The Society's representatives on Science House Management Committee were Mr. H. F. Conaghan and Dr. A. H. Low.

Council has pleasure in informing members that *Patronage* has been granted the Society by His Excellency the Right Honourable Lord Casey, P.C., G.C.M.G., C.H., D.S.O., M.C., K.St.J., the Governor-General of the Commonwealth of Australia and by the Governor of New South Wales, His Excellency Sir Roden Cutler, V.C., K.C.M.G., C.B.E.

Four parts of the "*Journal and Proceedings*" have been published during the year.

Council held 11 ordinary meetings and attendance was as follows: Dr. A. A. Day, 11; Mr. J. W. Humphries, 7; Prof. R. J. W. Le Fevre, 5; Mr. H. H. G. McKern, 6; Mr. W. H. G. Poggendorff, 9; Dr. A. H. Low, 11; Dr. A. Reichel, 7; Mr. H. F. Conaghan, 10; Mr. R. A. Burg, 10; Mr. A. F. A. Harper, 5; Prof. A. Keane, 8; Mr. T. E. Kitamura, 7; Dr. C. T. McElroy, 7; Mr. J. Middlehurst, 1 (absent-on-leave, 6); Mr. J. W. G. Neuhaus, 10; Mr. W. H. Robertson, 9; Ass. Prof. R. L. Stanton, 0; Dr. A. Ungar, 8.

The *Library*—Periodicals were received by exchange from 394 societies and institutions. In addition the amount of £123/16/6 ($247.65) was expended on the purchase of 11 periodicals.

Mr. A. F. Day was appointed Assistant Librarian on 18th November following the resignation of Mr. E. Reidy on 31st October.

Among the institutions which made use of the library through the inter-library loan scheme were :

N.S.W. Govt. Depts.—Dept. of Agriculture, Maritime Services Board, Prince Henry Hospital, Dept. Public Health, Dept. of Public Works, Railways Technical Library, Dept. of Soil Conservation, State Fisheries, W. C. and I. Commission, Division of Wood Technology.

Commonwealth Govt. Depts.—Aust. Atomic Energy Commission, Commonwealth Film Unit, Bureau of Mineral Resources, C.S.I.R.O. Depts.: Library, Canberra ; Coal Research, Ryde ; Animal Physiology, Prospect ; Fisheries and Oceanography, Cronulla ; National Standards Laboratory, Sydney ; Textile Physics, Ryde ; photocopies by Fisher Library have been sent to various divisions.

Universities and Colleges—Adelaide University, Australian National University, Monash University, Mount Stromlo Observatory, Newcastle University, New England University, New South Wales University, Queensland University, School of Public Health and Tropical Medicine, Sydney University, Tasmania University, University College of Townsville, Western Australia University.

Companies—Aust. Iron and Steel Pty. Ltd. ; Aust. Paper Manufacturers, Melbourne ; A.W.A. Ltd. ; Aust. Consolidated Industries ; Aust. Mineral Development Laboratory ; Blue Metal Industries ; C.S.R. Chemicals Ltd. ; C.S.R. Co. Ltd. Technical Library ; Commonwealth Industrial Gases ; I.C.I. Ltd. ; John Lysaght Ltd. ; S.T.C. Ltd. ; Telecommunications ; Unilever Technical Library ; Wheat Industries Pty. Ltd.

Research Institutes—Aust. Coal Industry Research Laboratory, B.H.P. Central Research Laboratories, Bread Research Institute, C.S.R. Research Library.

Museum—Australian Museum.

Miscellaneous—Aust. Medical Association, Aust. Coal Association, Institution of Engineers, Aust.

A. H. Low,
Hon. Secretary.

6th April, 1966.

Financial Statement

BALANCE SHEET AS AT 10th FEBRUARY, 1966

LIABILITIES

1965		£ s. d.	£ s. d.
500	Accrued Expenses		191 17 3
40	Subscriptions Paid in Advance		17 17 0
83	Life Members' Subscriptions—Amount carried forward		76 13 0
	Trust Funds (detailed below)—		
	Clarke Memorial	2,073 0 1	
	Walter Burfitt Prize	1,235 15 2	
	Liversidge Bequest	728 3 4	
	Ollé Bequest	248 7 7	
4,219			4,285 6 2
30,246	Accumulated Funds		30,014 16 4
—	Library Reserve Account		3,187 19 9
218	Employees' Long Service Leave Fund Provision ..		251 5 7
	Contingent Liability (in connection with Perpetual Lease)		
£35,306			£38,025 15 1

ASSETS

1965		£ s. d.	£ s. d.
4,203	Cash at Bank and in Hand		2,108 17 2
	Investments—		
	Commonwealth Bonds and Inscribed Stock—		
	At Face Value—held for :		
	Clarke Memorial Fund..	1,800 0 0	
	Walter Burfitt Prize Fund	1,000 0 0	
	Liversidge Bequest	700 0 0	
	General Purposes	4,840 0 0	
8,340			8,340 0 0
218	Fixed Deposit—Long Service Leave Fund.. ..		251 5 7
	Debtors for Subscriptions	124 19 0	
	Less : Reserve for Bad Debts	124 19 0	
—			—
14,835	Science House—One-third Capital Cost		14,835 4 4
6,800	Library—At Valuation		6,800 0 0
—	Library Investment—Special Bonds..		4,800 0 0
897	Furniture and Office Equipment—At Cost, *less* Depreciation		877 8 0
12	Pictures—At Cost, *less* Depreciation		12 0 0
1	Lantern—At Cost, *less* Depreciation		1 0 0
£35,306			£38,025 15 1

TRUST FUNDS

	Clarke Memorial £ s. d.	Walter Burfitt Prize £ s. d.	Liversidge Bequest £ s. d.	Ollé Bequest £ s. d.
Capital at 10th February, 1966 ..	1,800 0 0	1,000 0 0	700 0 0	—
Revenue—				
Balance at 28th February, 1965	253 13 0	202 6 11	*3 7 9*	266 2 7
Income for period	81 2 8	45 1 8	31 11 1	42 5 0
	334 15 8	247 8 7	28 3 4	308 7 7
Less : Expenditure ..	61 15 7	11 13 5	—	60 0 0
Balance at 10th February, 1966	£273 0 1	£235 15 2	£28 3 4	£248 7 7

ACCUMULATED FUNDS

	£ s. d.	£ s. d.
Balance at 28th February, 1965..	30,246 11 4	
Add—		
Transfer Salary Adjustment	3 0	
		30,246 14 4
Less—		
Transfer for Long Service Leave Fund Provision	25 0 0	
Increase in Reserve for Bad Debts ..	17 12 0	
Subscriptions Written Off	3 6 0	
Deficit for the period	186 0 0	
		231 18 0
		£30,014 16 4

Auditor's Report

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 10th February, 1966, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Chartered Accountants.
Registered under the Public Accountant Registration Act, 1945, as amended.

65 York Street,
Sydney.
28th March, 1966.

(Sgd.) H. F. CONAGHAN,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT

1st MARCH, 1965, to 10th FEBRUARY, 1966

1965				£ s. d.
—	Advertising			7 15 0
31	Annual Social			26 19 0
38	Audit			37 16 0
25	Branches of the Society			25 0 0
151	Cleaning			158 0 0
48	Depreciation			46 15 8
50	Electricity			40 5 0
7	Entertainment			13 12 0
37	Insurance			42 10 10
136	Library Purchases			132 17 7
195	Miscellaneous			263 8 8
148	Postages and Telegrams			106 11 7
	Printing—Journal—			
	Vol. 97, Part 6A—Vol. 98, Part 2	£1,575 6 3		
	Binding	37 10 0		
	Reprints	151 1 6		
	Postages	78 12 4		
	Wrappers	39 15 0		
	Provision for Reprints	69 17 3		
			1,952 2 4	
	Less :			
	Sale of Reprints	114 19 6		
	Subscriptions to Journal	320 19 8		
	Sale of Back Numbers	71 2 8		
	Refund Postages	21 12 3		
	Sale of Block	10 0 0		
	Provision for Vol. 97	500 0 0		
			1,038 14 1	
635				913 8 3
95	Printing—General			39 17 11
1,196	Rent—Science House Management			1,212 12 0
14	Repairs			6 5 3
1,502	Salaries			1,405 13 6
170	Storage Expenses			23 16 3
42	Telephone			40 10 8
593	Surplus for the Twelve Months			—
£5,113				£4,543 15 2

1965		£ s. d.
980	Membership Subscriptions	959 14 0
6	Proportion of Life Members' Subscriptions	6 6 0
750	Government Subsidy	750 0 0
2,362	Science House Management—Share of Surplus	2,094 0 0
230	Interest on General Investments	324 19 2
627	Sale of Library Assets	—
—	Donations	120 16 0
—	Company Membership	95 0 0
8	Sundry Receipts	7 0 0
150	Publication Grants Received	—
—	Deficit for the period	186 0 0
£5,113		£4,543 15 2

The Honorary Treasurer's Report

To avoid confusion in the Balance Sheet resulting from the introduction of decimal currency, the Society's books were closed as at 10th February, 1966.

The Society this year recorded a *deficit* of £186 ($372). Increases in expenditure of £278 ($556) in the cost of printing the Journal together with a decrease of £268 ($536) in the share of surplus from Science House and the non inclusion of the sale of assets in the income contributed towards this deficit.

On the credit side expenditure on salaries dropped £98 ($196) and on storage £146 ($292).

As a result of a letter drafted by the Finance Committee requesting views of a number of industrial organisations on *company membership*, three firms applied for company membership at rates varying from £20 ($40) to £50 ($100). A number of firms were not interested in company membership but two of these firms forwarded *donations* amounting to £120 ($240).

The President, Hon. Secretary and Hon. Treasurer of the Society were granted an *interview with the Minister for Education and Science* with a view to obtaining an increase in the government grant. The Minister pointed out that as his Department's estimates had already been prepared for the year 1965–66 he suggested that our request be re-submitted in time for the preparation of the 1966–67 estimates.

Following a recommendation from its auditors that the owner-bodies contribute £130 ($260) per annum for three years in order to build up cash resources, the *Management Committee of Science House* recommended that the sum set aside be £200 ($400) per annum. The Council of the Society agreed to pay £130 ($260) per year, the additional £70 ($140) being granted this year but further representation be made to future Councils for the additional £70 ($140).

The Society realised the sum of £3,187/19/9 ($6,375.99) on the *sale of library assets*. To preserve funds resulting from the sale of assets, Council approved of the establishment of a Library Reserve Account, the transfer of £4,800 to this account and the investment of the £4,800 ($9,600) in *Commonwealth Special Bonds*.

H. F. Conaghan,
Hon. Treasurer.

Annual Report of the New England Branch of the Royal Society of New South Wales for 1965

Officers for the year were:

Chairman:	J. H. Priestley.
Secretary-Treasurer:	R. H. Stanton.
Committee Members:	P. D. F. Murray,
	R. H. Stokes,
	N. H. Fletcher,
	N. W. Taylor,
	B. A. G. Plummer.

Six meetings were held as follows:

10*th June:* Dr. J. E. Harker, Fellow of Guter College, Cambridge. "Measurement of time by living organisms".

28*th June:* Professor H. Godwin, F.R.S., Professor of Botany, University of Cambridge, spoke on pre-historic studies.

30*th August:* Dr. R. D. Keynes, F.R.S., Director of the A.R.C. Institute of Animal Physiology, Babraham, Cambridge. "The generation of electricity by fishes".

13*th October:* Dr. I. E. Newman, Chief of the Division of Mineral Chemistry, C.S.I.R.O., "Science and Technology: the role of C.S.I.R.O.".

15*th October:* Professor R. W. Russell, Chairman of the Department of Psychology, University of Indiana, U.S.A. "Biochemical events and behaviour".

22*nd October:* Professor P. Maheshwari, F.R.S., Professor of Botany, University of Delhi. "Plants, Man and History".

Financial Statement

Credit balance at University of New England Branch, Commercial Banking Company of Sydney, 2nd April, 1965 ..		£78 2 0
Remittance from Royal Society of New South Wales, 6th May, 1965		25 0 0
Interest to 30th June, 1965		1 7 9
Interest to 31st December, 1965		1 16 5
		£106 6 2
Converted to Decimal Currency		$212.62
Expenditure		
Payment to Mrs. Roan, Geology Department for Duplicating	10·9	$1.09
Honorarium to Mrs. Roan, for secretarial assistance		6.00
Leaving a Balance of		$205.52

R. L. Stanton,
Hon. Secretary-Treasurer.

Abstract of Proceedings

7th April, 1965

The ninety-eight Annual and eight hundredth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. J. W. Humphries, was in the chair. There were present 44 members and visitors.

Edward Gordon Haig Manchester was elected a member of the Society.

The Annual Report of the Council and the Financial Statement were presented and adopted.

The following awards of the Society were announced :

The Society's Medal for 1964 : Mr. F. D. McCarthy.
The Clarke Medal for 1965 : Dr. M. Josephine Mackerras.
The James Cook Medal for 1964 : Dr. M. R. Lemberg, F.R.S., F.A.A.
The Edgeworth David Medal for 1964 : Dr. Mollie E. Holman.
The Archibald D. Ollé Prize for papers published in volume 97 : Joint award to Mr. J. L. Griffith and Dr. J. Roberts.

Office-Bearers for 1965–66 were elected as follows :

President : Alan A. Day, B.Sc. (Syd.), Ph.D. (Cantab.).
Vice-Presidents : J. W. Humphries, B.Sc. ; R. J. W. Le Fevre, D.Sc., F.R.S., F.A.A. ; H. H. G. McKern, M.Sc. ; W. H. G. Poggendorff, B.Sc.Agr.
Hon. Secretaries : A. H. Low, Ph.D. ; A. Reichel, Ph.D.
Hon. Treasurer : H. F. Conaghan, M.Sc.
Members of Council : R. A. Burg, A.S.T.C. ; R. M. Gascoigne, Ph.D. ; A. F. A. Harper, M.Sc. ; A. Keane, Ph.D. ; T. E. Kitamura, B.A., B.Sc.Agr. ; J. Middlehurst, M.Sc. ; J. W. G. Neuhaus, A.S.T.C. ; W. H. Robertson, B.Sc. ; R. L. Stanton, Ph.D. ; A. Ungar, Dr.Ing.

Messrs. Horley and Horley were re-elected auditors to the Society for 1965–66.

The retiring President, Mr. J. W. Humphries, delivered his Presidential Address entitled "Some Units and Standards of Weights and Measures".

The following papers were read by title only : "Clay Mineralogy of some Upper Devonian Sediments in Central New South Wales" by J. R. Conolly ; "Photographic Observations of Double Stars" by K. P. Sims ; "Late Quaternary Coastal Morphology of the Port Stephens-Myall Lakes Area, N.S.W." by B. G. Thom.

At the conclusion of the Presidential Address the retiring President welcomed Dr. Alan A. Day to the Presidential Chair.

5th May, 1965

The eight hundred and first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 50 members and visitors.

The following were elected members of the Society : Richard Andrew Facer and John William Pickett.

The following had now attained Life-Membership : A/Prof. R. L. Aston and Dr. G. F. K. Naylor.

An address entitled "Recent Geological Studies in the Upper Taylor Glacier Region, Antarctica" was delivered by Dr. C. T. McElroy, of the School of Applied Geology, The University of New South Wales.

2nd June, 1965

The eight hundred and second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 80 members and visitors.

Gabor Zoltan Foldvary was elected a member of the Society.

Through the courtesy of Kodak (A'sia) Pty. Ltd., Sydney, an address entitled "Four Keys to Colour" was delivered by Mr. J. R. Freeman and Mr. G. W. Martin.

7th July, 1965

The eight hundred and third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 22 members and visitors.

Bruce Ian Cruikshank was elected a member of the Society.

A symposium on Scientific Aspects of Fruit Storage and Ripening was held. The speakers were : Dr. R. Smillie—"Physiological regulation of plant growth and senescence" ; Dr. W. B. McGlasson—"The importance of ethylene in fruit ripening" and Dr. F. E. Huelin—"The chemistry of superficial scald, a functional disorder of stored apples".

The symposium had been arranged through the courtesy of Dr. J. R. Vickery, Chief of the Division of Food Preservation, C.S.I.R.O., Ryde, N.S.W.

4th August, 1965

The eight hundred and fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 80 members and visitors.

An address entitled "The Prehistory of Australia" was delivered by Mr. F. D. McCarthy, Principal, Australian Institute of Aboriginal Studies, Canberra, A.C.T.

1st September, 1965

The eight hundred and fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 24 members and visitors.

The following were elected members of the Society : Sydney Charles Haydon and Robin Edgar Wass.

It was announced that the following items were for sale : 1 Filing Cabinet ; 1 Revolving Book Case ; 2 Tin Trunks.

An address entitled "Research Activities of the C.S.I.R.O. Laboratory", was delivered by Dr. G. F. Humphrey, Chief of the Division of Fisheries and Oceanography, Cronulla.

6th October, 1965

The eight hundred and sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 18 members and visitors.

Notice of Motion: Additional clause to the Rules. After 15th February, 1966, all amounts occurring in the Rules to be converted to decimal currency at the rate of two dollars to the pound.

The following films were shown: "Meet the Nobel Prize Winners 1965", by courtesy of Dr. Andrew Ungar and "Biological Control of Insects", by courtesy of the N.S.W. Department of Agriculture.

3rd November, 1965

The eight hundred and seventh General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 14 members and visitors.

An address entitled "Electrical Activity in Smooth Muscle" was delivered by Dr. Mollie E. Holman, of the Department of Physiology, Monash University, Victoria.

1st December, 1965

The eight hundred and eight General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Dr. Alan A. Day, was in the chair. There were present 80 members and visitors.

Lloyd Hamilton was elected a member of the Society.

A letter informing the Society that His Excellency the Governor-General the Right Honourable Lord Casey, P.C., G.C.M.G., C.H., D.S.O., M.C., K.St.J., was pleased to grant Patronage was read.

An address entitled "Comets" was delivered by Dr. Harley W. Wood, Government Astronomer, Sydney Observatory.

Section of Geology

CHAIRMAN: D. S. Bridges. HON. SECRETARY: (Mrs.) M. Krysko v. Tryst.

Abstract of Proceedings, 1965

Four meetings were held during the year, the average attendance being 12 members and visitors.

19th March: Address by Mr. J. B. McManus: "The Role of the Geologist in siting Bore-holes, and interpreting Bore-hole Deviation".

Quite often as a result of many months and sometimes years of exploration, drilling is carried out, and quite often not sufficient thought is given to the siting of boreholes, either on the surface or underground.

The terms "deviation" and "deflection" were explained in relation to drilling, but in general the geologist should be concerned with deviation and allow engineers to handle deflection technicalities.

The siting of surface boreholes was discussed in relation to features such as creeks, swamps, topography, climate, drilling water, size of boreholes, rock hardness, foliation (cleavage), gneissosity, jointing, high underground water pressures, water table, type of drilling equipment and other features (natural and man-made). The laying-out of surface boreholes was illustrated by blackboard diagrams, and the advantages and disadvantages of both surface and underground boreholes were dealt with.

The siting of underground boreholes was next outlined, and in the siting the geologist can assist greatly by recommending the locations of drilling cuddies before exploratory drives are commenced, thus ensuring that the cuddies are cut while the mining equipment is nearby. Air, water and electricity locations should be noted in relation to proposed drilling sites. Other factors that should be considered in the siting of underground boreholes are: opposed boreholes for the purpose of pulling rods, the building of bulks, head-room rises, winzes for stacking rods, clearances required for rod-pulling, keeping out of the way of trucking and other mine operations, stand pipes, the marking-up of the boreholes and the location of exploratory drives for future drilling.

Deviation examples and problems were then given and explained. It was shown how gneissosity and cleavage affect the deviation of boreholes. By making use of deviation and deflection, a drilling machine need only be set up once in many cases, as opposed to say two, three or more "set-ups".

If one has knowledge of deviation rates in a particular locality, dog-legs in boreholes, brought about by deflection, can be overcome, thus enabling better oil or water flows from underground reservoirs. Geological structures can quite often be interpreted and predicted by making a close study of borehold deviation.

An example of making the maximum use of deviation was given. At Rosebery in Tasmania, many boreholes have been aimed away from targets to enable them to intersect the targets. In this area cleavage plays a major part in bringing about the deviation of boreholes. In other areas, such as Broken Hill, gneissosity plays a major part in causing borehold deviation.

Some direct and indirect deflection methods and techniques were outlined briefly. Bit pressures were considered to be allied with deflection rather than with deviation. For the sake of some degree of topic completeness, borehold surveying was mentioned.

The address was summed up by stating that, provided that one is acutely aware of deviation, it can be used to advantage, and the geologist should be the person to advise exploration personnel on borehold deviation matters and problems and the siting of boreholes.

21st May: Address by Dr. D. F. Branagan: "Geology of Puerto Rico".

The island of Puerto Rico may be divided into 3 broad geological provinces: a central mountainous complex of middle Cretaceous and earlier volcanic rocks and sediments intruded by granitic rocks and serpentinites, flanked by upper Cretaceous and Tertiary sediments and volcanics which are generally less deformed and which dip north or south off the east-west trending older complex.

Large-scale strike faults are important features and fault scarps form important physiographic features.

Although the average rainfall is high, it is irregularly distributed and the island shows a remarkable variation from tropical and semi-tropical (including fine stands of eucalypts) to semi-desert savannah vegetation. Some of the main streams, all of which are quite short, are subject to very high flash floods because the rainfall tends to be concentrated into a few days of the year.

The abundant limestones show many varieties of weathering. Karst features on a large scale are very well developed and many cave systems are being explored. A number of physiographic levels are recognised—some of these are lateritised. The origin of these levels is controversial.

Large-scale development of " porphyry copper " deposits associated with granite intrusions is at present being undertaken.

The origin of the island in relation to the rest of the West Indies is obscure and the island arc concept is questioned.

The geology of some of the important rock units was discussed using coloured slides and maps.

24th September : Election of Office-Bearers :—Chairman : Mr. D. S. Bridges ; Hon. Secretary : Mrs. M. Krysko v. Tryst.

Address by Prof. L. J. Lawrence on " Highlights of a recent overseas trip ".

Professor Lawrence gave an account of two mineral deposits which he had visited recently. The first of these was the Ontokompu Copper deposit in central Finland—one of the very recent mines of northern Europe. The ore is ascribed to a gabbroic sill-hike body—though disconformable in places—intrusive into Archaean metasediments. In the Ontokompu Companies northern workings chalcopyrite and pentlandite, also ascribed to a pene-conformable gabbro shows evidence of re-mobilization by a later granite.

The second deposit, historically one of the oldest in the world, the lead mines of Laurium in Greece, were worked in 1,000 B.C. by the Phoenicians. The ore bodies, currently being re-examined by a French Company, were epigenetically emplaced along the stratigraphic junctions between a lower Schist, a lower Marble, an upper Schist and an upper Marble unit ; they are thus pseudo-conformable. The ore consists essentially of galena and fluorite.

Professor Lawrence then discussed, with the aid of kodachromes, the mining and ore dressing methods employed by the Phoenicians.

19th November : Address by Dr. N. L. Markham entitled " Mineral Zoning in Sulphide Ore Deposits ".

Of recent years there has been renewed interest shown in problems connected with the zoning of mineral deposits. Thus, in 1963, a conference was held in Prague, Czechoslovakia, in which various aspects of ore zoning were discussed.

The reasons why ore deposits are zoned are however, still poorly understood. In part, this is due to the variety and complexity of zoned phenomena and in part to our lack of understanding of the chemistry of ore concentration, transportation and deposition. Zoned distribution of ore minerals can be demonstrated in environments as diverse as orthomagmatic, hydrothermal veins marginal to granite intrusions, volcanic vents, volcanic exhalative and sedimentary sulphide deposits. Clearly no single unified explanation of zoning is possible.

Medallists, 1965-66
Citations

Clarke Medal for 1966

Professor Dorothy Hill, D.Sc., F.R.S., F.A.A.

Professor Hill, Research Professor of Geology at the University of Queensland since 1959, was born in Brisbane on 10th September, 1907 and was educated at the Brisbane Girls' Grammar School, the University of Queensland and Newnham College, Cambridge.

After serving in the W.R.A.N.S. during World War II, Professor Hill became lecturer in geology at the University of Queensland, 1946–52.

She was President of the Royal Society of Queensland 1949-50, Chairman of the Queensland Division of the Geological Society of Australia 1955, and since 1958 has been Eeditor of the Geological Society of Australia.

In 1964 Professor Hill received the Lyell Medal of the Geological Society of London, and in 1965 was elected to Fellowship of the Royal Society, London.

She has published numerous papers on palaeontology, stratigraphy and geology, six of her papers having been published in the Society's " Journal and Proceedings ". Professor Hill was elected to membership of the Society in 1938.

This award is made to Professor Hill for her distinguished contributions in the field of geology, particularly her work on Palaeozoic fossil corals, their stratigraphical implications and the geological significance of their distribution on a world scale.

The Society's Medal for 1965

Francis Lions, Ph.D.

Dr. Lions has made distinguished contributions in the field of chemistry, notably to the chemistry and stereochemistry of sexadentate ligand coordination compounds.

Dr. Lions was elected to membership of the Society in 1929, served on the Council and was elected President in 1946. During his term as President, Dr. Lions represented the Society at meetings of the National Academy of Sciences, Washington, and the

American Philosophical Society respectively, held in Philadelphia and Washington from 8th to 23rd October, 1946.

Fifty-six papers by Dr. Lions have been published in the Society's " Journal and Proceedings ".

The Walter Burfitt Prize

Charles A. Fleming, O.B.E., B.A., D.Sc.

Dr. Fleming, Chief Palaeontologist, New Zealand Geological Survey, was born in Auckland on 9th September, 1916, and was educated at Kings College, Auckland.

In 1940 he was appointed Assistant Geologist and in 1945 Palaeontologist to the New Zealand Geological Survey.

Dr. Fleming was President of the Royal Society of New Zealand 1962–63 and 1964 to the present.

He has published 6 books and 116 scientific papers. His main contributions to science are (i) as a biogeographer interested in the relations of the New Zealand marine and to a lesser extent terrestrial faunas and floras to those of the rest of the world in time as well as in space ; (ii) as a palaeontologist interested in the description and classification of the New Zealand Faunas ; (iii) as a pioneer stratigrapher and (iv) as an administrator and a most unselfish promoter of sciences and regard for science in the community.

James Cook Medal for 1965

John Thomson Gunther, C.M.G., O.B.E., M.B., B.S., D.T.M., D.T.H.

Dr. Gunther was born in Sydney on 2nd October, 1910 and was educated at King's School and at Sydney University where he graduated as a Bachelor of Medicine.

After finishing his residency at Sydney Hospital he went to the British Solomon Islands. Returning to Australia in 1938 he became chairman of the medical board which investigated plumbism—a type of lead poisoning—at Mt. Isa, Queensland. He left this post in 1941 to join the Royal Australian Air Force as a medical officer and carried out research in Papua-New Guinea on malaria and scrub typhus.

At the end of the war he decided to return to the Territory to work for the Administration. In 1946 he was appointed the Territory's Director of Public Health and in this position showed the administrative flair which eventually lead to his appointment as Assistant Administrator.

Dr. Gunther has since been appointed the first Vice-Chancellor of the Territory's new university.

Edgeworth David Medal for 1965

Professor John L. Dillon, B.Sc.Agr., Ph.D. (Iowa).

John L. Dillon was born in Sydney on 21st April, 1931 and graduated B.Sc.Agr., Sydney University in 1951. Following a Fulbright Scholarship and Research Associateship in Agricultural Economics to Iowa State University, he was awarded a Ph.D. degree of that university in 1959. During 1959–60, he was Research Officer, Agricultural Research Liaison Section, C.S.I.R.O., Canberra ; in 1961, Reader in Agricultural Economics, University of Adelaide ; in 1964, Visiting Professor in Agricultural Economics, Universidad Catolica de Chile and in 1965 was appointed Professor of Farm Management at the University of New England.

Professor Dillon has made major contributions to the general development of his discipline in Australia and, in particular, in the field of decision making by farmers and graziers confronted by drought or the risk of drought. In this field he has undertaken a number of related studies which develop and apply analytical policies for drought reserves of feeding stuffs.

He has also compiled in co-operation with another worker, a monumental bibliography of Australian literature in agricultural economics.

Members of the Society, April, 1966

The year of election to membership and the number of papers contributed to the Society's Journal are shown in brackets, thus: (1934: P8), * indicates Life Membership.

Honorary Members

BLACKBURN, Sir Charles Bickerton, K.C.M.G., O.B.E., B.A., M.D., Ch.M., 231 Macquarie Street, Sydney (1960).

BRAGG, Sir Lawrence, O.B.E., F.R.S., The Royal Institution of Great Britain, 21 Albermarle Street, Piccadilly, London, W.1., England (1960).

BURNET, Sir Frank Macfarlane, O.M., Kt., D.Sc., F.R.S., F.A.A., c/o Department of Microbiology, University of Melbourne, Parkville, N.2., Victoria (1949).

FIRTH, Raymond William, M.A., Ph.D., Professor of Anthropology, University of London, London School of Economics, Houghton Street, Aldwych, W.C.2., England (1952).

FLOREY, Lord Howard, M.B., B.S., B.Sc., M.A., Ph.D., F.R.S., Professor of Pathology, Oxford University, England (1949).

O'CONNELL, Rev. Daniel J., S.J., D.Sc., Ph.D., F.R.A.S., Director, The Vatican Observatory, Rome, Italy (1953).

OLIPHANT, Sir Marcus L., K.B.E., Ph.D., B.Sc., F.R.S., F.A.A., Professor of Particle Physics, Australian National University, Canberra, A.C.T. (1948).

ROBINSON, Sir Robert, M.A., D.Sc., F.R.S., F.C.S., F.I.C., Professor of Chemistry, Oxford University, England (1948).

Members

ADAMSON, Colin Lachlan, B.Sc., 9 Dewrang Avenue, North Narrabeen (1944).

ADKINS, George Earl, A.S.T.C., A.M.Aus.I.M.M., A.M.I.E.(Aust.), Dip.App.Sc., School of Mining Engineering, The University of New South Wales, Kensington (1960).

*ALBERT, Adrien, D.Sc., F.A.A., Professor of Medical Chemistry, Australian National University, Canberra, A.C.T. (1938: P3).

ALEXANDER, Albert Ernest, Ph.D., F.A.A., Professor of Chemistry, University of Sydney (1950).

*ALLDIS, Victor le Roy (1941).

ANDERSON, Geoffrey William, B.Sc., c/o P.O. Box 30, Chatswood (1948).

ANDREWS, Paul Burke, B.Sc., Flat 4, 24 Kent Road, Rose Bay (1948: P2).

ARNOT, Richard Hugh Macdonald, B.A., B.Sc.Agr., 33 Hannah Street, Beecroft (1963).

*ASTON, Ronald Leslie, Ph.D., Associate Professor of Geodesy and Surveying, University of Sydney (1930; President 1948).

*AUROUSSEAU, Marcel, M.C., B.Sc., 229 Woodland Street, Balgowlah (1919: P2).

BADHAM, Charles David, M.B., B.S., D.R.(Syd.), M.C.R.A., "New Lodge", 16 Ormonde Parade, Hurstville (1962).

BAKER, Stanley Charles, Ph.D., Department of Physics, University of Newcastle, Tighe's Hill (1934: P4).

BANFIELD, James Edmund, M.Sc., Ph.D.(Melb.), Department of Organic Chemistry, University of New England, Armidale (1963).

BANKS, Maxwell Robert, B.Sc., Department of Geology, University of Tasmania, Hobart, Tas. (1951).

BASDEN, Kenneth Spencer, Ph.D., B.Sc., Department of Fuel, University of New South Wales, Kensington (1951).

BAXTER, John Philip, K.B.E., C.M.G., O.B.E., Ph.D., F.A.A., Vice-Chancellor and Professor of Chemical Engineering, University of New South Wales, Kensington (1950).

BEADLE, Noel Charles William, D.Sc., Professor of Botany, University of New England, Armidale (1964).

BEAVIS, Margaret, B.Sc., Dip.Ed., 3 Rosebank Avenue, Epping (1961).

BECK, Julia Mary (Mrs), B.Sc., Department of Geophysics, University of Western Ontario, London, Ont., Canada (1950).

BELL, Alfred Denys Mervyn, B.Sc.(Hons.), School of Applied Geology, University of New South Wales, Kensington (1960).

*BENTIVOGLIO, Sydney Ernest, B.Sc.Agr., 41 Telegraph Road, Pymble (1926).

BINNS, Raymond Albert, B.Sc.(Syd.), Ph.D.(Cantab.), Department of Geology, University of New England, Armidale (1964: P1).

*BISHOP, Eldred George, Unit 2, 12 Muston Street, Mosman (1920).

BLANKS, Fred Roy, B.Sc., 19 Innes Road, Greenwich (1948).

BLUNT, Michael Hugh, M.R.C.V.S., Veterinary Surgeon, 185 Markham Street, Armidale (1961).

BOLT, Bruce Alan, Ph.D., Professor of Seismology, Department of Geology and Geophysics, University of California, Berkeley, U.S.A. (1956: P3).

BOOKER, Frederick William, D.Sc., Government Geologist, Geological Survey of New South Wales, Department of Mines, Sydney (1951: P1).

BOOTH, Robert Kerril, B.Sc., Dip.Ed.(Syd.), Science Teacher, 46 Jellicoe Street, Hurstville (1964).

BOSSON, Geoffrey, M.Sc., Professor of Mathematics, University of New South Wales, Kensington (1951: P2).

BRADLEY, Edgar David, M.B., B.S.(Syd.), D.O., Ophthalmologist, 107 Faulkner Street, Armidale (1964).

BRENNAN, Edward, B.E.(Appl.Geology), c/o British Phosphate Commission, Christmas Island, Indian Ocean (1962).

BRIDGES, David Somerset, 19 Mount Pleasant Avenue, Normanhurst (1952).

*BRIGGS, George Henry, D.Sc., 13 Findlay Avenue, Roseville (1919: P1).

BROWN, Desmond J., D.Sc., Ph.D., Department of Medical Chemistry, Australian National University, Canberra, A.C.T. (1942).

BROWN, Kenneth John, A.S.T.C., A.R.A.C.I., 3 Karda Place, Gymea (1963).

BROWNE, Ida Alison, D.Sc., 363 Edgecliff Road, Edgecliff (1935 : P12 ; President 1953).

*BROWNE, William Rowan, D.Sc., F.A.A., 363 Edgecliff Road, Edgecliff (1913 : P23 ; President 1932).

BRUCE, Colin Frank, D.Sc., Physicist, 17 Redan Street, Mosman (1964).

BRYANT, Raymond Alfred Arthur, M.E., Nuffield Professor of Mechanical Engineering, University of New South Wales, Kensington (1952).

BUCKLEY, Lindsay Arthur, B.Sc., 9 Eulbertie Avenue, Warrawee (1940).

BULLEN, Keith Edward, Sc.D., F.R.S., F.A.A., Professor of Applied Mathematics, University of Sydney (1946 : P2).

BURG, Raymond Augustine, Senior Analyst, Department of Mines, N.S.W. ; p.r. 17 Titania Street, Randwick (1960).

BURNS, Bruce Bertram, D.D.S., Dental Surgeon, 6th Floor, Suite 607, T. & G. Building, Park Street, Sydney (1961).

BUTLAND, Gilbert James, B.A., Ph.D., F.R.G.S., Professor of Geography, University of New England, Armidale (1961).

CAMERON, John Craig, M.A., B.Sc.(Edin.), D.I.C., 15 Monterey Street, Kogarah (1957).

CAMPBELL, Ian Gavan Stuart, B.Sc., c/o Barker College, Hornsby (1955).

*CAREY, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Hobart, Tas. (1938 : P2).

CAVILL, George William Kenneth, Ph.D., D.Sc., Professor of Organic Chemistry, University of New South Wales, Kensington (1944).

*CHAFFER, Edric Keith, 27 Warrane Road, Roseville (1954).

CHALMERS, Robert Oliver, Australian Museum, College Street, Sydney (1933 : P1).

CHAMBERS, Maxwell Clark, B.Sc., 58 Spencer Street, Killara (1940).

CHAPPELL, Bruce William, B.Sc., Geology Department, Australian National University, Canberra, A.C.T. (1960 : P1).

CHURCHWARD, John Gordon, B.Sc.Agr., Ph.D., c/o The Australian Wheat Board, 528 Londsale Street, Melbourne, C.1. (1935 : P2).

CIENSKA, Christine, M.Econ.(Warsaw), Librarian, Sydney Technical College, Ultimo ; p.r. Flat 511, 54 High Street, Kirribilli (1963).

CLANCY, Brian Edward, M.Sc., Australian Atomic Energy Commission, Lucas Heights (1957).

COALSTAD, Stanton Ernest, B.Sc., Metallurgical Chemist, 54 Bridge Street, Sydney (1961).

COHEN, Samuel Bernard, M.Sc., 35 Spencer Road, Killara (1940).

COLE, Edward Ritchie, B.Sc., Associate Professor of Organic Chemistry, University of New South Wales, Kensington (1940 : P2).

COLE, Joyce Marie (Mrs.), B.Sc., 7 Wolsten Avenue, Turramurra (1940 : P1).

COLLETT, Gordon, B.Sc., 16 Day Road, Cheltenham (1940).

CONAGHAN, Hugh Francis, M.Sc., Senior Analyst, Department of Mines, N.S.W., p.r. 104 Lancaster Avenue, West Ryde (1960).

CONOLLY, John Robert, B.Sc.(Syd.), Ph.D.(N.S.W.), Department of Geology and Geophysics, University of Sydney (1963 : P3).

COOK, Cyril Lloyd, Ph.D., c/o Propulsion Research Laboratories, Box 1424 H, G.P.O., Adelaide, S.A. (1948).

CORTIS-JONES, Beverley, M.Sc., 65 Peacock Street, Seaforth (1940).

COSS, Paul, B.Sc., 10 Lucia Avenue, St. Ives (1963).

COX, Charles Dixon, B.Sc., 51 Darley Street, Forestville (1964).

CRAWFORD, Edwin John, B.E., "Lynwood", Bungalow Avenue, Pymble (1955).

CRAWFORD, Ian Andrew, cr. Barker and O'Grady Streets, Havenview, via Burnie, Tas. (1955).

*CRESSWICK, John Arthur, 101 Villiers Street, Rockdale (1921 : P1).

CROFT, James Bernard, B.E., Ph.D., Department of Geology and Mineralogy, University of Queensland, St. Lucia, Brisbane (1956).

CROOK, Keith Alan Waterhouse, Ph.D., Geology Department, Australian National University, Canberra, A.C.T. (1954 : P9).

CRUIKSHANK, Bruce Ian, B.Sc.(Hons.), 16 Arthur Street, Punchbowl (1965).

DAVIES, George Frederick, 57 Eastern Avenue, Kingsford (1952).

DAVIS, Gwenda Louise, B.Sc., Ph.D., Associate Professor, Department of Botany, University of New England, Armidale (1961).

DAVIS, Iain Horwood, B.Sc.(Lond.), Department of Geography, University of Queensland, St. Lucia, Brisbane (1961).

DAY, Arthur Alan, Ph.D., Department of Geology and Geophysics, University of Sydney (1952 ; President 1965).

DENTON, Leslie A., Bunarba Road, Miranda (1955).

DIVNICH, George, Engineer Agronom.(Yugoslavia), Engineering Analyst, 7 Highland Avenue, Punchbowl (1960).

DOHERTY, Gregory, B.Sc.(Hons.), Australian Atomic Energy Commission, Lucas Heights (1963).

*DONEGAN, Henry Arthur James, M.Sc., F.R.A.C.I., F.R.I.C., Chief Analyst, Department of Mines, N.S.W., c/o Mining Museum, George Street North, Sydney (1928 : P1 ; President 1960).

DRAKE, Lawrence Arthur, B.A.(Hons.), B.Sc., Director, Riverview College Observatory, Riverview (1962 : P1).

DRUMMOND, Heather Rutherford, B.Sc., 2 Gerald Avenue, Roseville (1950).

DULHUNTY, John Allan, D.Sc., Department of Geology and Geophysics, University of Sydney (1937 : P19 ; President 1947).

EADE, Ronald Arthur, Ph.D., School of Organic Chemistry, University of New South Wales, Kensington (1945).

EDGAR, Joyce Enid (Mrs.), B.Sc., 12 Calvert Avenue, Killara (1951).

EDGELL, Henry Stewart, Ph.D. Address unknown. (1950).

*ELKIN, Adolphus Peter, C.M.G., Ph.D., Emeritus Professor, 15 Norwood Avenue, Lindfield (1934 : P2 ; President 1940).

ELLISON, Dorothy Jean, M.Sc., 45 Victoria Street, Roseville (1949).

EMMERTON, Henry James, B.Sc., 37 Wangoola Street, East Gordon (1940).

ENGEL, Brian Adolph, M.Sc., Geology Department, University of Newcastle, Tighe's Hill, 2N. (1961: P1).

*ESDAILE, Edward William, 4 Towers Place, Arncliffe (1908).

ESSEX, Elizabeth Annette, B.Sc.(Hons.), Physics Department, University of West Indies, Mona, Kingston, Jamaica (1963).

EVERETT, Frederick A., B.Sc., Jannali Boys' High School, Jannali (1963).

FACER, Richard Andrew, B.Sc.(Hons.), " Moppity ", Parsonage Road, Castle Hill (1965).

FALLON, Joseph James, Loch Maree Place, Vaucluse (1950).

FAYLE, Rex Dennes Harris, Pharmaceutical Chemist, 141 Jeffrey Street, Armidale (1961).

FISHER, Robert, B.Sc., 3 Sackville Street, Maroubra (1940).

FLEISCHMANN, Arnold Walter, 5 Erang Street, Carss Park (1956).

FLETCHER, Harold Oswald, M.Sc., The Australian Museum, College Street, Sydney (1933).

FLETCHER, Neville Horner, B.Sc., M.A., Ph.D., Professor of Physics, University of New England, Armidale (1961).

FOLDVARY, Gabor Zoltan, B.Sc., 267 Beauchamp Road, Matraville (1965).

FRENCH, Oswald Raymond, 78 Hercules Street, Dulwich Hill (1951).

FRIEND, James Alan, Ph.D., Professor of Chemistry, University of West Indies, St. Augustine, Trinidad, W.I. (1944: P2).

FURST, Hellmut Friedrich, D.M.D.(Hamburg), 158 Bellevue Road, Bellevue Hill (1945).

GALLOWAY, Malcolm Charles, M.Sc., Geologist, 17 Johnson Street, Chatswood (1960).

GARAN, Teodar, Young Road, Ourimbah (1952).

GARRETTY, Michael Duhan, D.Sc., " Surrey Lodge ", Mitcham Road, Mitcham, Victoria (1935: P2).

GASCOIGNE, Robert Mortimer, Ph.D., Department of Philosophy, University of New South Wales, Kensington (1939: P4).

GIBSON, Neville Allan, Ph.D., 103 Bland Street, Ashfield (1942: P6).

GILES, Edward Thomas, M.Sc., Ph.D., D.I.C., F.R.E.S., Senior Lecturer, Department of Zoology, University of New England, Armidale (1961).

*GILL, Stuart Frederic, 45 Neville Street, Marrickville (1947).

GLASSON, Kenneth Roderick, B.Sc., Ph.D., 70 Beecroft Road, Beecroft (1948).

GOLDING, Henry George, M.Sc., Ph.D., School of Applied Geology, University of New South Wales, Kensington (1953: P4).

GOLDSTONE, Charles Lillington, B.Sc.Agr.(N.Z.), School of Wool Technology, University of New South Wales, Kensington (1951).

GORDIJEW, Gurij, Engineer Hydro Geology (Inst. Hydro Meteorology in Moscow, 1936), 41 Abbotsford Road, Homebush (1962).

GRAHAME, Mervyn Ernest, B.A., Schoolteacher, 161 Parry Street, Hamilton, N.S.W. (1959).

GRANT, John Narcissus Guerrato, Dip.Eng., 37 Chalayer Street, Rose Bay (1961).

GRAY, Charles Alexander Menzies, B.E., M.E., Professor of Engineering, Wollongong University College, Wollongong (1948: P1).

GRAY, Noel Macintosh, B.Sc., 1 Centenary Avenue, Hunter's Hill (1952).

GRIFFIN, Russell John, B.Sc., c/o Department of Mines, N.S.W., Sydney (1952).

GRIFFITH, James Langford, B.A., M.Sc., School of Mathematics, University of New South Wales, Kensington (1952: P15; President 1958).

GRODEN, Charles Mark, M.Sc., School of Mathematics, University of New South Wales, Kensington (1957: P3).

GUTMANN, Felix, Ph.D., Associate Professor of Physical Chemistry, University of New South Wales, Kensington (1946: P1).

GUTSCHE, Herbert William, B.Sc., Research Assistant, Geology Department, University of New England, Armidale (1961).

HALL, Norman Frederick Blake, M.Sc., 16A Wharf Road, Longueville (1934).

HAMILTON, Lloyd, B.E., 64 Finlayson Street, Lane Cove (1965: P1).

HAMPTON, Edward John William, 1 Hunter Street, Waratah, N.S.W. (1949).

HANCOCK, Harry Sheffield, M.Sc., 16 Koora Avenue, Wahroonga (1955).

HANLON, Frederick Noel, B.Sc., 11 Nelson Street, Gordon (1940: P14; President 1957).

HARPER, Arthur Frederick Alan, M.Sc., National Standards Laboratory, University Grounds, City Road, Chippendale (1936: P1; President 1959).

HARRIS, Clive Melville, Ph.D., Associate Professor of Chemistry, University of New South Wales, Kensington (1948: P6).

HARRISON, Ernest John Jasper, B.Sc., N.S.W. Geological Survey, Department of Mines, Sydney (1946).

HAYDON, Sydney Charles, M.A., Ph.D., F.Inst.P., Professor of Physics, University of New England, Armidale (1965).

*HAYES, Daphne (Mrs.), B.Sc., 98 Lang Road, Centennial Park (1943).

HIGGS, Alan Charles, c/o Colonial Sugar Refining Co. Ltd., Building Material Division, 1–7 Bent Street, Sydney (1945).

HILL, Dorothy, D.Sc., F.R.S., F.A.A., Professor of Geology and Mineralogy, University of Queensland, St. Lucia, Brisbane (1938: P6).

*HOGARTH, Julius William, B.Sc., Unit 4, " Hillsmore ", 20 Joubert Street, Hunter's Hill (1948: P6).

HORNE, Allan Richard, 7 Booralee Street, Botany (1960).

HOWE, Bernard Adrian, c/o Exploration Physics, 265 Old Canterbury Road, Dulwich Hill. (1963)

HUMPHRIES, John William, B.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale (1959: P1; President 1964).

*HYNES, Harold John, D.Sc.Agr., 7 Futuna Street, Hunter's Hill (1923: P3).

IREDALE, Thomas, D.Sc., 8 Nulla Nulla Street, Turramurra (1943).

IZSAK, Dennis, 5 Ormond Gardens, Coogee (1961).

JACKSON, Robert James, M.A.(Q'ld.), M.B., Ch.M. (Syd.), Medical Practitioner, 132 Faulkner Street, Armidale (1961).

JAEGER, John Conrad, D.Sc., F.A.A., Geophysics Department, Australian National University, Canberra, A.C.T. (1942: P1).

JAMIESON, Helen Campbell, 3 Hamilton Street, Coogee (1951).

Jenkins, Thomas Benjamin Huw, Ph.D., Department of Geology and Geophysics, University of Sydney (1956).

Jones, James Rhys, 25 Boundary Road, Mortdale (1959).

Jones, Robin Marie (Mrs.), B.Sc., Imperial College of Science and Technology, London (U.K.) (1963 : P2).

Joplin, Germaine Anne, D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T. (1935 : P10).

Keane, Austin, Ph.D., Professor of Mathematics, Wollongong University College, Wollongong (1955 : P4).

Kemp, William Ronald Grant, B.Sc., Physicist, 16 Fig Tree Street, Lane Cove (1960).

*Kenny, Edward Joseph, 65 Park Avenue, Ashfield (1924 : P1).

Kimble, Frank Oswald, 31 Coronga Crescent, Killara (1948).

Kimble, Jean Annie, B.Sc., 383 Marrickville Road, Marrickville (1943).

*Kirchner, William John, B.Sc., " Fairways ", Linkview Avenue, Blackheath (1920).

Kitamura, Torrence Edward, B.A., B.Sc.Agr., Special Agronomist, N.S.W. Department of Agriculture, Sydney (1964).

Koch, Leo E., D.Phil.Habil., School of Applied Geology, University of New South Wales, Kensington (1948).

Krysko v. Tryst, Moiren (Mrs.), School of Applied Geology, University of New South Wales, Kensington (1959).

Lambeth, Arthur James, B.Sc., " Talanga ", Picton Road, Douglas Park, N.S.W. (1939 : P3).

Landecker, Kurt, D.Ing.(Berlin), Department of Physics, University of New England, Armidale (1961).

Lassak, Erich Vincent, B.Sc.(Hons.), A.S.T.C., Research Chemist, 167 Berowra Waters Road, Berowra (1964).

Lawrence, Laurence James, D.Sc., Ph.D., Associate Professor, School of Applied Geology, University of New South Wales, Kensington (1951 : P3).

Leach, Stephen Laurence, B.Sc., c/o Taubmans Industries Ltd., P.O. Box 91, Chatswood (1936).

Leaver, Gaynor Eiluned (Mrs.), B.Sc.(Wales), F.G.S. (Lond.), 30 Ingalara Avenue, Wahroonga (1961).

Le Fevre, Raymond James Wood, D.Sc., F.R.S., F.A.A., Professor and Head of the School of Chemistry, University of Sydney (1947 : P2 ; President 1961).

Lemberg, Max Rudolph, D.Phil., F.R.S., F.A.A., Assistant Director, Institute of Medical Research, Royal North Shore Hospital, St. Leonards (1936 : P3 ; President 1955).

*Lions, Francis, Ph.D., Department of Chemistry, University of Sydney (1929 : P56 ; President 1946).

Lions, Jean Elizabeth (Mrs.), B.Sc., 160 Alt Street, Haberfield (1940).

Lloyd, James Charles, B.Sc., 1 Spurwood Road, Turramurra (1947).

Lockwood, William Hutton, B.Sc., c/o Institute of Medical Research, Royal North Shore Hospital, St. Leonards (1940 : P1).

Lovering, John Francis, Ph.D., Department of Geophysics, Australian National University, Canberra, A.C.T. (1951 : P4).

Low, Angus Henry, Ph.D., Department of Applied Mathematics, University of Sydney (1950 : P2).

Lowenthal, Gerhard, Ph.D., M.Sc., 17 Gnarbo Avenue, Carss Park (1959).

Lyons, Lawrence Ernest, Ph.D., Professor of Chemistry, University of Queensland, St. Lucia, Brisbane (1948 : P2).

Maccoll, Allan, M.Sc., Department of Chemistry, University College, Gower Street, London, W.C.1., England (1939 : P4).

McCarthy, Frederick David, Dip.Anthr., Principal, Australian Institute of Aboriginal Studies, Box 553, City P.O., Canberra, A.C.T. (1949 : P1 ; President 1956).

McClymont, Gordon Lee, B.V.Sc., Ph.D., Professor of Rural Science, University of New England, Armidale (1961).

McCoy, William Kevin, 86 Ave Da Republica, Macao, via Hong Kong. (1943).

McCullagh, Morris Behan, 23 Wallaroy Road, Edgecliff (1950).

McElroy, Clifford Turner, Ph.D., M.Sc., School of Applied Geology, University of New South Wales, Kensington (1949 : P2).

McGlynn, John Albert, B.Sc.(Hons.), Analyst, Department of Mines, N.S.W., Sydney (1964).

McGregor, Gordon Howard, 4 Maple Avenue, Pennant Hills (1940).

McKay, Maxwell Herbert, M.A., Ph.D., School of Mathematics, University of New South Wales, Kensington (1956 : P1).

McKern, Howard Hamlet Gordon, M.Sc., Senior Chemist, Museum of Applied Arts and Sciences, Harris Street, Broadway, Sydney (1943 : P11 ; President 1963).

McMahon, Barry Keys, B.Sc., Colorado School of Mines, Denver, Col., U.S.A (1961).

McMahon, Patrick Reginald, Ph.D., Professor of Wool Technology, University of New South Wales, Kensington (1947).

McNamara, Barbara Joyce (Mrs.), M.B., B.S., 167 John Street, Singleton, N.S.W. (1943).

Magee, Charles Joseph, D.Sc.Agr., 4 Alexander Parade, Roseville (1947 : P1 ; President 1952).

Males, Pamela Ann, 13 Gelding Street, Dulwich Hill (1951).

Manchester, Edward Gordon Haig, M.B., B.S.(Syd.), M.C.R.A., Radiologist, 4 Georges' Road, Vaucluse (1965).

Manser, Warren, B.Sc.(Syd.), L. A. Cotton School of Geology, University of New England, Armidale (1964).

Marsden, Joan Audrey, A.S.T.C.(Dip.App.Chem.), 203 West Street, Crow's Nest (1955).

Marshall, Charles Edward, D.Sc., Professor of Geology and Geophysics, University of Sydney (1949 : P1).

Meares, Harry John Devenish, 27 Milray Avenue, Wollstonecraft (1949).

*Mellor, David Paver, D.Sc., Professor of Inorganic Chemistry, University of New South Wales, Kensington (1929 : P25 ; President 1941).

Middlehurst, Jack, M.Sc., C.S.I.R.O., Division of Food Preservation, Delhi Road, North Ryde (1960).

Millership, William, M.Sc., 18 Courallie Avenue, Pymble (1940).

Minns, Robert William, Industrial Chemist, c/o O. T. Lempriere & Co. Ltd., Box 117, G.P.O., Sydney (1963).

MINTY, Edward James, M.Sc., B.Sc., Dip.Ed., 2 Dowel Street, Chatswood (1951 : P2).
MORGAN, Jascha Ann, M.Sc., Department of Zoology, University of New England, Armidale (1961).
MORRIS, Ronald James Huntbatch, M.Sc.(Melb.), Department of Physiology, University of New England, Armidale (1963).
*MORRISON, Frank Richard, 4 Mona Street, Wahroonga (1922 : P34 ; President 1950).
MORRISSEY, Matthew John, M.B., B.S., 152 Marsden Street, Parramatta (1941).
MORT, Francis George Arnot, 29 Preston Avenue, Fivedock (1934).
MOSHER, Kenneth George, B.Sc., 9 Yirgella Avenue, Killara (1948).
MOSS, Francis John, M.B., B.S., Department of Biochemistry, University of New South Wales, Kensington (1955).
MOYE, Daniel George, B.Sc., Chief Geologist, Snowy Mountains Hydro Electric Authority, Cooma, N.S.W. (1944).
*MURPHY, Robert Kenneth, Dr.Ing.Chem., 68 Pindari Avenue, North Mosman (1915).
MURRAY, Patrick Desmond Fitzgerald, D.Sc., F.A.A., Department of Zoology, University of New England, Armidale (1950).

NASHAR, Beryl, Ph.D., Associate Professor of Geology, University of Newcastle, Tighe's Hill, N.S.W. (1946 : P2).
*NAYLOR, George Francis King, Ph.D., Department of Psychology and Philosophy, University of Queensland, St. Lucia, Brisbane (1930 : P7).
*NEUHAUS, John William George, 32 Bolton Street, Guildford (1943).
NEWMAN, Ivor Vickery, Ph.D., Botany Department, University of Sydney (1932).
NEWMAN, Thomas Montague (1962).
NOAKES, Lyndon Charles, B.A., Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1945 : P1).
*NOBLE, Robert Jackson, Ph.D., 32a Middle Harbour Road, Lindfield (1920 : P4 ; President 1934).
NYHOLM, Ronald Sydney, D.Sc., F.R.S., Professor of Inorganic Chemistry, University College, Gower Street, London, W.C.1., England (1940 : P26 ; President 1954).

O'FARRELL, Antony Frederick Louis, A.R.C.Sc., B.Sc., Professor of Zoology, University of New England, Armidale (1961).
OLD, Adrian Noel, B.A., B.Sc.Agr., Senior Chemist, N.S.W. Department of Agriculture, p.r. 13 Fallon Street, Rydalmere (1947).
OXENFORD, Reginald Augustus, B.Sc., 75 Alice Street, Grafton, N.S.W. (1950).

PACKHAM, Gordon Howard, Ph.D., Department of Geology and Geophysics, University of Sydney (1951 : P4).
*PENFOLD, Arthur Ramon, Flat 516, Baroda Hall, 6A Birtley Place, Elizabeth Bay (1920 : P82 ; President 1935).
PERRY, Hubert Roy, B.Sc., 74 Woodbine Street, Bowral, 1S, N.S.W. (1948).
PHILIP, Graeme Maxwell, M.Sc.(Melb.), Ph.D. (Cantab.), F.G.S., Professor of Geology, University of New England, Armidale (1964).
PHILLIPS, Marie Elizabeth, Ph.D., 16 Lawley Place, Deakin, A.C.T. (1938).
PHIPPS, Charles Verling Gayer, Ph.D., Department of Geology and Geophysics, University of Sydney (1960).
PICKETT, John William, M.Sc.(N.E.), Dr.phil.nat. (Frankfurt/M), Palaeontologist, N.S.W. Geological Survey, Mining Museum, 28 George Street North, Sydney (1965).
PINWILL, Norman, B.A., The Scots College, Victoria Road, Bellevue Hill (1946).
PLUMMER, Brian Alfred George, M.A., F.R.G.S., Department of Geography, University of New England, Armidale (1961).
POGGENDORFF, Walter Hans George, B.Sc.Agr., Chief, Division of Plant Industry, N.S.W. Department of Agriculture, Box 36a, G.P.O., Sydney (1949).
POLLARD, John Percival, Dip.App.Chem.(Swinburne), Mathematician with the Australian Atomic Energy Commission ; p.r. 25 Nabiac Avenue, Gymea (1963).
*PRICE, William Lindsay, B.Sc., 107 Spring Street, Killara (1927).
PRIDDLE, Raymond Arthur, B.E., 34 Cleveland Street, Wahroonga (1956).
PRIESTLEY, John Henry, M.B., B.S., B.Sc., Medical Practitioner, 137 Dangar Street, Armidale (1961).
PROKHOVNIK, Simon Jacques, B.A., B.Sc., School of Mathematics, University of New South Wales, Kensington (1956 : P3).
*PROUD, John Seymour, B.E., Finlay Road, Turramurra (1945).
PUTTOCK, Maurice James, B.Sc.(Eng.), A.Inst.P., Principal Research Officer, C.S.I.R.O., Sydney, p.r. 2 Montreal Avenue, Killara (1960).
PYLE, John Herbert, B.Sc., Analyst, Mines Department, N.S.W., Sydney (1958).

*QUODLING, Florrie Mabel, Ph.D., B.Sc., 145 Midson Road, Epping (1935 : P5).

RADE, Janis, M.Sc., Box 28a, 601 St. Kilda Road, Melbourne (1953 : P6).
*RAGGATT, Sir Harold George, Kt., C.B.E., D.Sc., F.A.A. 60 Arthur Circle, Forrest, A.C.T. (1922 : P8).
RAMM, Eric John, Experimental Officer, Australian Atomic Energy Commission, Lucas Heights, N.S.W. (1959).
*RANCLAUD, Archibald Boscawen Boyd, B.E., 79 Frederick Street, Merewether, N.S.W. (1919: P3).
*RAYNER, Jack Maxwell, O.B.E., B.Sc., Director, Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1931 : P1).
READ, Harold Walter, B.Sc., c/o B.H.P. Prospecting Party, Groote Eylandt, N.T. (1962).
REICHEL, Alex, Ph.D., M.Sc., Department of Applied Mathematics, University of Sydney (1957 : P4).
RICE, Thomas Denis, B.Sc., 24 Alliott Street, Campbelltown, N.S.W. (1964).
RIGBY, John Francis, B.Sc.(Melb.), Geology Department, University of Newcastle, Tighe's Hill, 2N. (1963).
RIGGS, Noel Victor, B.Sc.(Adel.), Ph.D.(Cantab.), F.R.A.C.I., Associate Professor of Organic Chemistry, University of New England, Armidale (1961).
RITCHIE, Arthur Sinclair, M.Sc., Senior Lecturer in Geology, University of Newcastle, Tighe's Hill, 2N. (1947 : P2).
RITCHIE, Ernest, D.Sc., F.A.A., Chemistry Department, University of Sydney (1939 : P19).

ROBBINS, Elizabeth Marie (Mrs.), M.Sc., Waterloo Road, North Ryde (1939: P3).

ROBERTS, Herbert Gordon, Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1957).

ROBERTS, John, Ph.D., Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1961: P3).

ROBERTSON, William Humphrey, B.Sc., c/o Sydney Observatory, Sydney (1949: P24).

ROBINSON, David Hugh, 12 Robert Road, West Pennant Hills (1951).

ROSENBAUM, Sydney, 5 Eton Road, Lindfield (1940).

ROSENTHAL-SCHNEIDER, Ilse, Ph.D., 48 Cambridge Avenue, Vaucluse (1948).

ROSS, Victoria (Mrs.), B.Sc.(Hons.), "Merroo", Mill Road, Kurrajong (1960).

ROUNTREE, Phyllis Margaret, D.Sc., Royal Prince Alfred Hospital, Sydney (1945).

ROYLE, Harold George, M.B., B.S.(Syd.), 161 Rusden Street, Armidale (1961).

*SCAMMELL, Rupert Boswood, B.Sc., 10 Buena Vista Avenue, Clifton Gardens (1920).

SCHOLER, Harry Albert Theodore, M.Eng., Civil Engineer, c/o Harbours and Rivers Branch, Public Works Department, Phillip Street, Sydney (1960).

SCOTT, John Alan Belmore, B.Sc.(Q'ld.), 28 Duncan Street, Punchbowl (1964).

SEE, Graeme Thomas, B.Sc., School of Applied Geology, University of New South Wales, Kensington (1949).

SELBY, Edmond Jacob, Box 175D, G.P.O., Sydney (1933).

*SHARP, Kenneth Raeburn, B.Sc., c/o S.M.H.E.A., Cooma, N.S.W. (1948).

SHERRARD, Kathleen Margaret (Mrs.), M.Sc., 43 Robertson Road, Centennial Park (1936: P6).

SHERWOOD, Arthur Alfred, B.Sc.(Eng.), Department of Mechanical Engineering, University of Sydney, p.r. 9 Whitton Road, Chatswood (1959: P1).

SIMMONS, Lewis Michael, Ph.D., The Scots College, Victoria Road, Bellevue Hill (1945: P3).

SIMONETT, David Stanley, Ph.D., Assistant Professor of Geography, University of Kansas, Lawrence, Kansas, U.S.A. (1948: P3).

SIMS, Kenneth Patrick, B.Sc., 25 Fitzpatrick Avenue East, French's Forest (1950: P12).

SLADE, George Hermon, B.Sc., W. Hermon Slade & Co. Pty. Ltd., Mandemar Avenue, Homebush (1933).

SLADE, Milton John, B.Sc., Dip.Ed.(Syd.), M.Sc.(N.E.), 20 Dobie Street, Grafton (1952).

SMITH, Ann Ruth (Mrs.), B.Sc., Box 134, P.O., Queenstown, Tasmania (1959).

SMITH, Glennie Forbes, B.Sc., Box 134, P.O., Queenstown, Tasmania (1962).

SMITH, William Eric, Ph.D.(N.S.W.), M.Sc.(Syd.), B.Sc.(Oxon.), School of Applied Mathematics, University of New South Wales, Kensington (1963: P1).

SMITH-WHITE, William Broderick, M.A., Associate Professor, Department of Mathematics, University of Sydney (1947: P4; President 1962).

*SOUTHEE, Ethelbert Ambrook, O.B.E., M.A., Trelawney Street, Earlwood (1919).

SPITZER, Hans, Dr.Phil(Vienna), Senior Research Chemist, Monsanto Chemicals (Aust.) Ltd., Rozelle; p.r. 35 Redan Street, Mosman (1961).

STANTON, Richard Limon, Ph.D., Associate Professor of Geology, University of New England, Armidale (1949: P2).

STAPLEDON, David Hiley, B.Sc., 61 Francis Street, Brighton, South Australia (1954).

*STEPHENS, Frederick G. N., M.B., Ch.M., 133 Edinburgh Road, Castlecrag (1914).

STEPHENS, James Norrington, M.A.(Cantab.), Ph.D., 170 Brokers Road, Mt. Pleasant, Wollongong (1959).

STEVENS, Eric Leslie, B.Sc., Lot 17, Chaseling Avenue, Springwood (1963).

STEVENS, Neville Cecil, Ph.D., Geology Department, University of Queensland, St. Lucia, Brisbane (1948: P5).

STEVENSON, Barrie Stirling, B.E.(Mech. and Elec.), (Syd.), 21 Glendower Avenue, Eastwood (1964).

STOCK, Alexander, D.Phil., Ph.D., Associate Professor of Zoology, University of New England, Armidale (1961).

STOKES, Robert Harold, Ph.D., D.Sc., F.A.A., 45 Garibaldi Street, Armidale (1961).

*STONE, Walter George, 26 Rosslyn Street, Bellevue Hill (1916: P1).

STRUSZ, Desmond Leslie, Ph.D., B.Sc., Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1960: P3).

STUNTZ, John, B.Sc., 11 Jackson Crescent, Pennant Hills (1951).

SURRY, Charles, 11 Helena Street, Randwick (1961).

SWANSON, Thomas Baikie, M.Sc., Technical Service Department, I.C.I.A.N.Z., Box 1911, G.P.O., Melbourne (1941: P2).

SWINBOURNE, Ellice Simmons, Ph.D., 69 Peacock Street, Seaforth (1948).

TAYLOR, Nathaniel Wesley, M.Sc.(Syd.), Ph.D.(N.E.), Department of Mathematics, University of New England, Armidale (1961).

THEW, Raymond Farly, 88 Braeside Street, Wahroonga (1955).

THOMAS, Penrhyn Francis, Suite 22, 3rd Floor, 29 Market Street, Sydney (1952).

THOMSON, David John, B.Sc., Geologist, 61 The Bulwark, Castlecrag (1956).

THOMSON, Vivian Endel, B.Sc., Geology Department, Wollongong University College, Wollongong (1960).

THURSTAN, Arthur Wyngate, A.S.T.C., A.R.A.C.I., Metallurgist, 99 Stoney Creek Road, Beverly Hills (1964).

THWAITE, Eric Graham, B.Sc., 8 Allars Street, West Ryde (1962).

TICHAUER, Erwin R., D.Sc.(Tech.), Dipl.Ing., Department of Industrial Engineering, Texas Technological College, Lubbock, Texas, U.S.A. (1960).

TOMPKINS, Denis Keith, Ph.D., M.Sc., Department of Geology and Geophysics, University of Sydney (1954: P1).

TOW, Aubrey James, M.Sc., c/o Community Hospital, Canberra, A.C.T. (1940).

TREBECK, Prosper Charles Brian (1949).

UNGAR, Andrew, Dr.Ing., 6 Ashley Grove, Gordon (1952).

VALLANCE, Thomas George, Ph.D., Associate Professor, Department of Geology and Geophysics, University of Sydney (1949: P2).

VAN DIJK, Dirk Cornelius, D.Sc.Agr., c/o C.S.I.R.O. Division of Soils, Cunningham Laboratory, St. Lucia, S.W.6, Queensland. (1958).

VEEVERS, John James, Ph.D., Bureau of Mineral Resources, Geology and Geophysics, Canberra, A.C.T. (1953).

VERNON, Ronald Holden, M.Sc., Department of Geology and Geophysics, University of Sydney (1958 : P1).

VICKERY, Joyce Winifred, M.B.E., D.Sc., 17 The Promenade, Cheltenham (1935).

VOISEY, Alan Heywood, D.Sc., Professor of Geology and Head of the School of Earth Sciences, Macquarie University, Eastwood (1933 : P11).

*VONWILLER, Oscar U., B.Sc., Emeritus Professor, Rathkells, Kangaroo Valley, N.S.W. (1903 : P10 ; President 1940).

WALKER, Donald Francis, 13 Beauchamp Avenue, Chatswood (1948).

WALKER, Patrick Hilton, M.Sc.Agr., Research Officer, C.S.I.R.O., Division of Soils, Canberra, A.C.T. (1956 : P3).

*WALKOM, Arthur Bache, D.Sc., 5/521 Pacific Highway, Killara (1919 and previous membership 1910–1913 : P2 ; President 1943).

WARD, Judith (Mrs.), B.Sc., 50 Bellevue Parade, New Town, Hobart, Tasmania (1948).

*WARDLAW, Hy. Sloane Halcro, D.Sc., 71 McIntosh Street, Gordon (1913 : P5 ; President 1939).

WASS, Robin Edgar, B.Sc.(Hons.), (Q'ld.), Department of Geology and Geophysics, University of Sydney (1965 : P1).

*WATERHOUSE, Lionel Lawry, B.E., 42 Archer Street, Chatswood (1919 : P1).

*WATERHOUSE, Walter L., C.M.G., M.C., D.Sc.Agr., F.A.A., 30 Chelmsford Avenue, Lindfield (1919 : P7 ; President 1937).

WATTON, Edward Charlton, B.Sc.(Hons.), A.S.T.C., School of Chemistry, University of New South Wales, Kensington (1963).

WENHAM, Russell George, B.Sc., B.E., 17 Fortescue Street, Bexley North (1960).

WEST, Norman William, B.Sc., c/o Department of Main Roads, Sydney (1954).

WESTHEIMER, Gerald, Ph.D., University of California, School of Optometry, Berkeley 4, California, U.S.A. (1949).

WHITLEY, Alice, M.B.E., Ph.D., 39 Belmore Road, Burwood (1951).

WHITLEY, Gilbert Percy, F.R.Z.S., Honorary Associate of the Australian Museum, College Street, Sydney (1963).

WHITWORTH, Horace Francis, M.Sc., c/o The Mining Museum, George Street North, Sydney (1951 : P4).

WILKINS, Coleridge Anthony, Ph.D., M.Sc., Department of Mathematics, Wollongong University College, Wollongong (1960 : P1).

WILKINSON, John Frederick George, M.Sc.(Q'ld.), Ph.D.(Cantab.), Associate Professor of Geology, University of New England, Armidale (1961 : P1).

WILLIAMS, Benjamin, 12 Cooke Way, Epping (1949).

WILLIAMSON, William Harold, M.Sc., 6 Hughes Avenue, Ermington (1949).

WOOD, Clive Charles, Ph.D., B.Sc. (1954).

WOOD, Harley Weston, D.Sc., M.Sc., Government Astronomer, Sydney Observatory, Sydney (1936 : P15 ; President 1949).

WRIGHT, Anthony James, B.Sc., Department of Geology, Victoria University of Wellington, Wellington, N.Z. (1961).

WYLIE, Russell George, Ph.D., M.Sc., Physicist, National Standards Laboratory, University Grounds, City Road, Chippendale (1960).

YATES, Harold, M.Sc.(Syd.), 102 Eyre Street, Ballarat, Victoria (1962).

YEATES, Neil Tolmie McRae, D.Sc.Agr.(Q'ld.), Ph.D. (Cantab.), Associate Professor of Livestock Husbandry, University of New England, Armidale (1961).

Associates

COLLINS, Angus Robert, 16 Hull Road, Beecroft (1965).

DENTON, Norma (Mrs.), Bunarba Road, Miranda (1959).

DONEGAN, Elizabeth (Mrs.), 18 Hillview Street, Sans Souci (1956).

EMERY, Hilary Mary Myvanwy (Mrs.), 8 Havelock Parade, Wynnum, Queensland. (1965).

FLOOD, Richard Henry, B.Sc.(Hons.), Wright College, University of New England, Armidale (1965).

GORMAN, Helen Anne, B.Sc., Department of Geology, University of New England, Armidale (1965).

GRIFFITH, Elsie A. (Mrs.), 9 Kanoona Street, Caringbah (1956).

GUNTHORPE, Robert John, B.Sc.(Hons.), Department of Geology, University of New England, Armidale (1965).

LEAVER, Harry, B.A., B.Sc., M.B., Ch.M., M.R.C.O.G., F.G.S., 30 Ingalara Avenue, Wahroonga (1962).

LE FEVRE, Catherine Gunn, D.Sc.(Lond.), 6 Aubrey Road, Northbridge (1961).

McCLYMONT, Vivienne Cathryn, B.Sc., Handel Street, Armidale (1961).

MORGAN, James Albert, Flat 5, "Sunnyville", 54 Hopewell Street, Paddington (1961).

NICHOLLS, Anthony Oldham, Wright College, University of New England, Armidale (1965).

ROSENTHAL, Hans Samuel Arthur, Dr.Ing.(Berlin), Consulting Engineer, 48 Cambridge Avenue, Vaucluse (1961).

SHERWOOD, Joan (Mrs.), 9 Whitton Road, Chatswood (1962).

STANTON, Alison Amalie (Mrs.), B.A., 35 Faulkner Street, Armidale (1961).

STOKES, Jean Mary (Mrs.), M.Sc., 45 Garibaldi Street, Armidale (1961).

WATSON, Helen Jean, Mary White College, University of New England, Armidale (1965).

WEST, Kenneth Norman, 109 Artarmon Road, Artarmon (1965).

WOODBURN, Timothy Lewis, Botany Department, University of New England, Armidale (1965).

Obituary

1964 - 65	1965 - 66
Victor A. BAILEY (1924)	Robert L. CORBETT (1933)
John R. BARDSLEY (1919)	Thomas J. HOLM (1952)
Frederick A. COOMBS (1913)	Charles W. R. POWELL (1921)
Kenneth P. FORMAN (1932)	George F. SUTHERLAND (1919)
Anthony G. FYNN (1959)	Harold B. TAYLOR (1915)
Jack M. SOMERVILLE (1959)	Sir Robert D. WATT (1911)

Robert Lorimer Corbett, who died on 14th December, 1965, came of a very old noble Scottish family which lost most of its position and importance when his forbears joined the Covenantors. A man of strong faith and courage, he pioneered the manufacture in Australia of many basic chemicals which were themselves basic to the production of other materials and he was, therefore, directly responsible for the establishment here of many secondary industries which have contributed largely to the development of the nation.

At the very early age of 21 years, he commenced business on his own account with a partner in Melbourne, importing and marketing a wide range of chemicals and allied products and developing a considerable turnover. However, Mr. Corbett withdrew from this company in 1925, selling his shares to his partner, and came to Sydney to establish his own private business under the title of Robert Corbett & Company. His capital then was £1500. In 1939 the capital of the company had increased to £1,000,000. Besides a wide range of manufacturers, the Corbett company was acting as the local distributor for several very large overseas organizations and in addition indenting on its own account many complementary materials. It therefore literally fulfilled its slogan " Chemicals for all Industries " which became synonymous with the name of Corbett in the chemical trade of this country and overseas. It was, however, in the field of manufacturing that Mr. Corbett made his major contribution to the stability and future of his country.

When Australian dried fruits upon arrival overseas were continually found to be infested with various pests, and unsaleable, it was his company which evolved and produced fumigants giving 100% kill which resulted in the firm establishment of the export trade in these primary products. His company pioneered the production here of Acetone, commencing this operation before World War II in the realisation of the importance this material would have in the event of hostilities. It was his company also which produced the solvents necessary for the local manufacture of Penicillin, and many other notable developments can be put to the credit of this quiet, unobtrusive citizen.

Mr. Corbett is survived by his widow, son and two daughters.

His election to membership of the Society took place in 1933.

Thomas John Holm died suddenly on 22nd November, 1965 at the age of fifty-two. He was elected to membership of the Society in 1952.

Mr. Holm was born in 1913, attended Fort Street High School, and later studied geology under Dr. G. D. Osborne at Sydney Technical College. He was engaged for many years in the motor body building industry, but was keenly interested in geology as a hobby. He was a regular attendant at meetings of the Society, and of the Section of Geology. He was a lay-reader at St. Andrew's Cathedral, Sydney.

Mr. Holm's other interests included: teaching the guitar; speleology, especially at Jenolan Caves, of which he had a very good knowledge; photography —he was a keen amateur; Returned Servicemen's activities—he assisted in the organisation of Anzac Day marches and other events. He was also a regular donor of blood to the Blood Bank (having given over 100 pints), and was an honorary driver for the same organisation.

Mr. Holm will be remembered for his friendliness, love of children, and his constant desire to help everyone he knew to the utmost of his ability.

Charles Wilfred Roberts Powell, a member of the Society since 1921, died in Sydney on 24th June, 1965.

In 1908 Mr. Powell joined the Colonial Sugar Refining Co. Ltd. as a chemist. In 1912 and 1913 he attended the University of Sydney on a Science Research scholarship. His research work was published in the following journals—Journal of the Chemical Society, London; Journal of the Society of Chemical Industry, London; Journal and Proceedings of the Royal Society of New South Wales. At that time he was working with Professor G. E. Fawsitt.

Mr. Powell enlisted for active service in 1916 and on proceeding overseas was transferred to the Munitions Department and was in charge of the Gretna factory for two years.

On returning he was appointed Refinery Inspector and in January, 1933, he was appointed a Senior Executive officer, and was responsible for establishing four major building materials industries, each new to Australia apart from the development of existing processes. He contributed greatly to the growth and efficiency of the Refinery Division.

He made numerous trips overseas as a representative of the company, initially in the sphere of sugar technology, and later with building materials activities.

Mr. Powell had completed 43 years with the C.S.R. Co. Ltd. when he retired in 1951.

Mr. Powell was a remarkable man of energy and vision and coupled with his extraordinary memory, made him a most interesting companion.

Two papers by Mr. Powell were published in the " Journal and Proceedings ".

George Fife Sutherland, a member of the Society since 1919, was born in Aberdeen, Scotland, on 1st January, 1883, and lost his father when only three years old. Although his mother was not left destitute it was evident that George and the other children of the family would have to work for anything they wanted to become.

Mr. Sutherland received his early education at Robert Gordon's College, Aberdeen. He became apprenticed to James Abernethy & Co., Engineers, Ferryhill Foundry, Aberdeen, in February, 1898. He was allowed to break off his apprenticeship in December, 1902, as he wished to devote his time to study for a " Whitworth " Exhibition. This Exhibition took him to the Royal College of Science, London (now the Imperial College of Science), where he spent three years (1903–1906).

At the end of this course, as his idea was to become a teacher of engineering design rather than a practical engineer, he was recommended to a school for the special training of teachers of scientific subjects, tertiary standard. For gaining top place in the year he was awarded the Queen's Prize.

To gain experience in various branches of engineering he took short term jobs at such places as Humbers Ltd., Motor Car Manufacturers ; an arsenal ; Fairfields Shipbuilding and Engineering Co. Ltd., and, also, a place making weaving machinery.

In 1911 he became a teacher in the Engineering Section of the Barrow-in-Furness Technical College, Wales, where he had charge of the Mechanics classes and practical work in the Mechanics laboratory, also Heat Engine classes. In the machines and hydraulics examination his class, collectively, had the best pass from all over Britain and one of his students won a King's Prize in that subject.

In 1912 Mr. Sutherland came to Australia to take up a lectureship in Mechanical Engineering at Sydney University and later became an Assistant Professor. On two occasions he was Acting Professor during the absence overseas of the Professor. He retired from the University in 1947 but did part time lecturing for a further five years to relieve the rush of post-war students.

During his forty years at Sydney University he took great interest in the University Union, being President on two occasions and Senate Representative on the Board of Directors for over twenty years. Also he was curator of the War Memorial Carillion until his retirement.

Mr. Sutherland was an Associate Member of the Institution of Mechanical Engineers, England ; a Member of the Institution of Engineers, Australia ; and University representative on the Standards Association of Australia. He died on 26th September, 1965.

Harold Burfield Taylor, who died on 15th March, 1966, was born in Sydney on 10th August, 1890. He was educated at Sydney High School and at Sydney University. After graduation, he joined the State Department of Public Health.

Brigadier Taylor served in the 19th Battalion, A.I.F., World War I, 1914–1918. After his return to Australia in 1919 he obtained the degree of D.Sc.

He was Commandant University of Sydney Regiment 1925–29 ; 18th Battalion 1929–34 ; 30th Battalion N.S.W. Scottish Regiment 1934–39 ; 5th Infantry Brigade 1939–40.

In 1940, he was World War II Commandant 22nd Australian Infantry Brigade. Brigadier Taylor fought through the Malayan Campaign and was taken prisoner of war at Singapore in 1942.

He returned to Australia in 1945 and resumed his work at the State Department of Public Health and was appointed State Government Analyst in 1946 which position he held until his retirement in 1954.

Brigadier Taylor was a member of Standards Association of Australia and consultant in Industrial Chemical Problems.

He was elected to membership of the Society in 1915 and had had three papers published in the " Journal and Proceedings ".

Emeritus Professor Sir Robert Watt. On the 10th April, 1965, Emeritus Professor Sir Robert Dickie Watt, the first Professor of Agriculture in the University of Sydney, died at the age of 83 years.

Sir Robert was born on April 23rd, 1881 in Ayrshire, Scotland, and graduated from Glasgow University as Master of Arts and Bachelor of Science in Agriculture. He was also awarded a National Diploma in Agriculture with First Class Honours.

In 1907 he went to the Transvaal where he became Chief Chemist in the Department of Agriculture.

In 1910 he accepted the appointment to the new Chair of Agriculture at the University of Sydney and became the first full-time Professor of Agriculture in Australia. The story of his early struggles to overcome the prejudices of the traditional faculties, and his difficulty with accommodation for lectures and practical work for his students have become part of the history of the Faculty. When the Faculty of Agriculture was established in 1920 he became its Dean, an office he held until he retired.

Sir Robert was a Fellow of the Senate of the University in 1934 and 1935, and again in 1946 and 1947. He was awarded the Farrer Medal by the Farrer Memorial Trust in 1950, which award is just one indication of the recognition he received for his untiring endeavours in the field of Agricultural Science. He was held in high regard by all his students, and even after retiring from his professional duties in 1946 he kept up an active interest in agriculture and in the work of the Faculty of Agriculture at the University. He has published many articles which have proved to be and will continue to be of valuable reference to those in the Faculty who under his guidance are striving for greater efficiency in rural production in this country. His book, " The Romance of the Australian Land Industries ", published in 1955, is regarded by members of the agricultural profession as a classic.

In February, 1947 the Faculty of Agriculture placed on record its appreciation of the work done for the Faculty by Sir Robert during the 37 years he had been Professor of Agriculture and 27 years as Dean of the Faculty with the following words. " As the first full-time Professor of Agriculture in Australia he was responsible for formulating and establishing a university course in agriculture in this country. Throughout the years many students have passed through his hands, and graduates have brought honour to the University in this and other lands. His influence has thus been felt throughout the agricultural and educational community and Australia is richer for his labours."

Sir Robert Watt was knighted in 1960 for his services to agriculture and is regarded as one of Australia's most distinguished scientists.

Outside the University and outside his field of agriculture, Sir Robert Watt gave service to the community as an Elder of St. Stephen's Presbyterian Church for 35 years.

Sir Robert contributed much to Australia and will long be remembered by his students and the community.

He is survived by Lady Watt and one daughter, Marnie, wife of Professor Yeates of the University of New England.

Professor Sir Robert Watt had been associated with the Society for many years having been elected to membership in 1911. He was a member of Council during 1921–1924; was elected President in 1925 and was Vice-President for the years 1926, 1928–1932. One paper was published in the " Journal and Proceedings ".

JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY OF NEW SOUTH WALES

VOLUME 100 — 1966 — PARTS 3 and 4

CONTENTS

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Papers should be prepared according to the general style adopted in this Journal. They should be as concise as possible, consistent with adequate presentation. Particular attention should be given to clarity of expression and good prose style.

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The approximate positions of Figures, Plates and Tables should be indicated in the text between parallel ruled lines. Captions of Figures and Plates should be typed on a separate sheet.

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Journal and Proceedings, Royal Society of New South Wales, Vol. 100, pp. 105–118, 1966

Centenary Oration*

The Challenge to Science, 1866 ; the Challenge of Science, 1966

DELIVERED TO THE ROYAL SOCIETY OF NEW SOUTH WALES

BY

EMERITUS PROFESSOR A. P. ELKIN, C.M.G., M.A., Ph.D.

IN THE HALL OF SCIENCE HOUSE

Friday, 28th October, 1966

PART I

THE CHALLENGE *TO* SCIENCE, 1866

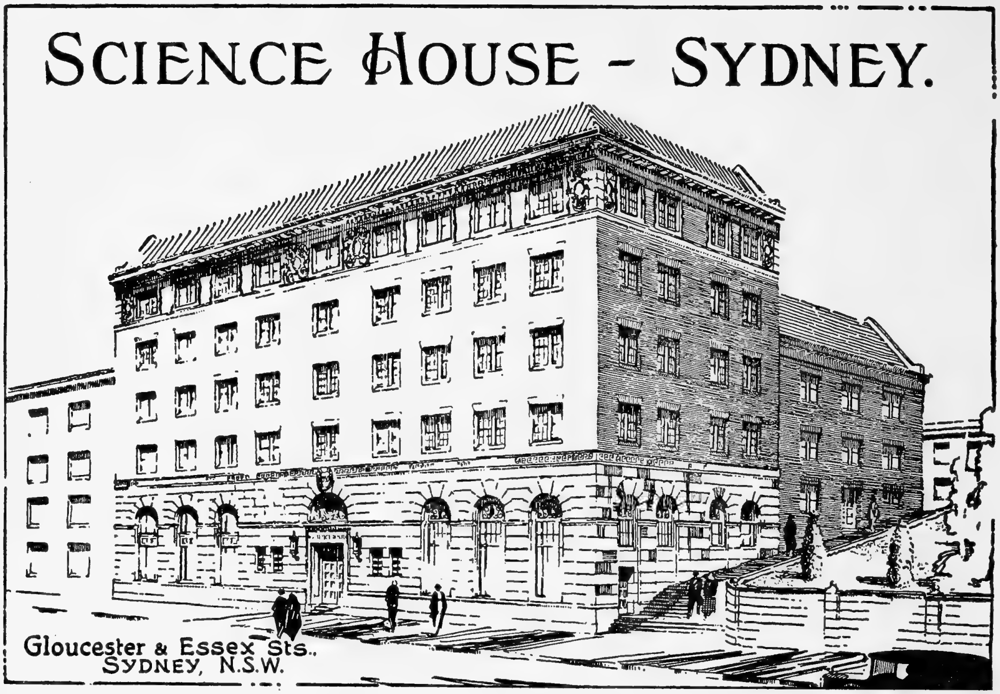
The Vision of Solomon's House

The philosopher-scientist Francis Bacon near the end of his life had a vision. It was of a kingdom, the New Atlantis. In it the King instituted an order or society, called Solomon's House, " the noblest foundation, as we think, that ever was upon the earth, and the lanthorn " of the kingdom. Its object was to reveal " the true nature of all things "—to come to a knowledge of their causes and secret motions, and so to increase the use of all things possible for the good of men. As a means to this end, two ships were to be sent every twelve years " to several voyages ", with three of the fellows or brethren of Solomon's House in each ship. Their mission was to obtain knowledge " especially of the sciences, arts, manufactures and inventions of all the world ".

Little did Bacon dream that such a ship would be sent about 150 years later from the kind of society he envisaged to bring back knowledge, not only of the " secret motions " of heavenly bodies, but also of the sure existence of a new continent, Australia.

He died in 1626. His emphasis on observation, induction and experiment, and his vision of scientific expeditions may have seemed to fade away with him under the political cloud which enveloped the one-time Lord Chancellor of England. But this was not so. The tumults, wars and proscriptions of the second third of the 17th century had, in Macaulay's words, " stimulated the faculties of the educated classes, and had called forth a restless activity and an insatiable curiosity such as had not before been known among us ". Many busied themselves with framing constitutions for a republican era, but a few, withdrawing from the distractions and wasteful futilities of civil strife, devoted themselves to scientific inquiry. Amongst them were Boyle and Harvey, Napier and Newton, a quartette surely constituting " the noblest lanthorn in the Kingdom ". No wonder that from the meetings of such men in the Bull's Head Tavern the Royal Society of London came into being—a veritable Solomon's House. It was royally founded when it received its charter in 1662 from the new monarch, Charles II. Its objective was the promotion of the experimental method of natural science as distinguished from supernatural arts, e.g. witchcraft and divination.

The times were propitious. With the collapse of the Cromwellian Commonwealth, the revolutionary spirit of that period ceased to operate in politics and began to exert itself with unprecedented vigour and hardihood in natural science. In Macaulay's phrase, divines, jurists, statesmen, princes and even the King himself " swelled the triumph of the Baconian philosophy ". Poets sang of the approach of a new golden age. Dryden foretold things which, in the opinion of that same historian, neither he nor anyone else understood. The Royal



Science House—the home of the Royal Society of New South Wales since 1931. The building won the Sulman Award for Architecture in 1932.

Society, Dryden predicted in his *Annus Mirabilis*, would soon lead us to the last verge of the globe and

"From thence our rolling neighbours we shall know,
And on the lunar world securely pry."

We of these latter days admit that the poet's imaginative flight was not altogether astray, but without at once making a soft landing on the moon, we record that the Royal Society of London, just over a century after its foundation, induced the King and the Admiralty to send a ship from Solomon's House, as Bacon would have said, in search of knowledge to the "globe's last verge". The primary destination was Tahiti, an island set in a vast ocean, little known to the Western world. And the purpose! The observation of the transit of Venus in June, 1769, "as the foundation for calculations which would determine the distance of the earth from the sun".

The Royal Society commissioned James Cook, with the co-operation of the Admiralty, to undertake the project. He had shown, in a report on an eclipse of the sun in 1766 observed in New Foundland waters, that he "was a good mathematician and very expert in his business". In addition, the Admiralty gave him instructions, marked secret, that having finished the astronomical task, he was to sail south and west to discover in the south seas a "Continent of Land of great extent" which there was "reason to imagine" did exist. If he found it, he was to observe and report on its soil and precious metals, beasts, birds and plants, and on its natives, and to take possession of it. Thus the Admiralty and Cook, probably quite unwittingly, were carrying out Bacon's principle (defined in his *Novum Organum*) that "the true and legitimate goal of the Sciences is none other than this, to endow human life with new discoveries and resources".

So James Cook, whose accustomed business was in the great waters, and whose eyes were ever scanning the heavens, sailed by way of the Antarctic to Tahiti, New Zealand and then westward until the eastern coast of Australia arose before European eyes.

Cook's mission was scientific—to make contributions to astronomy, geographical discovery and natural history. He had with him an experienced astronomer and also as

" paying guests " Joseph Banks and his suite. Banks was wealthy and young, a Fellow of the Royal Society and a keen botanist. His suite included the " ablest botanist in England ", Dr. D. C. Solander, F.R.S. Wherever the *Endeavour* touched land, these two went into " the woods botanizing as usual ", nowhere with greater success than at Botany Bay.

Nine years later Banks recommended Botany Bay to a committee of the House of Commons as a satisfactory site for a penal colony. His opinion was weighty, for in addition to having been in New Holland, he was now (since 1778) President of the Royal Society.

The First Fleet arrived there in 1788, but thanks to the wise judgment of Captain Phillip moved on to Port Jackson. The small settlement soon augmented by further shiploads of men and some women, mostly convicts, experienced short rations and other stresses and strains during its first twenty years. Supplies from England, over four months away, were neither regular nor sufficient. So search had to be made for farming and grazing land, and a watchful eye kept for minerals that might be a source of revenue. That is, the very existence of the settlement put out a challenge to natural history ; it depended on the results of exploration, on gaining a knowledge of the environment, of its soils, waters, climate, plants and animals. This implied observation and collecting, and in this the spirit of Banks overshadowed the Colony. His collecting urge was infectious. Every vessel from New South Wales took to him botanical, zoological, geological and anthropological specimens. Governors assisted, White and Considin, surgeons with the First Fleet, and Robert Brown and George Caley in the first decade of the 19th century were amongst those who collected for him. Allan Cunningham did likewise in the 1820's for Kew Gardens. In addition, three French expeditions, each with its team of naturalists, visited the Colony between 1802 and 1829. And all were rewarded ; for though the regions traversed did not flow with milk and honey, but rather challenged

Elizabeth House, 5 Elizabeth Street, Sydney—the home of the Royal Society of New South Wales from 1875–1927.

the stamina and versatility of man, it was very rich in rewards for the student of the natural sciences. New varieties and species of trees and plants, of birds and insects, of marsupials and reptiles awaited him. And the heavens were new, too, dazzling in their brightness, ready to be mapped. As Dante had dreamed

> " . . . I turned, and fixed my mind
> On the other pole attentive, where I saw
> Four stars ne'er seen before save by the ken
> Of our first parents. Heaven of their rays
> Seemed joyous . . . "
>
> (*Purgatory*, Canto I.)

The Philosophical Society of Australasia, 1821

The sixth Governor of New South Wales, Sir Thomas Brisbane, was intent on watching the southern sky, and brought with him in 1821 equipment and a first-class astronomer, Dr. Charles Stargard Rumker. Moreover, with the Governor's encouragement, the Philosophical Society of Australasia* was formed in that same year " with a view to inquiring into the various branches of physical science of this vast continent and its adjacent regions ".

It was actually a small scientific club consisting of ten members besides Brisbane. Meeting in turn in their houses, lending books to one another, reading and discussing papers, they encouraged one another in the pursuit, usually part-time, of their scientific interests. These little gatherings held out hopes of being oases of refreshment in what must have seemed a cultural desert : of the Colony's total population of 30,296 in 1829, only 2,097 had arrived free or were born in the Colony. Here was an expression of that deep-seated urge to which T. H. Huxley referred in his Anniversary Address to the Royal Society of London over sixty years later. Wherever English-speaking communities have been planted and have had time to develop, " the instinct which led our forefathers to come together for the promotion of natural knowledge has worked in them and produced most notable results ".

This would be the outcome also in New South Wales, but only after early disappointments. Towards the end of 1822, the little Society " expired in the baneful atmosphere of distracted politics ", as one of its members, Judge Barron Field, wrote. More precisely, as the Reverend W. B. Clarke said in his Inaugural Address to our own Royal Society in 1867, " the fictitious, variable value assigned to the dollar, the coin then prevalent [in 1822], was the cause of the breaking up of the little band who cultivated science for the love of it ".

Dr. Henry Grattan Douglas, M.D. (1791–1865). Foundation Secretary of the Philosophical Society of Australasia (1821–1822), of the Australian Philosophical Society (1850–1855) and of The Philosophical Society of New South Wales (1855–1866). The latter body became the Royal Society of New South Wales in 1866.

" His connection with scientific effort in Australia was very important "—(Obituary).

One of this band was Henry Grattan Douglass, M.D., who, arriving in the Colony in 1821, took a keen interest in the social and intellectual welfare of the community. In 1848 he returned from a visit to England fired with the idea of establishing a University in Sydney. He persuaded F. L. S. Merewether and then W. C. Wentworth to take the necessary steps with the result that the University Act of Incorporation received the Royal Assent on October 1, 1850, and the first Senate was appointed two months later. Douglass was a

* Barron Field, in his introduction to *Geographical Memoirs of New South Wales*, refers to the Philosophical Society of Australia. W. B. Clarke, in the Inaugural Address to the Royal Society of N.S.W., uses both " Australia " and " Australasia ". The latter was used by the Society on the tablet placed to mark the place at Botany Bay where Cook and Banks first landed in 1770.

member, and when the Great Hall was built, his coat of arms was one of the ten carved at the eastern end.

The Australian Philosophical Society, 1850

But what about the former Philosophical Society which Judge Field hoped in 1825 was not extinct, but only in a " state of suspended animation " ? Perhaps Dr. Douglass could revive it. According to Mr. Clarke, the chief credit for its revival in 1850 belonged to Douglass, its Honorary Secretary then as in 1821–2. We may accept this opinion, for getting the Society going again was complementary to making a university a reality. Certainly, in his person and in that of Alexander Berry, the Society of Brisbane's day was carried forward into the Australian Philosophical Society of 1850, the object of which was " the encouragement of Arts, Sciences, Commerce and Agriculture in Australia ". Indeed, until the end of the century the Anniversary Addresses were numbered from 1821. Thus, J. H. Maiden's Address as President, given in May, 1897, was on the seventy-sixth anniversary of our Society.

In the intervening years, 1823 to 1850, the future pattern of eastern Australia was set. Exploration by Mitchell, Sturt, Hume, Leichhardt and others revealed the variable moods of our country, while natural history was pursued by Cunningham, Strzelecki and W. B. Clarke. Settlement had spread and the population of New South Wales in 1851 was 187,243 and the new colony of Victoria 78,260, about an eightfold increase since 1821. Sydney itself had now a population of 44,240. The convict system was gone. The economic depression of the 1840's had been endured, and by an Act of the British Parliament in August, 1850, the Australian Colonies were endowed with self-government. Thus, stability and progress were to depend on the determination, wisdom and knowledge of the colonists. This was a situation demanding advance in education, in professional training and in scientific research—the very context for universities and scientific societies. Appropriately, Sir Charles FitzRoy, the Governor, was Visitor of the University of Sydney and Patron of the Philosophical Society, while Sir Charles Nicholson was Vice-President of the latter and Vice-Provost of the former.

The Philosophical Society of New South Wales, 1855

The revived Society was very active for a while, but amid the excitement of the first gold rush it ceased to function—but not to exist—and a meeting in 1855 made a territorial change in its title, substituting New South Wales for Australia. This was very fitting, because the several Colonies were drawing up their own constitutions, and in November, 1855, a new one was adopted for New South Wales. The first Parliament elected under it met first on May 22, 1856. This was thirteen days after the renamed Philosophical Society held *its* first meeting in the School of Arts. Thus do the political, economic and scientific aspects of society interact with each other.

During the next eleven years, seven or eight meetings were held each year, and a total of 100 papers was given by 42 contributors. Membership rose to a peak of 186 in 1885 and then fell to little over 100 in 1886. Looking back from our vantage point eighty years later, we may well regard this as very creditable. For we are aware of the many problems which confronted the Colony in the aftermath of the gold rush : the rapid and somewhat turbulent increase in population, the inadequacy of education, especially of what we define as secondary, and the correspondingly small contribution the University could make to the pursuit of science and its application. Even twenty years later Professor Liversidge described the University as financially very poor. The Reverend W. B. Clarke, however, who was Vice-President of the Society for most of the 1856–67 period and its acknowledged leader, was very perturbed. He seems to have hoped for a worthwhile membership drawn from the general community, but now admitted that such support would not come " from persons whose leisure is generally given to the frivolities of ephemeral excitement, or whose mental occupation is only exercised by sensational novels or a railway literature." That was 1867. Thirty-four years later, Professor Liversidge was to hold the railways and tramways responsible in another way for a corresponding drop in the Society's membership. As a result of the opening of suburban tram lines and of additional railways, miles of new suburbs had grown up ; streets near the Society's House which had been residential were now lined by professional offices and business premises. Consequently, large numbers of people, particularly of those who would be interested in science and culture, now lived in the suburbs and found difficulty in attending night meetings. In those years membership had fallen from 494 in 1884 and 1885 to 368 in 1901. But even in 1885 only 35 of the 494 members had contributed

Prof. Archibald Liversidge, F.R.S., F.C.S., F.G.S. (1847–1927). Hon. Secretary of the Royal Society of New South Wales for 13 years, 1874–1884 and 1886–1888. He served three terms as President, 1885, 1889, 1900.

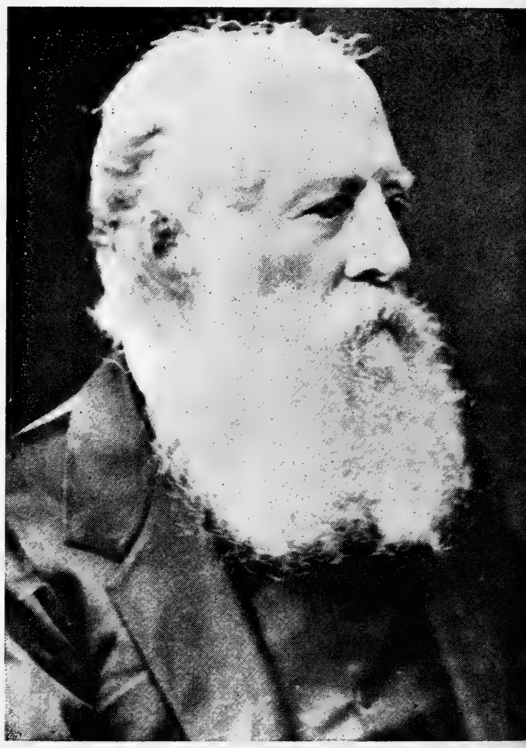
" We never got a move on till Liversidge came." (Obituary)

papers, and indeed most of these were given by seven or eight persons. This brought the comment from Professor Liversidge : " There are few men of leisure in the Colonies, and still fewer of learned leisure."

The Royal Society of New South Wales, 1866

To return to the comparative doldrums of the 1860's : Mr. Clarke sensed an explanation in the very ascription in the title of the Society, namely, the term Philosophical. Likely members might be frightened off by the thought of abstruse papers, although the discussion and advancement of philosophy as such had never been a concern of the Society. Moreover, as far as Clarke was concerned, to do so would be useless, for in the words of S. H. Lewes, the empiricist : " Philosophy is a Desert, whose only semblance of vegetation is a mirage—the Desert without fruit, without flower, without habitation and without horizon : arid, trackless, silent but vast, awful and fascinating." For the " founding father " of our Royal Society, the grand questions beyond that horizon would never be answered by any human process. Whence came the world ? Why is the universe formed as it is ? What is the nature of God and of the human mind ? As a man of religion, Mr. Clarke had a faith grounded in those " records in which Antiquity found its consolation and hope ". But for the rest, he was an empiricist. The former systems of philosophy had passed away. Intellectual inquiry no longer aimed at finding out by the " processes of logic those invisible things which are beyond the attainment of reason ". It was rather trying " to make discoveries *in* things visible, hoping thus to obtain an insight into that which mere Philosophy can never reach ".

In true Baconian spirit he steered the Society along that path in which it would be able to



Rev. William Branwhite Clarke, M.A., F.G.S. (1798–1878). " The pioneer geologist of Australia." Foundation Vice-President of the Philosophical Society of New South Wales and of the Royal Society of New South Wales till 1878. He was effectively President—the Governor of the State actually occupied this position.

" Our true position is that of pioneers, sowers, foundation layers . . ." (Anniversary Address, 1876).

take up the challenge of the country and the nation *to* science. " We ought to be labouring ", he proclaimed, " for the development of the physical character of the country we live in ", and to reveal its natural history and productions, " since this appears to be now admitted as the especial object of our researches ".

So after due steps had been taken the offending word " Philosophical " was deleted from the Society's title, and thanks to the good offices of the Society's President, His Excellency the Right Honourable Sir John Young, the Queen's sanction and authority were obtained " for us to carry out our future labours under the Royal Patronage ". The letter from Downing Street conveying this information was dated September 24, 1866. It was received at a meeting of the Philosophical Society of New South Wales on December 12, 1866, which, at the conclusion of business, adjourned as the Royal Society of New South Wales. Moreover, its Fundamental Rules made its objective quite clear: " to receive at its stated meetings original papers on subjects of Science, Art, Literature and Philosophy ", as in the Rules of the Philosophical Society, but with the following addition: " and especially on such subjects as tend to develop the resources of Australia, and to illustrate its Natural History and Productions ".

Drawing attention to the amended objective, Mr. Clarke concluded his Inaugural Address to the first meeting of the Society under its Royal title, on July 9, 1867, with a charter of research. " We have in this Colony a vast region, much of which is still untrodden ground. We have, as it were, a new heaven for astronomy and a new earth for geology. We have climatical conditions of the atmosphere, which are not to be viewed by us merely as phenomena interesting to the meteorologist. We have facts to accumulate relating to Droughts and Floods which have a deep financial and social importance. We have a superficial area which may engage the attention of Surveyors, Agriculturists, and Engineers for years to come. We have unrevealed magazines of mineral wealth in which Chemists and Miners may find employment for ages after we shall have mingled with our parent earth."

There indeed was the challenge *to* science, as the leaders of our Society saw it a century ago. To repeat, the spirit of Francis Bacon was there with his dictum: " the true and legitimate goal of the Sciences is none other than this, to endow human life with new discoveries and resources." This may not seem to us to be the whole duty of scientists, but it is a duty, and in a new country it loomed large.

Actually, there were two trends. On the one hand, workers carried out their observations and studies in the fields of natural history, palaeontology, astronomy and mathematics (including geometry and statistics) for the sole purpose of adding to our knowledge and understanding of phenomena, whether or not their results had any bearing on the development of Australia's resources. Indeed, the first paper given to our Society after being designated Royal was entitled " Non-Linear Coresolvents ". The writer was the Chief Justice of Queensland, an F.R.S. Papers on the anthropology and languages of the native peoples of Australia and the Pacific were also accepted.

On the other hand, many papers and anniversary addresses for thirty years and more after the revival of the Philosophical Society in 1850 were concerned with matters on which the development of the Colony did depend: particularly, on storing and reticulating adequate water; on geological surveys indicating or confirming the presence of valuable metals, minerals and coal; on improved and increased means of transport and communications; and on safeguarding public health. Only a few references, including one in 1888 to Farrer's work, were made to agriculture and animal husbandry. Research in these fields and indeed in many others would follow the establishment of relevant University Departments.

Water, metals, transport and health: these four: but the greatest was water. Back in 1825 Barron Field of the first Philosophical Society ended the Preface to his *Geographical Memoirs of New South Wales* with a graphic text:

> " Thou hast given me a south land; give me also springs of water."

And for such springs we have been searching ever since. Much of the story of that search, especially in relation to Sydney's water supply, is recorded in the Journals of our Society. The core of the problem was put very succinctly by Professor John Smith just 98 years ago. " Sydney is not favourably situated for an abundant water supply, and it cannot be procured without enormous outlay." Hence arose inevitable arguments about sites for dams and reservoirs, with consequent delays and hesitation to implement reports (especially if rain followed their presentation, as Professor

Smith noted in 1871). Delays were followed by water shortages and restrictions, but the population continued to increase and crises were never far away. So it was one hundred years ago, and fifty years ago; yes, and one year ago. Australia has not changed, and the challenge still goes forth to science to solve our water problem! to cause the clouds to release rain, which the Society's President in 1882, astronomer Russell, thought improbable; and the salty waters to be so treated chemically and economically that they can be used to refresh the land where and when it is dry.

The Pioneering Role of the Society

The contributions of the Clarke period—the 1850's to 1870's—were of observed phenomena, rather than of scientific analysis or theory. Such was the goal set by Clarke. " We do not boast at present", he said in his 1876 Anniversary Address, " of taking a lead in Science or Literature. Our true position is that of pioneers, sowers, foundation-layers, and in that respect we have assuredly an honourable occupation." Or, as Mr. C. Rolleston, Auditor-General, put it in the anniversary address of the following year, when ill-health prevented Mr. Clarke from being present: " In a new country we may not perhaps look for great original thinkers or investigators of the calibre of Darwin, Tyndall or Huxley"; rather " the laborious collection of facts must always hold first place amongst us", and foremost in that work was Mr. Clarke. The Royal Society of London thought likewise and made that one of its reasons for electing him to Fellowship on June 1, 1876; but it also cited his part in re-founding the Philosophical and Royal Society of New South Wales, and in promoting scientific knowledge in the Colony.

Pioneers must serve their generation in the context of their day, and the members of the Philosophical and the Royal Society of New South Wales laid foundations on which in the next phase (the Liversidge phase, as I would call it) a lasting scientific structure would be built.

Engraved in the outside wall of the Chapel of St. Paul's College in the University of Sydney, a College of which W. B. Clarke was an original Fellow, is part of a striking passage in the Sixth Book of Vergil's *Aeneid*, which we may apply to ourselves in this our House:

> " Hic . . . dum vita manebat,
> Inventas aut qui vitam excoluere per artes
> Quique sui memores alios fecere merendo "

which being interpreted reads:

> " Here we remember those who in their day have civilized life by the sciences they have discovered, and who by their merit have established a memorial among their fellows."*

For W. B. Clarke, the greatest memorial was the Royal Society itself. *Esto perpetua*, he challenged, and " with somewhat of parental pride" sought ways to increase its effectiveness and to ensure its right to the liberal support of future generations. We must have a home, he said—a home for meetings and for the library, and not be " like dwellers in the desert living in tents, without a spot of earth to call our own". In the year of his death, 1878, the Society was able to buy its own home, and no longer be nomadic.

He wished, too, that the Society be incorporated with a Charter, so that its members " should not be simply annual subscribers for the purpose of an evening's amusement, but be men who have nobler objects and a more resolute will to be of use to others". The Act of Incorporation was passed on December 16, 1881.

Further, in his last Anniversary Address, May 17, 1876, he suggested the formation of Sections or Committees so as to get more individuals contributing to the advance of knowledge. There " may be thousands of facts of apparently little importance at the moment"; nevertheless they may be worth recording " as either bearing on some past discussion or leading to some future application". Small committees could garner such material and preserve it in the Society's *Proceedings*.† So Clarke spoke, and Sections began to appear in that same year: Astronomy and Physics; Chemistry and Mineralogy; Geology and Palaeontology; Zoology and Ethnology; Literature and Fine Arts, including Architecture; Medical Science; Social Science and Statistics. Engineering and Economics, Agriculture and Industry came later. Amongst the most active were the Medical and Engineering Sections, providing much needed meeting grounds for the keener members of those professions. Speaking generally of the Sections, however, there were

* The reference to St. Paul's College is appropriate, for the third Warden of the College, the Reverend William Scott, M.A. (1865–1877), was a member of our Society from 1865 until his death. He was a student of astronomy, gave eight papers to the Society, served on its Council, and was Honorary Secretary for eight years.

† The *Journal and Proceedings* had been published annually from 1868.

periods of activity and of inactivity; there were appearances, disappearances, and re-appearances, and in time dissolutions. Only Geology is with us today. But the Section scheme played a significant role in developing the disciplines which they fostered. Australian science owed much to the Royal Society of New South Wales for giving rise from 1876 onwards to many of the important scientific and scientifically-based professional institutions of the present day: biological, physical, social and medical. The trend was seen as early as 1880 for Sections to become self-contained; they met, not just for informal discussion of matters of common interest as had been envisaged, but formally, to read papers and even to have Section-Presidential Addresses. Thus, the hiving-off of Sections into separate societies was to be inevitable, especially when University Departments were established to further their specialized disciplines. Indeed, the Royal Society itself was to the fore in pressing for such Departments.

The Liversidge Phase

The provision of organizational aids to meeting Australia's challenge *to* science was a feature of the thirty years or so following Mr. W. B. Clarke's death. He was himself the symbol and leader of the movement to lay a sure foundation for the structure of "Solomon's House", that is, of science, in New South Wales, just as for the earlier period, 1821–51, Dr. H. G. Douglass focused the urge of scholarly men in a far-off land to find a setting for that foundation. So, too, because of his scientific prestige, administrative skill and wide vision, Professor Liversidge became the symbol of, and main influence in, the thirty-year phase of our scientific history from the late 1870's onward. Largely through his efforts, our Society obtained its first home and its Act of Incorporation and, more importantly, grew in scientific stature. On a wider scale, he repeated in 1886 an idea he had put forward tentatively seven years earlier. This was the establishment of a sort of federation or association of the 38 scientific bodies which then existed in Australasia. He suggested ways in which the Royal Society of New South Wales might bring this about. He was hopeful. For such an inter-Colonial outlook in science would be in keeping with the movement towards political federation in Australia. In addition, in Liversidge's view "progress in material affairs would not be made unless a corresponding advance were first made in science". He suggested the formation of an Australasian Association for the Advancement of Science, possibly to become a reality in 1888. It did. Following the initiative taken by our Society in 1886, the first General Meeting of the new body was held in Sydney in 1888 with Professor Liversidge as Honorary Secretary and Mr. H. C. C. Russell, F.R.S., a past President of our Society, as President. And so began the long and fruitful history of the A.A.A.S., or A.N.Z.A.A.S. (Australian and New Zealand Association for the Advancement of Science), as it has been called since 1930.

Science in Australia Comes of Age

The successful foundation and functioning of this scientific association with its regular congresses was an essential step for the well-being of science in our region. Moreover, it was the background for a very significant event which followed in due time almost as a logical corollary. This was a meeting in Australia, in 1914, of the British Association for the Advancement of Science. The Premier of Victoria had proposed such a meeting as far back as 1885, but Professor Liversidge pronounced the proposal as premature. Now, however, retired in England since the end of 1910, he used his influence to bring it about.

Science in Australia had come of age. The coming of the office-bearers and members of the British association, including leading scientists, to our southern land in days of relatively slow sea travel to hold their eighty-fourth meeting was a very generous undertaking on their part. For our scientists it was a significant and stimulating experience. It was a peak in a zestful upward curve of scientific venture and achievement in the Australian region, a trend which was not deflected by the outbreak of World War I during the congress. This period of optimistic, purposeful and even enthusiastic progress in science is best symbolized in the person of Professor Edgeworth David. In him the challenge *to* science was met with eagerness and on occasions with oratory. Determining our coal resources; probing tropical coral formations in search of their history; exploring the icy wastes of Antarctica until the magnetic south pole was located; or devoting his special knowledge in the battlefields of the First World War to keep western Europe and Australia free from domination: in these and other undertakings he conveyed a zest for science to those associated with him in the Society, in the university, in expeditions, in congresses and in institutions in which he played any part.

C.S.I.R. and A.N.R.C.

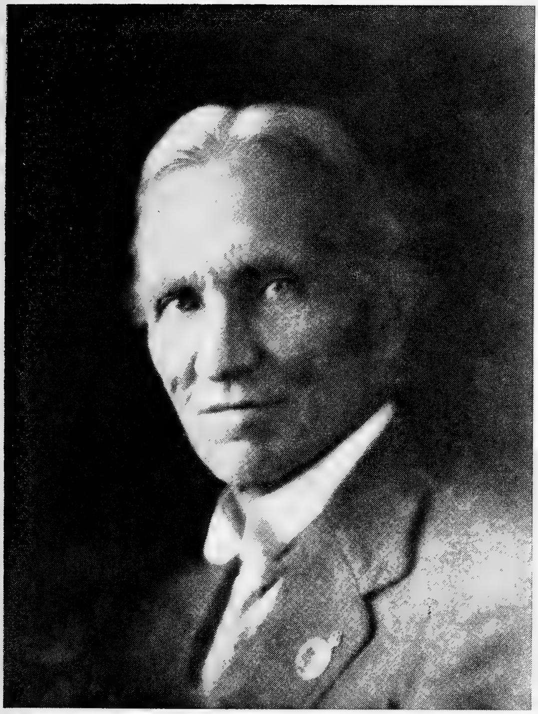
Two such institutions were the Council for Scientific and Industrial Research and the Australian National Research Council, both of which grew in soil at least partly prepared by the Royal Society of New South Wales. As far back as 1868, Mr. G. R. Smalley, Vice-President, in the Anniversary Address, claimed that the Society could be useful to the Government by acting as a board of reference to discuss and report upon questions of practical importance. He listed several which might have been so referred with advantage : Sydney's water supply, the best means of ensuring health in this populous but badly drained city ; the preservation of the harbour by preventing it from being silted in ; disease in fruit trees ; and a compilation of a history of the Aborigines of New South Wales before they became extinct. As the years passed by, several Presidents lamented the lack of appreciation by Government and people of the practical importance of men of science. One of them, Mr. C. O. Burge, urged in 1904 that we should emulate Germany in furthering science and technical education, and then in prophetic words he posed two alternatives : either we get a proper appreciation of these urgent matters, or we may be " rudely awakened from self complacency by some crushing loss in trading or in war ". And war came in 1914. Then as the President in 1916, Dr. R. Grieg-Smith, pointed out, we realized how dependent we had been on Germany for certain fundamental materials, though now, rather late in the day, we recognized how much a nation depends for its existence on scientific research. For Australia was at last considering the establishment of a Commonwealth Institute of Science and Industry to promote the investigation of matters of importance to primary and secondary industries. In time, in 1920, this Institute (later the C.S.I.R.) was established. It has made an immeasurable contribution to scientific research as well as to the development of Australia's resources—thus meeting the challenge to science in a way that W. B. Clarke and his keenest contemporaries could hardly have dreamt of.

Even more imaginative, however, was the vision of Professor Liversidge which he outlined in the Anniversary Address of 1901. By then the Australian colonies were united as States in a Federation, and appropriately, the many scientific societies were associated in the A.A.A.S., so that scientists could share their discoveries and thoughts with each other. But something more was needed : a scientific élite to which scientists would aspire, and from which governments would seek and accept advice. Professor Liversidge proposed an organization, resembling the Continental Academies, but under rules more like those of the Royal Society of London, with elective membership based on proven scientific contributions of an original nature. The seat of such Academy, Liversidge took for granted, would be in the Federal Capital when built, where a suitable site should be reserved for the Academy's House, as well as for museums, libraries, art galleries, and for other educational and scientific institutions, including a Federal university. That was 1901. Canberra had not yet been selected as the site of the Federal Capital, but there today Liversidge's vision has been expressed in buildings and equipment and in men and women.*

The Academy did not appear suddenly. There was an intermediate phase in the inauguration of which our Society acted. Towards the end of World War I an International Research Council was formed, and early in 1919 the Royal Society of London, a foundation member of that Council, invited Australia to join the latter. It asked our Society, as the senior scientific institution in Australia, to take the necessary steps towards forming an organization to act as a National Research Council and to be the Australian member of the international body. The object

* Another example of Professor Liversidge's foresight is given in the same address. After arguing in favour of the metric system of weights and measures, he added that our currency could easily become metric. The half sovereign could be the standard (and called a Victoria), with the shilling being a tenth and the penny, which is only a token, used as a tenth of a shilling. He did not have to consider the cost of converting money-calculating machines, but he pointed out that the change to the metric system for weights and measures would involve a loss (cost) of untold millions both to England and the United States of America, since nearly all the machines in use would have to be altered. Its introduction, however, would save children a year or two of school time which could be spent on modern languages, elementary science and English composition, with the object of teaching them to think and to put their thoughts into clear, intelligible English. Perhaps we should still heed Liversidge's advice.

The idea of decimal currency was not new then. In 1868 Mr. Smalley, our Vice-President, suggested that ladies might attend some general meetings, and not only the Conversaziones, and indeed might have at least elementary training in some scientific subjects, including " the rules of decimals which will enable them to keep the accounts of their houses without difficulty when the decimal coinage becomes law " : nearly one hundred years later as it has turned out.



Prof. Tannatt William Edgeworth David, K.B.E., C.M.G., D.S.O., M.A., D.Sc., Sc.D., F.R.S. (1858–1934). Geologist. Served many terms on the Council of the Royal Society of New South Wales, as President in 1895–1910.

" Science was to him the eager quest for truth, a joyous adventure in which fresh wonders and delights were ever appearing to reward the diligent searcher . . . " (Obituary).

of this new Council would be to promote scientific and industrial research in its various branches, including those of national defence. Our Society acted, and at a conference on August 21, 1919, the Australian National Research Council was formed on a provisional basis until a more widely based meeting could be held during the Congress of the Australasian Association for the Advancement of Science in January, 1921. Professor David was its first President (1919–1922) and a member of the Executive Committee until his death (1934). The Council, with a limited and elected membership, acted as an Academy; it encouraged research and also advised the Commonwealth Government on scientific matters. But when by 1955 the number of scientists in Australia, being Fellows of the Royal Society of London or recognized by them as of high calibre, had increased sufficiently to justify the step, the Council gave way to the Australian Academy of Science. A Social Sciences Research Committee which had been established under its auspices became the Social Science Research Council of Australia.

Personal Symbols of Scientific Phases

While sketching the way in which our Society tried to meet Australia's challenge to science up to the 1930's, I have selected four persons as symbols of succeeding phases in our Society's history, and indeed in the history of science in New South Wales. These are Douglass, Clarke, Liversidge and David; but these men did not build our scientific edifice alone. They were associated with an increasing band of workers, many of equal or even greater calibre in some aspects, but they became the names to conjure with, and we indeed in several ways, e.g. by lectureships and medals, never cease to pay honour to Clarke, Liversidge and David, as the actual artificers of our Solomon's House. It is the names, the devoted purposefulness and the inspiration of a small series of persons, not just their particular achievements, which symbolize and give life to great movements, be these scientific or other. Those who knew Edgeworth David can readily conjure up the verve with which in his Anniversary Address to the Society on May 20, 1896, he quoted the following panegyric from the *Pall Mall Gazette* following the death of Thomas Huxley (1895): " Four Kings laboured to build a mighty hall, the Hall of a Hundred Columns at Karnak. In a century they built it, and they died; but the Hall remains. Four men (Darwin, Tyndall, Huxley and Spencer) more than all others have raised up within the 19th century an edifice which is the crowning glory of British science, and before the century closes three of them are dead; but the edifice stands and will stand, as a lasting monument to the power of truth and fearless investigation." Douglass, Clarke, Liversidge and David were scientific builders, too, meeting a challenge in another context, in a " new " land—in a new society.

Part II

The Challenge *of* Science, 1966

The Passing of the Former Challenge

As we have seen, when our Society received its Royal Charter in 1866 it openly accepted the challenge of the Australian environment *to* science, by adding to its objects the clause: " to receive papers especially on such subjects as tend to develope the resources in Australia ". In working for this objective it prepared the way through its Sections for the rise of specialist, scientific and scientifically based professional institutions, and through the thinking and advocacy of its leading members contributed in no small degree to the setting up of the C.S.I.R. (now C.S.I.R.O.) and the A.N.R.C. and the latter's successors. These various bodies have been meeting that challenge in their several ways, and as a result our Society is not sure of its role. Moreover, specialization within the sciences has made meaningless the presentation of original contributions to general meetings. Discussion and evaluation must be reserved for specialists within the narrow fields involved—and for the most part this means reference to specialist societies. Moreover, specialist journals now provide for such material so that it will not be "hidden" in general scientific journals, but be readily available to workers in the particular fields. Consequently, the range of material served by the Royal Society's Journal has been limited, and that quite apart from the increased cost of publication.

Consequently, during the past twenty years our Society has been passing through a period of uncertainty.

These changes have affected membership and attendance at meetings, and have given rise to a re-examination of the Society's role in the present phase of science in New South Wales. Is there anything for it to do? One possible service which has been tried was to provide a means of bringing together scientists from their apparently deeply separated fields so that they should become aware of what each was doing, and also realize the extent to which they might be studying different aspects of common problems. So lectures and symposia have been and are arranged. In this effort, however, the Society may be in danger of becoming what W. B. Clarke sought to avoid, namely, a group of persons who subscribe for the purpose of being "entertained" intellectually once a month. This measure, while being logical and useful, is rather stop-gap in character. A more positive role is needed. It is at hand.

The Philosophy of Science

The objects of the Society still include the discussion of original papers on subjects of Science, Art, Literature and Philosophy. We have tended over the century to confine ourselves to the first: only occasional papers or lectures have been given on Art and Literature; while, in line with W. B. Clarke's strictures on Philosophy as he conceived it, that subject has been given scant consideration. I suggest that the Society pay serious attention to the Philosophy, and by implication to the History, of Science, a subject which is now at last being recognized by universities. We are of age and should think seriously on these things. By its theories, accomplishments and discoveries and by what it makes possible, science is a challenge to our thinking and behaviour, and to our social and international order. The very discreteness of present-day science, its almost limitless specialization, and the tremendous range of its revelations, from the apparently boundless to the infinitesimal—these facts constitute a challenge to that sense of unity, which we gain both from our own being and also from our own common existence in one universe. We may well say with Plato (in the *Republic*) that the true lovers of knowledge—and every member of the Royal Society would claim to be such—"will not rest in the multiplicity of particular things which is an appearance only, but will go on: the keen edge will not be blunted, nor the force of his desire abate until he have attained the knowledge of the true nature of each particular being, and then, and not till then, will he cease from his travail".*

The philosophical problems raised by science, apart from those inherent in the basic concepts we use, such as change, causation, space, time, matter, force, equilibrium, and so on, are moral and social on the one hand, and cosmological on the other—and although the latter is fundamental, we tend to avoid it. The probable reason is that so far we have failed to arrive at a sure and certain theory of the cosmos as a system, let alone at that knowledge of an ultimate reality which would explain that system, its why and whence, as well as its how. We are not satisfied with such classical explanations as are preserved, for example, by Vergil (in the *Aeneid*)

> "In the beginning know that heaven and
> earth,
> The rivery plains, the glittering orb of
> the moon,
> And the Titanic stars were animated
> By a Spirit within, and a Mind interfused
> Through every fibre of the Universe
> Gave vital impulse to its mighty form."†

* From *The Works of Plato.* Selected and edited by Irwin Edman. Benjamin Jowett translation. The Modern Library, 1928.

† *The Aeneid,* Book VI, lines 724–727. Patric Dickinson's translation. A Mentor book.

This may be judged anthropomorphic, and yet the tremendous advances made in our grasp of relationships within the world, in space and time—the advances made in arriving at general formulae under which these relationships can be subsumed and by which events, natural or initiated by man, can be predicted—these advances, I suggest, imply a universe, a system in which what we mean by mind and by logical order is expressed. As Mr. Knibbs, Statist, in the Anniversary Address in 1899, put it, " The world which the mathematician explores, and in which his discoveries are made, is the world of mind ; the depths he sounds are the depths of human consciousness ; the forms of truth which he perceives are the structures of that imponderable world not seen by the eye, but by the soul, for the relations and laws discovered are conceptual, not physical. The elements of the mathematician's world are those ideas, which it is the high function of intellect to project on to the world of sense in order to render it intelligible."

However, we do not imagine that we are thereby changing the fundamental being of the universe from something not capable of being comprehended to a system which can be so grasped. True, what nature is in itself we may not yet know, but only what it seems to be and how it works ; and yet it would be presumptuous to add that we will never understand. When we remember the great advances made in knowledge, shall we not ask with Galileo, "Who is willing to set limits to the human intellect ? "

Today, however, we seem all too ready to set such limits, to make our intellect a collector and observer of facts—obtained with marvelous technological aids—which are fed into a computer, on the principle that only what can be treated in this statistical fashion can provide reliable information. But we should ask ourselves whether the urge to quantify and to reduce to statistical formulae aspects of, and factors in, every situation, living and mental as well as physical, does more than keep the machines working. Does it lead to understanding ?

Possibly we are less intellectually venturesome than some previous generations, or maybe we are so occupied with the technical demands of industry and defence, with meeting the challenge to science, that we are blind to the intellectual challenge of science itself. Copernicus not only moved the earth, as it were, from the centre of our universe to a place in the periphery of the solar system ; Darwin not only substituted for cataclysms and new creations a theory of the inter-relatedness of all forms of life on the earth ; but in doing so these great expositors undermined men's cherished beliefs. Their visions, their theories, substantiated in a limited field, affected men's interpretation of the universe. After initial shocks, however, thinkers set out to explore it philosophically in the light of the new " revelations ". Eventually these became part of man's intellectual adaptation to the universe, as Milton showed with regard to the Copernican cosmology :

> " What if the sun
> Be centre to the world, and other stars,
> By his attractive virtue and their own
> Incited, dance about him various rounds ?
> Their wandering course now high, now low, then hid,
> Progressive, retrograde, or standing still,
> In six thou seest ; and what, if seventh to these,
> The planet Earth, so steadfast though she seem,
> Insensibly three different motions move ? "
>
> (*Paradise Lost*, Book VIII.)

And what if there be other suns ! Man will still pursue his daily tasks and accept its joys.

But Einstein's Relativity theory ; the Quantum theory ; the space-time concept ; the concept of the curvature of space ; and even the suggestion that the universe may be tending towards a goal of eternal monotony marked only by " the random motion of minute particles " : a Nirvana of individual nothingness ! None of these concepts seems to have set us furiously to think. Do we just regard them as mathematical complexities worked up by specialists ? Or are we so hypnotized by our apparently boundless technological achievements that we are unaware of the intellectual and metaphysical implications of what is happening ?

Perhaps we have become blasé ! Exploration of space is just another air journey ? We bounce information off man-projected satellites ; we relay information back from the moon ; and before long we may relay men off the moon to explore other reaches of the solar system, somewhat as Plutarch suggested on " high authority that a good explanation of the moon is its function as a staging area for departed souls before they move out into the cosmos " ; though we today expect that those who will launch off the moon will eventually return to earth.

The Moral and Social Challenge of Science

However, we are not quite so indifferent to the moral and social challenge which arises from the use of scientific knowledge. During World War II and in the years immediately following it, we talked much about the social implications of science. Indeed, my own Presidential Address to the Society just twenty-five years ago was on " Science, Society and Everyman ". We also became concerned about, and are still concerned about, the requirement of secrecy in competitive industrial research and even more in defence research. This may involve duplication of effort, and barriers between workers in the same fields of fundamental inquiry. Moreover, it is contrary to scientific tradition. And yet we know that in time of stress, such as war, the nation is put before such tradition.

Unfortunately, this same condition of secrecy in prescribed fields of research is required in a fear-of-war phase such as we are now in. We live in the shadow of a great fear, because war could mean total destruction of civilization and/or some unforeseen biological tragedy—a consequence of the use made of the results of research in the study and laboratory. And scientists, being citizens and moral beings, cannot shrug the whole responsibility for this fear on to the shoulders of statesmen, industrialists and soldiers. These difficult questions of moral responsibility for the use made of discoveries and for the effects of secrecy requirements in research are problems for moral philosophy; and scientists, being involved, should not shrink from the challenge.

This great fear is the continuing psychological fall-out from the two atomic bombs which ended the Second World War so dramatically, and from the many, much more powerful, bombs stockpiled by several nations. Peace is being balanced precariously on fear, and none of the nations is prepared singly or collectively to make harmless the immediate cause of that fear, that is, nuclear bombs. If they did, they could work freely together for the solution of the basic economic, historical, social and racial issues behind international tensions. Research has done much to enable us to meet the challenge of these issues, provided that we can first meet the challenge of science itself: this is to grasp the nettle of the moral and social problems involved in the use we make of science and of its technological applications, both in and between nations.

We read in Vergil's *Aeneid* that as Aeneas and his Trojan expedition came near the shores of Italy, four white horses were feeding on the meadow grass. On seeing them, his father, Anchises, spoke:

> " Strange land, it is war you offer—it is war
> These horses are equipped for—it is war
> These creatures threaten. But it is also true
> That these four-footed creatures can be trained
> To draw a chariot yoked in harmony
> And happily harnessed—so there is also hope for peace."

And then (says Aeneas) we offered up our prayers.*

Today these horses on the cliffs just ahead of us can be likened to physical, chemical and biological forces of immense potential, which have been revealed through science and made available to man. They can be harnessed for *peace*, for the well-being of man, of all men everywhere—provided that the fourth horse, our moral strength, be great enough.

Therein lies the supreme challenge of science, 1966.

Perhaps we should add as Aeneas did:

" *Tum numina sancta precamur.*"

* *The Aeneid*, Book III, lines 537–543. Patric Dickinson's translation. A Mentor book.

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Cyclic Sedimentation In The Carboniferous Continental Kuttung Facies, New South Wales, Australia

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ABSTRACT—The thick sequence of continental rocks of Carboniferous age (Kuttung Facies) of the Hunter Valley, New South Wales, includes fluvial and glaciolacustrine sediments which display several types of cyclical lithology. Cyclothems attributed to fluvial genesis in the Wallaringa Formation, a red-bed, molasse-like rock unit, have a scoured substrate above which are variants of the " fining upwards " sequence conglomerate-coarse sandstone-fine sandstone-red siltstone. These types resemble some described from the Old Red Sandstone and the cyclicity is attributed to fluvial facies variation as a stream channel, or a single channel strand in a river bed, migrates from one locale.

Unusual cyclothems from a facies described as " flysch in molasse " (Italia Road Formation) are characterized by an alternation of coarse, clastic debris, rapidly deposited during a shortlived episode, with fine clastic material accumulated with biolithic material over a longer period of time in a subsiding, continental basin. These bear some resemblance to other cyclothems in which a single, graded sandstone alternates with varved siltstones of proglacial lake beds (Grahamstown Lake Formation) that show signs of periodic emergence. The primary cause of these cycles is believed to be climatic, and spasmodic continental turbidity currents associated with glacial climates are proposed as the means of clastic dispersal and deposition of basal, coarse, graded sands of the cyclothems.

Introduction

Rattigan (1967*a*) has described the Kuttung Facies (Engel, 1965) in the Balickera district, N.S.W. This paper discusses the types of cyclothem developed in different units of this Carboniferous sequence.

The recording of cyclic sedimentation in the Carboniferous of New South Wales is of interest for two reasons. Firstly, whereas some cyclothems resemble those described from similar facies in the Northern Hemisphere, others present unusual features not previously described. Secondly, there are numerous references to cyclical phenomena in the Northern Hemisphere and but few in the Southern Hemisphere although Booker (1961) has described cyclothems from Permian coal measure sequences of the Hunter Valley.

General Geology

The broad features of the Carboniferous stratigraphic succession in the Hunter Valley, New South Wales, have been described by Osborne (1922), Sussmilch and David (1919), and David (1950), and by Rattigan (1967*a*) who described exposures from deep excavations for a civic water scheme at Balickera, New South Wales. The oldest rocks of the system are the thick, marine, Burindi Facies (Engel, 1965) of dark mudstones, graywackes, conglomerates, thin limestones and volcanic rocks.

The Burindi Facies is succeeded in the Lower Hunter Valley by rocks of the continental Kuttung Facies which consists of plantbearing sediments and volcanics. The oldest rocks of the Kuttung Facies, comprising the Wallaringa Formation, represent a molasse-like facies which succeeds the flysch-like Burindi Facies of the New England Eugeosyncline (Voisey, 1958) with some interdigitation near the base. It is probable that these sediments were deposited in continental troughs between the flanks of a geanticline that was rising along the axis of the New England Eugeosyncline and a high standing foreland to the south-west of the present Hunter River.

Between two major epochs of volcanism represented by the acid to intermediate lavas and pyroclastic rocks of the Carboniferous Gilmore Volcanic Group and the basic lavas and tuffs of the Permian Dalwood Group, (Rattigan, 1967*b*, Fig. 1) rocks of the dominantly sedimentary Kings Hill Group were laid down. These are considered to be continental in character because of the occurrence of casts of plants in situ normal to bedding surfaces, the occurrence of highly carbonaceous strata and inferior coal (Rattigan, 1964) and the occurrence of interstratified welded tuffs.

The group consists of three formations, the Balickera Conglomerate, the Italia Road Formation and the Grahamstown Lake Formation, and corresponds with what was once termed the " Glacial Stage " of the " Kuttung Series " (Osborne, 1922, 1925). It is presumed to be at least partly glacigene (Rattigan, 1967*b*) because of the abundance of varved sediments with exotic dropstones, and diamictites (possibly tillites) in the uppermost formation, and because of one glaciated pavement (Osborne and Browne, 1921). Clear evidence of glaciation is not recorded however in the two older formations.

Cyclic Sedimentation

Rhythmic features of sedimentation are evident in many of the Carboniferous units. The Burindi Facies shows repetitions of the sequence conglomerate, graywacke, mudstone and limestone in some of the exposed sections. However the sedimentology of the marine, flysch-like unit has not been studied in detail and the aim of this contribution is the description and interpretation of cyclothems of the continental Kuttung Facies.

The Wallaringa Formation

This formation consists dominantly of consolidated, lithic, polymictic gravels and sands. Current-induced features, inferred to be fluvial in genesis, include scouring, cut and fill, coarse crosslamination intermediate between the tabular and trough end-member types of Potter and Pettijohn (1963), heavy mineral lineation and pebble imbrication. Red siltstones and sandy siltstones are interbedded with sandstones throughout the formation.

The sequence conglomerate-sandstone-mudstone or sandstone-siltstone (Fig. 1) is repeated near the base of the formation exposed at Balickera but the regular cyclical character does not persist over the complete section of the unit.

Fluvial environments and the interpretation of their lithologies have been discussed by Allen (1964, 1965*a*) in his studies on Old Red Sandstone cyclothems. Allen (1965*b*) has also reviewed the classification of alluvial deposits and describes them, according to the morphological features of their accumulation, as principally of two types. The first or lateral accretion type is characterized by point bars, channel bars and alluvial islands, and results from progressive bed load accumulation with sideways migration of channels. The second type, vertical accretion deposits, derive from suspended load from overbank floods in levees, crevasse splays and floodbasins. Channel-fill deposits, those accumulated in channels that are being or have been bypassed are transitional between the two types.

Older analogues of recent deposits are difficult to classify in any rigid classificatory scheme unless the full geometry of each lithosome is observable and this is rarely so. However, in those deposits from the basal part of the Wallaringa Formation (Fig. 1) the cyclothems are believed to represent single cycles of deposition much like that observed in present day flood plains, as a stream channel wandered into and away from a particular locale. Conglomerates are believed to represent channel lag deposits comprising phenoclasts left from bed load by the winnowing of finer fractions by currents. The coarser, weakly graded sandstones may be point bar deposits where downward coarsening is frequently described (Allen, 1965*b*, p. 140) or perhaps channel fill deposits at an early stage in the diversion of the main channel whilst sediment is still being passed through the channel openings. Flat bedded fine sandstones may have been lateral accretion channel deposits or perhaps channel-fill deposits, and sandy siltstone or siltstone may have been vertical accretion, topstratum deposits arising from overbank flood sediment deposited over filled channels.

The upper part of the Wallaringa Formation has more complex relationships in deposits interpreted chiefly as consolidated channel or channel-fill sands and gravels. In this part of the sequence red, massive or laminated, siltstone and sandy siltstone lithosomes were observed to be small, tabular bodies somewhat elongated in the direction of the palaeocurrents evidenced by cross-bedding. These lithosomes have a scoured upper surface and sharp, near vertical contacts at one or both lateral terminations with the sandstones against which they abut.

The shape and character of the siltstone lithosomes accord with emergent or submerged mid-channel alluvial islands or channel-edge mudbars scoured by narrow active channel current strands of low water in the bed of the present Colorado River near Moab and Potash, Utah, U.S.A.

The alternation of sandstones and red siltstones in this upper part of the sequence can therefore be attributed merely to channel deposition by the formation of mudbars in wide river channels at low water. Normal scouring by currents at low water may have

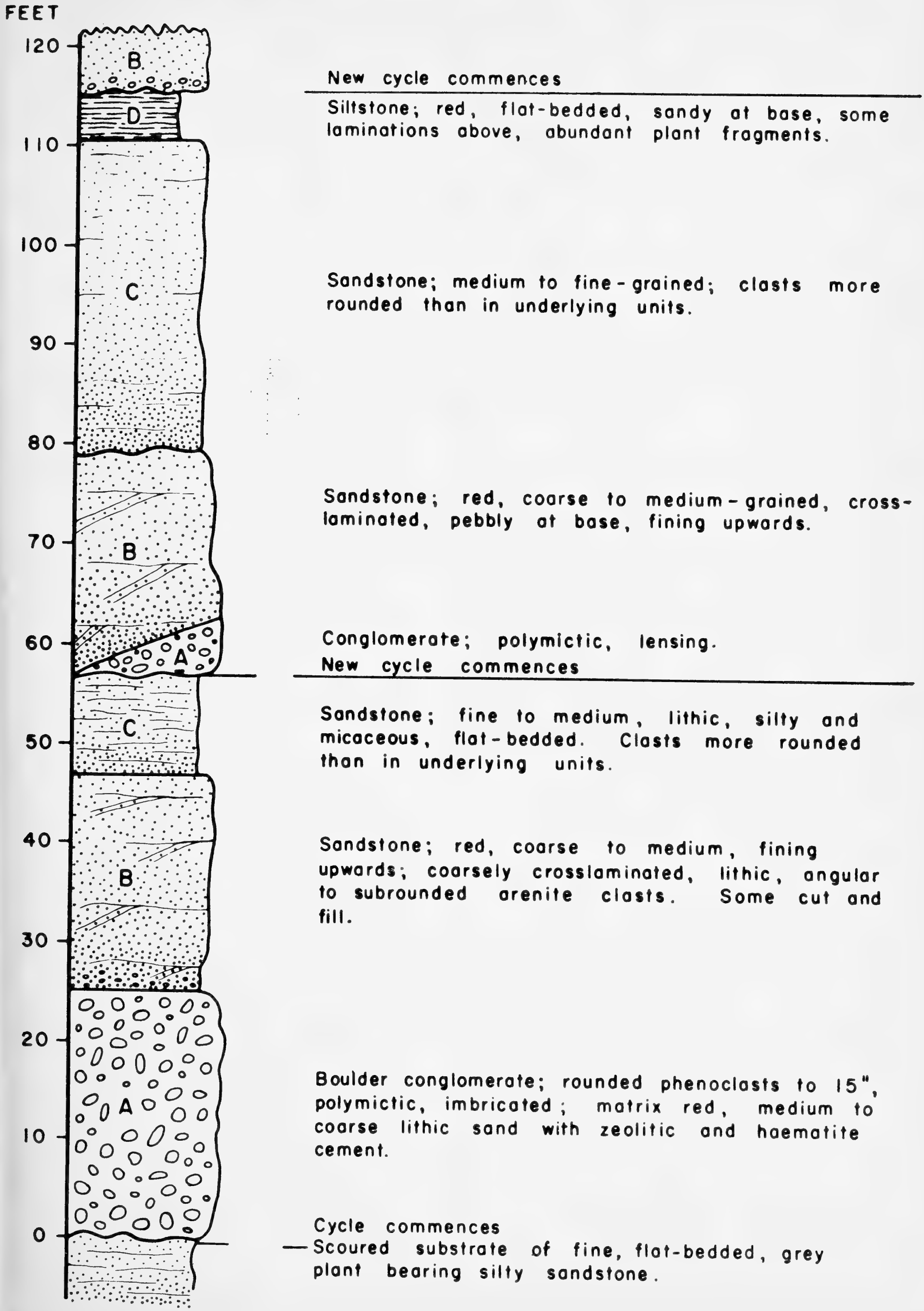

FIG. 1.—Character of cyclothems in the basal part of the Wallaringa Formation, Balickera, N.S.W. The partial section is from the inlet channel near a point 1600 feet west of the Balickera Pumping Station.

been responsible for their scoured, lateral abutments with adjoining lithosomes and active currents of high water may have caused scouring of the upper surface and deposition of coarse clastic debris on this scoured surface.

The King's Hill Group

The most regular cyclical features are in the King's Hill Group. In gross aspect the group itself shows a significant sedimentological grading ranging from a coarse, basal boulder conglomerate, the Balickera Conglomerate, through the dominantly sandy Italia Road Formation to the dominant mudstones, siltstones and fine sandstones of the lower part of the rahamstown Lake Formation. One interpretation of this gross grading of clastic strata is that it was tectonically determined, the basal boulder conglomerates representing the piedmont deposits formed during the immediate aftermath of a diastrophic episode which raised highland sources of clastic debris and led to its dispersal over a foreland trough. The characteristics of these conglomerates resemble the near source alluvial fans of the arid basin and range province of western U.S.A. The finest clastic sizings have been winnowed out though the deposits as a whole are poorly sorted. There is only crude stratification and no cyclical features are observed in this unit.

The younger units show in their sedimentary record evidence of flood plain, paludal and lacustrine conditions and the depositing areas are interpreted to have been at most times near base level and either distant from rapidly eroding, highland source areas or otherwise protected from entry of very coarse detritus. Such alternative protection may have been by ice caps covering previous areas of degradation since the inferences from palaeomagnetic data by Irving (1964) show palaeolatitudes of about 75°S during the time these units were being deposited.

Cyclothems of the Italia Road Formation

Within the King's Hill Group very regular, repetitive stratification is developed in the Italia Road Formation which in the type section at Balickera (Rattigan, 1967*a*) consists of 1160 feet of lithic sandstones (wackes), mudstones and carbonaceous strata. Minor conglomerate and sporadic ashfall and ashflow tuffs, bentonites and cherts are associated. The facies might be termed " flysch in molasse " (Walton and Duff, 1967). On the basis of internal lithological characteristics, or sequences, the formation can be subdivided into ten members (M_1 through M_{10}, Fig. 2*a*). The units M_1 and M_6 are conglomerates which lie beneath sequences of well graded units. M_{10} is a volcanic unit and the other seven units show well developed rhythmic sequences, each with related but with somewhat differing character.

The cycles of M_2 have the following types of unit in sequence from base to top (Fig. 2*b*).

A. This is a single, massive, graded, poorly sorted, polymictic, coarse to medium, lithic arenite of the order of ten feet, but ranging from three to 14 feet, in thickness. The basic contact is sharp but may show scouring of the substrate. A few exotic and local pebbles, and soft pellets scoured from the substrate, occur near the base. No cross lamination or rippling has been observed. The grading over the full thickness is macroscopically visible with careful observation of the sand fraction and readily apparent in size analyzes of grains in thin sections. The attributes of the sediment denote its immaturity. Typically a mud fraction is prominent throughout the unit suggesting that depositional conditions allowed little winnowing of the finer fractions. The sand fraction has many labile constituents (feldspar, mica and rock fragments) and the grains are angular to subangular. The abundant cement is chloritic and zeolitic.

B. The bed A is succeeded abruptly by a fine, lithic, silty sandstone bed which shows better sorting, a lesser mud fraction and a higher rounding index for the grains than the basal, massive bed. This sandstone is commonly laminated, but may pass upwards into cross-bedded, ripple units (ripple-drift lamination).

C. The unit C is a sequence of thin beds rather than a single bed as the underlying units are. The unit varies in character somewhat from cyclothem to cyclothem chiefly in the number and arrangement of carbonaceous beds or laminae. This unit consists of grey mudstones or shales and one or more black, pyritic, carbonaceous bands. It is sometimes capped by a laminated mudstone or a very fine, laminated or cross-laminated, ripple-marked sandstone. Plant remains are common and pith casts normal to bedding may be truncated by the basal bed of the next succeeding cycle, or project into it, being filled with the component material of this succeeding bed. The C type units are commonly affected by ashfalls ranging from crystal tuff to fine vitric material now converted to bentonite. These pyroclastic layers range from one-tenth of an inch to seven feet in thickness. Where the thicker layers of pyroclastic material are present, the

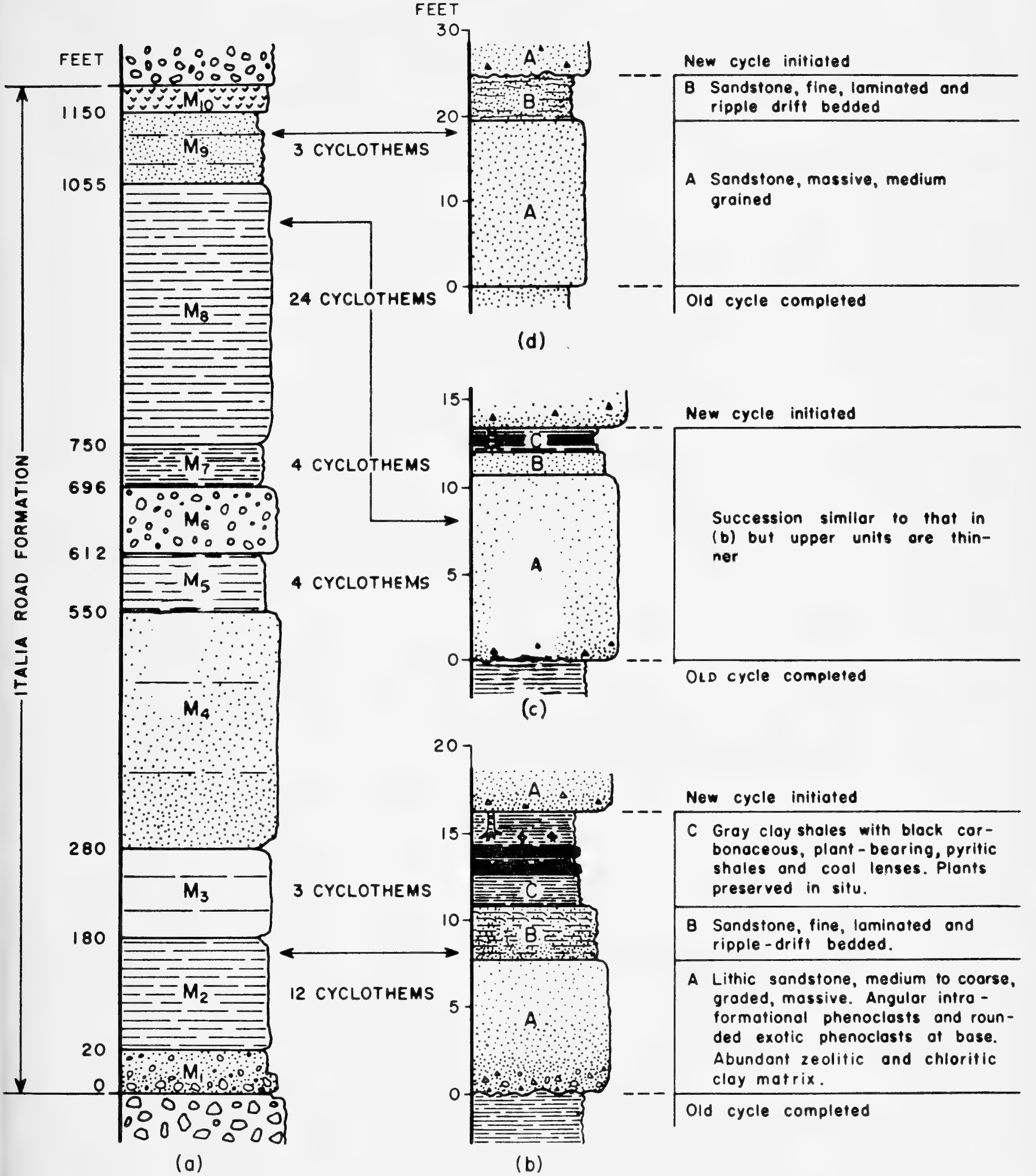

Fig. 2.—The component members of the Italia Road Formation and typical cyclothems of different units.

Fig. 2*a* is the section in the Balickera Outlet Channel between the east portal of Balickera Tunnel and the Pacific Highway. Figs 2*b*, 2*c* and 2*d* are measured cyclothems from the positions in the section indicated by the arrows.

plant bearing shales and fine sandstones are often converted to cherts by secondary silicification. The pyroclastic and chert beds are not considered normal units in the cycle but as intermittent natural accidents which mask normal sedimentological rhythm.

The carbonaceous layers are chiefly dark, laminated, fine argillites but some are very inferior coals and are associated with large fragments of carbonized wood and massive pyrite layers, lenses and nodules. Some dark, mottled argillaceous bands, and some clay shales can, from the attitude of spreading rootlets and rhizomes and the positions of casts of trunks of lycopods, be interpreted as soil horizons of "seat earth" type. Rare ferruginous bands are perhaps fossil "ferricrete" soil horizons. Other dark sands and silts were stained by humic colloids and may represent parts of old soil profiles.

Twelve of the rhythmic units comprise member M_2. That figured (Fig. 2*b*) is an actual sectioned cyclothem. Others vary in their absence of unit B, and in the number of carbonaceous bands in C. The cyclothems of M_3 are similar in character to those of M_2, except that A is generally thicker. The increase in the thickness of unit C is commonly due to thicker ashfalls. The member M_4 differs from those of M_2 and M_3. On casual inspection it appears to be a massive sand unit but from detailed lithological sectioning and thin sectioning it appears as a sequence of very thick (to 40 feet) repeated, graded beds of the type of A, sometimes separated by thin C type units (two inches to 12 inches) of grey mudstone and carbonaceous shale. The cyclothems of M_5 have the character of those of M_3 but the A type units are often strongly stained with humic colloids because they settled in or incorporated a considerable amount of peaty water.

The cyclothems of units M_7 through M_8 (Figs 3*b* and 3*c*) have general similarities to those of underlying members M_2—M_4 though the grading of the A type units is not so prominent the mud fraction is smaller. The cyclothems of M_8 (Fig. 2*c*) are very regular in their development. The basal units of M_9 cyclothems have conglomeratic phases and have more obvious fluvial characteristics than those of underlying members.

Cyclothems of the Grahamstown Lake Formation

Rattigan (1967*b*) has described aspects of the sedimentology of laminite sequences of the Grahamstown Lake Formation and its correlate, the "Main Glacial Beds" of Osborne (1922, 1925). The formation contains laminite sequences which are referred to as varve members and varvoid members. Varved members contain siltstones with close spaced regular graded laminations (varves), whereas the less regular and coarser laminations are termed varvoid. The laminites have an array of sedimentary structures that includes a few that are emergent features such as mudcracks and also most types of sole, internal and deformational structures that have been discussed by Dzulynski and Walton (1965) as characterizing marine flysch and greywacke. These include graded bedding, flute moulds, groove and striation moulds, load casts, intraformational contortion and pull-apart structures. The varved sediments are clearly glacigene and such features as a basal glaciated pavement, have been observed and dropstones and large erratics are common.

Associated with varve siltstones in varved members at Balickera and near Paterson, New South Wales, are graded sandstones and diamictites (Fig. 3). The latter are considered accidents in a series of cyclothems in which single, graded sandstone beds alternate with multiple varves. This type of cyclothem bears some resemblance to that of the Italia Road Formation. Both are characterized by a single basal graded sandstone bed (A) deposited during a single episode alternating with fine clastic sediments deposited over a much longer period of time.

There are differences between the two types of cyclothem in that overall sorting and grading is more marked in the sandstones of the Grahamstown Lake Formation and the sandstones therein are much thinner than in the Italia Road Formation. The fine sediments of the cyclothems differ in that one (Italia Road type) was clearly deposited partly under flood basin paludal conditions. In the other fine sediments accumulated in a presumably shallow lake (Rattigan, 1967*b*) with parts of the bed emergent at times.

The Cause of the Cyclical Features in the King's Hill Group

The cyclothems of the Italia Road Formation and of the Grahamstown Lake Formation or its correlates have some features in common. The basal A-type units are extensive, single, graded, wacke beds on a scoured or rippled substrate and comprise an array of clastic components in which granule, sand and mud

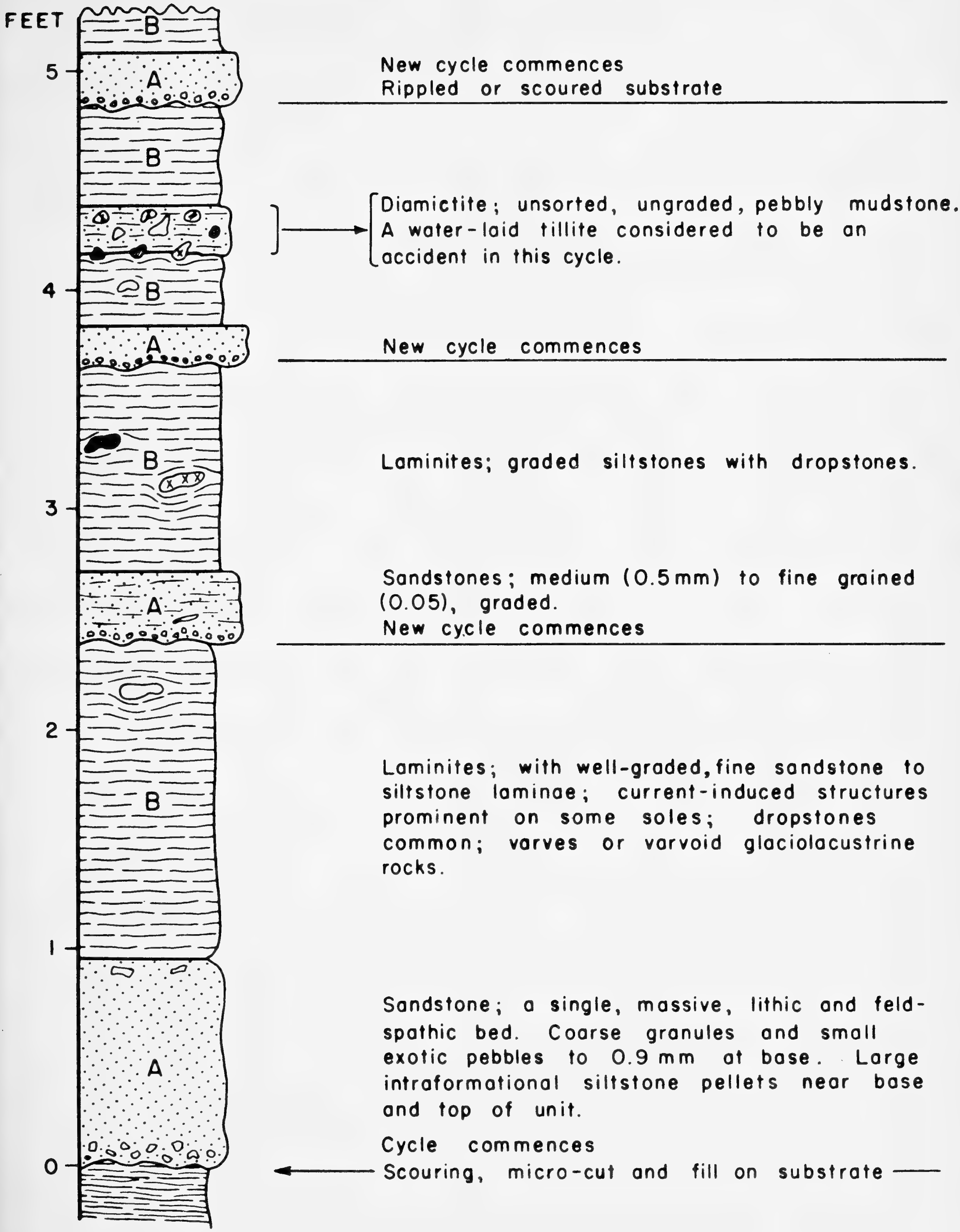

FIG. 3.—A section through part of a varved member in the basal part of the Grahamstown Lake Formation in the Balickera outlet channel from a point 500 feet west of the Pacific Highway overbridge.

size-fractions are all prominent and intraformational siltstone pellets are common. Apart from some units of member M_9 of the Italia Road Formation the A-type units have none of the normal aspects of channel sands whether considered from the aspects of lithology, geometry or sedimentary structures. Nor do they closely resemble normal vertical accretion deposits of recent fluvial flood plains. For this reason alternative means of genesis that would explain their formation in a continental environment have been sought.

Glacigene turbidites and the Grahamstown Lake Formation

The continental, glaciolacustrine environment inferred for the Grahamstown Lake Formation (Rattigan, 1967*b*) and the sedimentology of varve members (Fig. 3) give grounds for picturing the cause of the cyclothems in this formation as follows.

The character of the varves is such that they accord with the conventional interpretation of seasonal deposition of coarser and finer layers in proglacial lakes (Rattigan, 1967*b*). Alternatively they may form by non-seasonal, repeated turbidity current generation. The entry and dispersal of fine sediment in a shallow lake ahead of an ice front was possibly through quiet turbidity currents of a " steady " type (Dunbar and Rodgers, 1957, p. 108) and this may explain the grading of the varves and other laminites which are composed of fine, graded, single laminae rather than pairs of individual laminae of different sizing.

It is proposed also that periodically, possibly during a single, seasonal period of abnormal thaw at the icefront, strong, fluvioglacial floods carrying coarse, clastic detritus entered the shallow glacial lakes and became forceful, spasmodic, density currents which scoured and rippled their siltstone beds and deposited the A type graded units (Fig. 3). Sole and other markings so typical of marine turbidites of flysch and greywacke type support the turbidite concept even though the environment was continental.

Italia Road Cyclothems

The cause of the cycles so clearly marked in the Italia Road Formation is of some interest as the unit is the oldest of this Gondwana Province which shows repeated signs of the coal forming conditions which reached their peak in the succeeding Permian Era. In the northern hemisphere cyclical sedimentation has been described as a phenomenon commonly associated with Carboniferous coal measure sequences.

The component clasts, sorting, sizing, stratification and structures of the three units of the cyclothems give indications of the conditions of deposition through each cycle but the genesis and mode of transportation of the A type units in the Italia Road case are not fully understood.

Units of C type are considered to result chiefly from deposition under somewhat varying water levels in a lowlying, continental, flood basin to which only fine clastic debris was being supplied. The carbonized plants of several highly carbonaceous beds, poor coal and high content of sulphide imply imperfect coal-forming conditions and an environment that was clearly paludal at times. Minor changes in base level of this depositing basin while C type units were accumulating are evidenced by the composite nature of the units. Graded ashfall tuffs and ignimbrites, plants in situ, and soil profiles indicate periods of emergence or near emergence and laminated, non-carbonaceous shales and fine sandstones with current structures may indicate deepening of the swamps to shallow lakes wherein plant growth over the depositing basin was inhibited. Overbank flooding could produce this result as could deepening by tectonism in this once tectonically and volcanically active region.

Up to four individual, highly carbonaceous beds and bands are recorded in some C units and these, whether they may be inferior fossil peats or humic parts of a soil profile, probably were some time in forming. Thus C type units can reasonably be interpreted to represent periods of many years of relatively stable, vertical accretion of fine clastic, chemical and biolithic components under gently fluctuating water levels in back swamps of a flood plain.

As with the varves of the overlying formation the relative quietude of the environment was interrupted at intervals by the entry of coarse, clastic debris forming the A type units. These are single beds each varying in thickness and, particularly in the lower members, very similar in character. They do not have the characteristics of channel sands but could perhaps be somewhat unusual interchannel fluvial sands of overbank floods. If this were their genesis they were vertical accretion deposits in which grading may be interpreted to result from a waning fluvial traction current. The succeeding finer deposit (B) would also represent a vertical accretion deposit of the flood plain.

This explanation would assign periodic, overbank-spilling, flash floods to the prime role in causing cyclothem development. However the thickness, the considerable mud fraction, the poorly sorted nature of the A type units and the grading and absence of traction current structures suggest that an alternative explanation should be sought and turbidity current genesis, somewhat analagous to that proposed for the graded sandstones of the Grahamstown Lake Formation, is also proposed for the basal Italia Road Formation cyclothem units.

Continental turbidity currents termed " courants turbides de surface " have been proposed to account for sedimentological features of " flysch in molasse " (Walton and Duff, in press). These presumably traverse exposed or submerged alluvial plains as flash floods.

The writer prefers the following explanation for the Italia Road cyclothems. Paludal areas of a flood plain were deepened periodically and shortlived, periodic, diving, fluvial outwash gave rise to spasmodic " diving " density currents. From such currents regular single, thick, graded beds were deposited. The succeeding B type units, which have a modal sizing about or less than that of the topmost part of A, were then formed by bottom traction currents that stirred, redeposited and rippled the topmost graded sands and silts of the turbidite. The sharp boundary of B with A favors this mechanism rather than that of waning traction or other current action.

The role of glaciation in contributing source sediment and in changing water levels offers a possible explanation of the cyclical features. Palaeolatitude studies based on remanent magnetism (Irving, 1964) and the fact that the succeeding formation has ample evidence of glacial phenomena, indicate that it is probable that ice caps existed near the Hunter River region during the time the Italia Road Formation was accumulating. It is possible that during irregular, single seasons of abnormal thaw, vegetated paludal areas or shallow lakes beyond the icefront were transformed to deeper lakes by melt waters. Density currents formed by diving, fluvioglacial melt waters during each single, abnormally regressive glacial episode dispersed graded sands widely over the lakes. Following periods of stirring, sorting, and redeposition of the tops of turbidites by gentle traction currents the lake basins reverted to shallow lacustrine or paludal environments from which coarse clastic debris was excluded by more intensive glaciation along the prograding icefront.

Conclusions

Explanations have been sought for three types of cyclical lithology observed in continental rocks of the Kuttung Facies. The fining upwards sequences of parts of the Wallaringa Formation are fluvial and are considered to be due to wandering of channels from one locale to another and to mud or alluvial island development in wide river beds.

The cause of cyclothems in varved members of the Grahamstown Lake Formation can reasonably be attributed to shortlived, periodic, spasmodic turbidity currents that interrupted " steady " turbidite deposition which was characteristic of the normal, proglacial lake regime.

In the case of the less obviously glacigene Italia Road Formation it is believed that a series of irregularly spaced climatic accidents are the direct cause of initiating each cycle. These accidents may merely have been periodic flash floods which swept fluvial sediment sheets widely over flood plain swamps and during the waning phases of the floods a " fining upwards " grading was developed as is the normal course of events in recent alluvia. However it is possible that with the onset of glaciation the coarse basal members formed from diving melt waters carrying muddy sediment as a turbidity current over drowned vegetated swamps in a manner analagous to that proposed for the coarse, graded sandstones of the Grahamstown Lake Formation varve members.

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Petrology and Origin of the Cocoparra Group, Upper Devonian, New South Wales.

John R. Conolly

Abstract—The Cocoparra Group in south-western New South Wales consists of approximately 20,000 feet of red and white quartzose conglomerate, sandstone, and siltstone, and was deposited in fluvial and lacustrine environments. The basal sediments were deposited on a basement complex and consist now of immature and submature lithic sandstones and protoquartzites. The upper formations mainly consist of white and red orthoquartzites and protoquartzites, and were deposited by streams and rivers flowing northwards from a southerly land mass. Tourmaline, zircon, rutile and ilmenite occur as heavy minerals throughout the sandstones and are derived from granitic and reworked sedimentary rocks. Leucoxene-limonite and hematite-limonite heavy mineral complexes are characteristic of the white and red sandstones respectively and have a secondary origin. Differences in sandstone mineralogy are related to differences in both mineralogical and textural maturity and are reflections of distance from source area and local variations in the environment of deposition. Data from 123 thin sections show that the maturity of the sandstones increases to the north away from a source land consisting of folded Lower Palæozoic quartzose sedimentary rocks, granite and acid volcanics. Evidence from regional geology, facies changes, and palæocurrents shows that this source was probably located in southern New South Wales and northern Victoria.

Introduction

Sedimentary rocks of the Cocoparra Group crop out over an area of approximately 7,000 square miles in south-western New South Wales. The sequence, which reaches a maximum thickness of 20,000 feet, was deposited essentially during Upper Devonian time probably contemporaneous with sequences of similar lithologies which were deposited elsewhere in southern and central New South Wales. These sequences include the Hervey, Mulga Downs, Lambie and Catombal Groups, and the Upper Devonian rocks of the south-eastern part of New South Wales (Conolly, 1967).

This investigation is an integral part of a regional study of the Upper Devonian rocks of central New Scuth Wales by the writer and is meant to outline some of the major features of the petrology of the Cocoparra Group. Other petrologic investigations of Upper Devonian strata include those on the Catombal Group in central-eastern New South Wales (Conolly, 1963), and the Hervey Group in central New South Wales (Conolly, 1965*c*). Brief reference has been made to the sandstones of the Cocoparra Group in another report (Conolly, 1965*a*).

This investigation is essentially of a regional nature, being the first investigation of the petrology of the Cocoparra Group. Although all the intricate problems of environment of deposition, dispersal, and provenance will certainly not be solved by these studies, it is intended that they will form a basis for further more detailed work in this exceptionally thick and extensive sequence.

Stratigraphy

The Cocoparra Group is separated from the Mulga Downs Group to the north and the Hervey Group to the west by older Palæozoic basement rocks and Tertiary to Recent alluvial sediments. The stratigraphy of the Upper Devonian of the Lachlan Geosyncline has been recently reviewed by the writer (Conolly, 1967).

The Cocoparra Group crops out over an area 150 miles long and 50 miles wide, in two distinct synclinal belts called the Cocoparra Syncline in the west, and the Ardlethan Syncline in the east (Fig. 1). The Cocoparra Group in the Cocoparra Syncline consists of the following formations in ascending order: the Barrat Conglomerate, Naradhan Sandstone, Womboyne Formation and the Rankin Formation. The

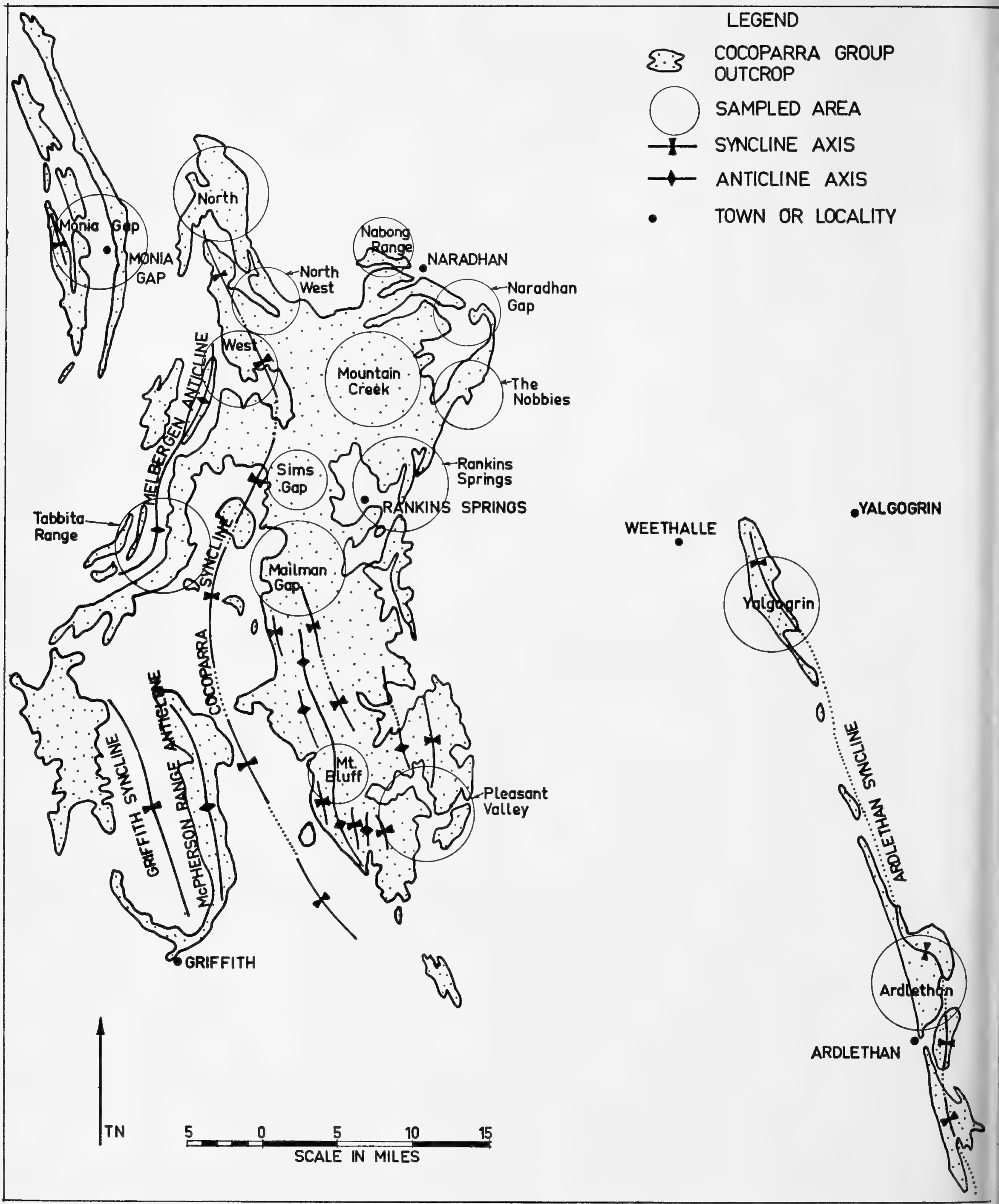

FIGURE 1—Outcrop area and structure of the Cocoparra Group, showing major sampling areas.

Womboyne Formation is subdivided into the Confreys Shale Member, Melbergen Sandstone Member and the Stitts Member. The base of the Rankin Formation is marked by a conglomerate sequence called the Mailman Gap Conglomerate Member. Further east in the Ardlethan Syncline, the Barrat Conglomerate persists at the base of the sequence, and is overlain by a red sequence called the Ardlethan Sandstone (Table 1).

TABLE 1

Stratigraphy of the Cocoparra Group in the two major outcrop areas, the Cocoparra and the Ardlethan Synclines.

	Cocoparra Syncline		Maximum Thickness in Feet
Top	Rankin Formation		5,200
	Womboyne Formation	Stitts Member	4,000
		Melbergen Sandstone Member	3,800
		Confreys Shale Member	1,800
	Naradhan Sandstone		2,100
Base	Barrat Conglomerate		1,440
	Ardlethan Syncline		
Top	Ardlethan Sandstone		3,200
Base	Barrat Conglomerate		2,000

Techniques

Samples of sandstones, siltstones and conglomerates were collected from localities throughout the Cocoparra Group in the Cocoparra Syncline and the Ardlethan Syncline. Sandstones were sampled in preference to siltstones. Approximately 150 thin-sections were cut, and of these, 123 were used for petrographic analysis. Mineral composition was determined by making 500 counts for each thin-section ; this gives an accuracy of plus or minus 3% for 95% of the analyses (Chayes, 1956). The lower limit of definite particle recognition was reached in sandstones with a modal size between 0·05 and 0·1 mm. so that only analyzes of sandstones with a modal size greater than 0·1 mm. were considered to fall within the accuracy limits described above. To avoid errors due to bias or preconceived ideas or trends, the thin-sections were counted in a random order and later grouped into their respective localities and formations.

The sandstones of the Cocoparra Group can be classified as orthoquartzites, protoquartzites and lithic sandstones. Their variation in composition is most suitably illustrated using a modification of the classification proposed by Packham (1954) (Fig. 2).

Barrat Conglomerate

General

The Barrat Conglomerate is the basal formation of the Cocoparra Group and consists of red and thick (five to 20 feet) conglomerate beds and thinner beds of pebbly sandstones, sandstones and siltstones and is commonly between 1,000 and 1,500 feet thick. Conglomerates and pebbly sandstones characteristically make up 10 to 30 percent of the sequence ; sandstones 20 to 60 percent ; the remainder is siltstone. Although conglomerates are not always the dominant lithology, they are the characteristic lithology and define the limits of the formation in the field (Conolly, 1962, 1967).

Almost all sandstones or pebbly sandstone beds are cross-stratified. They frequently occur as cosets of trough cross-strata (McKee and Weir, 1953), or as infillings of solitary scours in the underlying sediments.

Conglomerates

Conglomerate beds generally contain well-rounded pebbles that range in size from one-quarter to six inches in diameter. Most pebbles are a half to two inches in diameter. The pebbles occur in a red lithic sandstone matrix which may make up to 30% (conglomerates) to greater than 90% (pebbly sandstones) of the total rock volume.

The following pebble varieties are found in the Barrat Conglomerate in the Pleasant Valley area :

1. Polycrystalline or vein quartz (40 to 70 percent of the pebble content).
2. Quartzose sedimentary rocks (40 to 60 percent of the pebble content).
3. Chert (five to 20 percent of the pebble content).
4. Rare pebbles of acid or intermediate volcanic rocks.

Thin-sections of these pebble types show that the quartzose sedimentary pebbles consisted mainly of orthoquartzite sandstones and siltstones. The sandstones are poorly-sorted and consist of monocrystalline quartz grains set in a matrix of recrystallized white and green mica. The original rounded boundaries of the quartz grains are corroded and replaced by secondary mica and the rocks are, in places, cut by veins containing secondary quartz and mica intergrowths. Many quartz grains show undulatory extinction and trains of liquid or gaseous inclusions frequently pass from one quartz grain to another. The siltstones are fine-grained equivalents of these sandstones and normally consist of 55 to 75 percent of subangular quartz. The dark brown to black cherts are generally laminated or massive recrystallized chloritic shales with only small amounts (10 to 30 percent) of detrital silt-size quartz.

Sandstones

The sandstones of the Barrat Conglomerate are characteristically dark brown or red, medium to coarse-grained, moderately to well-sorted, consisting of angular to subrounded quartz, sedimentary and volcanic rock fragments, clay pellets, iron oxide patches, set in a clay matrix, and frequently cemented by iron oxide or secondary quartz (Table 2).

Quartz

Quartz grains include monocrystalline and polycrystalline types. The amount of polycrystalline quartz present in the total quartz content increases with increase in modal grain size (Fig. 3). Similar figures showing increase in the percent of polycrystalline quartz with increase in grain size have been shown for other Upper Devonian sandstones in New South

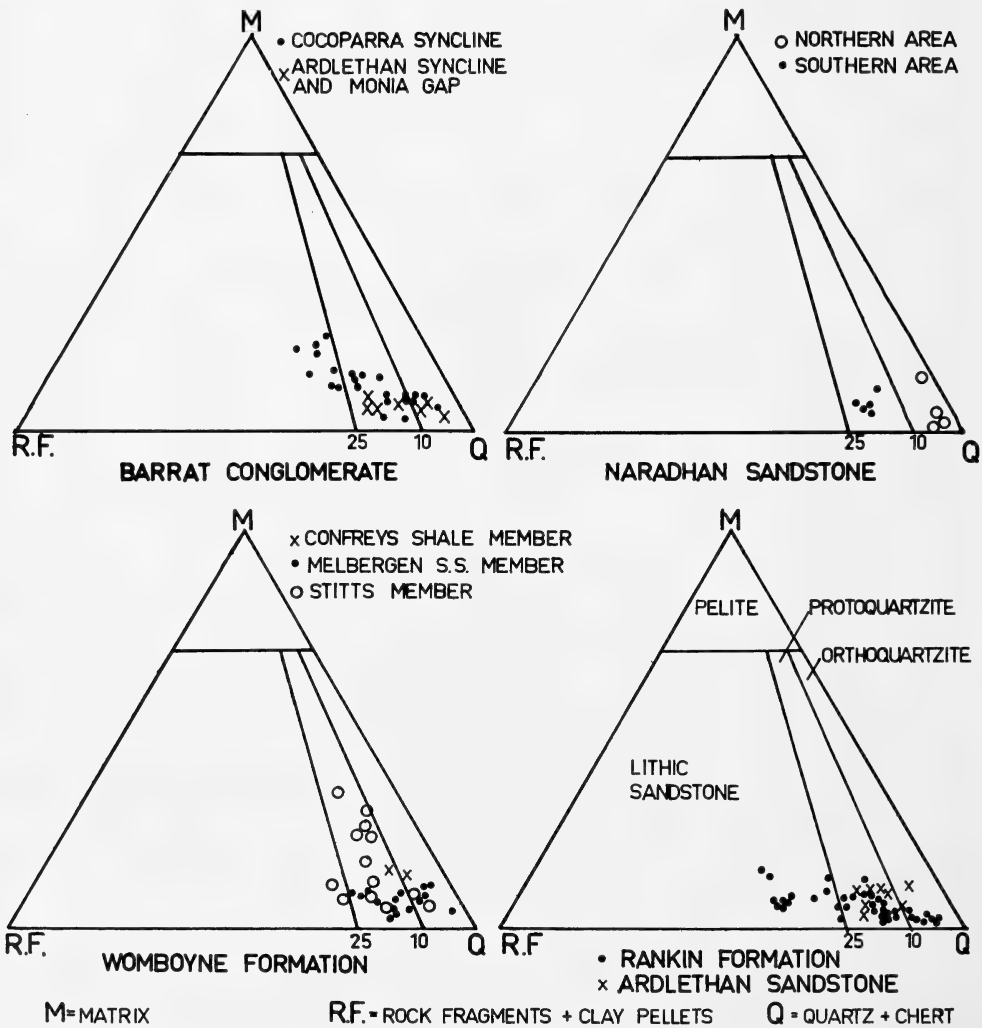

FIGURE 2—Composition of sandstones of the Cocoparra Group using a modified version of the classification proposed by Packham (1960).

TABLE 2

Petrographic analyzes of sandstones of the Cocoparra Group. Each number is a percentage of the total count except the amount of undulatory quartz which is a percent of the monocrystalline quartz (M). Sample numbers refer to samples used by Conolly (1962) and stored in the School of Applied Geology the University of New South Wales.

Locality	Sample Number	Monocrystalline Quartz (M)	Polycrystalline Quartz	Percent Undulatory Quartz in (M)	Chert	Volcanic Rock Fragments	Quartzose Sedimentary Rock Fragments	Shale Rock Fragments	Clay Pellets	Iron Oxides	Secondary Quartz	Matrix	Modal Grain Size (mm.)
BARRAT CONGLOMERATE													
Nabong Range ..	889	25	46	81		9	4			tr		16	1·0
Nabong Range ..	888	57	20	94	tr	tr	12	1	2	2	2	4	0·33
Nabong Range ..	887	70	10	92		1	3	1	5			10	0·3
Nabong Range ..	886	56	10	84		3	5	3	7	2		14	0·24
North West ..	885	35	38	85	tr	3	10	5	1	2	tr	6	0·7
North West ..	884	58	25	78		3	2	2		tr	tr	10	0·55
Nobbies	940	53	7	70		2	6	4	10	1	tr	17	0·18
Nobbies	941	50	5	89		3	4	7	6	2		23	0·25
Nobbies	942	38	20	98	1	1	13	3	5	3		16	0·23
Nobbies	943	40	10	96		2	6	8	7	6	tr	21	0·25
Nobbies	944	35	20	78		3	10	11				21	0·6
Nobbies	946	54	9	45		8	1	5	4	4		15	0·38
Nobbies	947	45	11	43		9	2	2	5	10		16	0·3
Nobbies	948	49	17	35		2	14	2	1	6	tr	9	0·55
Pleasant Valley ..	451	47	14	72			7	10	2	2		18	0·41
Pleasant Valley ..	450	51	32	55		tr	4	3		1	1	8	0·5
Pleasant Valley ..	449	58	5	58		2	2	17	3	1		12	0·32
Pleasant Valley ..	930	40	34	64		3	8	3			3	9	0·8
Pleasant Valley ..	929	31	57	90		tr	4	2			tr	6	1·0
Pleasant Valley ..	928	43	24	85		2	12	5	3	1	tr	10	0·65
Pleasant Valley ..	931	35	30	60		6	3	10		1		15	0·8
Rankin's Springs ..	933	43	38	80		2	10	2	1		tr	4	0·8
Rankin's Springs ..	932	70	15	85		tr	4	1		2	1	7	0·6
Rankin's Springs ..	907	61	14	61		8	3	2	3	1	3	5	0·45
Rankin's Springs ..	906	38	18	73		4	6	4	6	tr	tr	24	0·42
Ardlethan	473	50	30	79		4		3	3	1	tr	9	0·5
Ardlethan	472	42	38	64	tr	4	3	1		tr	4	8	1·0
Ardlethan	471	52	20	62	1	5	4	5	2		2	9	0·48
Ardlethan	470	53	32	56		3	2	1	1		tr	8	0·56
Ardlethan	469	81	10	60			2		2		1	4	0·4
Yalgogrin	950	79	8	55		2	3	2	1		tr	5	0·32
Yalgogrin	951	70	9	63	1	1	9	2			tr	8	0·29
Monia Gap	500	52	20	32		13	3		3	tr	4	5	0·6
Monia Gap	501	66	10	46		4	2	1	2	3	2	10	0·25

TABLE 2 (*Continued*)

Petrographic analyzes of sandstones of the Cocoparra Group. Each number is a percentage of the total count except the amount of undulatory quartz which is a percent of the monocrystalline quartz (M). Sample numbers refer to samples used by Conolly (1962) and stored in the School of Applied Geology at the University of New South Wales.

Locality	Sample Number	Mono-crystal-line Quartz (M)	Poly-crystal-line Quartz	Percent Undula-tory Quartz in (M)	Chert	Volcanic Rock Frag-ments	Quartzose Sedi-mentary Rock Frag-ments	Shale Rock Frag-ments	Clay Pellets	Iron Oxides	Second-ary Quartz	Martix	Modal Grain Size (mm.)
NARADHAN SANDSTONE													
North	503	88	6	26					1		3	2	0·35
North	502	86	7	38					1		4	2	0·32
Naradhan	484	80	2	78					2		tr	16	0·3
North West ..	882	83	8	66		tr	1		1		2	5	0·26
North West ..	883	66	6	61		2	3	1	4	1	1	6	0·3
Rankin's Springs ..	903	64	9	74		1	3	2	10	tr	3	8	0·21
Rankin's Springs ..	904	70	4	75	tr	2	5	3	8		1	7	0·23
Rankin's Springs ..	905	69	7	63	1	4	3	2	4	2	2	6	0·26
Confreys Tank ..	919	62	11	88		1	4	2	9		tr	11	0·21
WOMBOYNE FORMATION — Confreys Shale Member													
Mountain Creek ..	482	70	8	98		1	2	1	6		tr	13	0·14
Mountain Creek ..	483	69	5	89		1		1	9			15	0·11
Melbergen Sandstone Member													
Mountain Creek ..	481A	79	8	74					4		tr	10	0·07
Mountain Creek ..	481B	84	3	72					2			11	0·07
Mountain Creek ..	890	72	7	66	3	1	2	4	3		1	7	0·3
Mountain Creek ..	891	64	5	81	2	3	3	6	10		tr	7	0·18
Mountain Creek ..	892	63	5	78	1	4	8	5	6	tr		8	0·24
Mountain Creek ..	893	70	12	80	5	3	1	3	2		1	3	0·28
Mountain Creek ..	894	80	6	76	2	4	1	2	2		tr	3	0·27
Pleasant Valley ..	927A	72	4	75	tr	1	2	8	6	1		6	0·21
Pleasant Valley ..	927B	65	5	64	1	1	2	5	11	2	1	7	0·2
Pleasant Valley ..	924	82	4	78		1	1	1	3	tr	tr	8	0·12
Pleasant Valley ..	925	78	7	82		1		1	7		tr	6	0·13
Pleasant Valley ..	926	73	6	83		1	2	2	8	tr	1	7	0·2
North West ..	880	72	8	75	1	2	2	5	8			2	0·3
North West ..	881	71	10	64		3	1	5	5		1	4	0·28
North West ..	879	81	3	72		8	1	2	1		tr	4	0·2
West	493	90	4	70					2			4	0·09
West	494	78	8	68	1	2	4	1	2			4	0·32

Stitts Member

Mountain Creek ..	895	61	2	69		1		1	9	2		24	0·07
Mountain Creek ..	896	62	3	64	1	1		1	9	10		13	0·14
Mountain Creek ..	897	63		75					10	2		25	0·06
Mountain Creek ..	898	56	1	71	1	tr			5	15		22	0·08
Mountain Creek ..	899	50	1	79		2			4	13		30	0·06
Mountain Creek ..	900	59	6	68	1	2	3	4	10	tr		5	0·2
West	491	70	9	88	3	1	6	5	1		1	4	0·41
West	492	78	6	85		1	1	1	3	tr	2	8	0·22
North West ..	876	82	6	89	2	1	1	2	2			4	0·23
North West ..	877	73	1	67	2	5	1	4	6		tr	8	0·24
North West ..	878	67	5	87	2	3	3	2	8			10	0·42
Pleasant Valley ..	453A	52	11	94	2	4	5	8	8			10	0·35
Pleasant Valley ..	454	58	8	96	tr	1		2	3	6		22	0·3

ARDLETHAN SANDSTONE

Ardlethan	479	74	3	71		5	6	2	2	2	2	4	0·2
Ardlethan	478	67	6	62	1	8	4	3	2	1	1	7	0·22
Ardlethan	477	70	5	58	2	4	4	1	1	tr	4	9	0·25
Ardlethan	475	78	6	48	2	4	3	3	1	tr	2	11	0·32
Ardlethan	474	74	3	64	2	7	1	1	3	tr	1	8	0·21
Yalgogrin	952	69	9	65		5	12		2	tr	tr	3	0·33

RANKIN FORMATION

Mailman Gap Conglomerate Member

Mailman Gap ..	911	67	15	82	4	3	3	4			tr	4	0·6
Mailman Gap ..	910	67	9	58	2	3	3	7		1		8	0·42
Mountain Gap ..	909	16	56	80	8	4	5	10				1	1·3
Tabbita	920A	33	50	85	6	4	1	2			2	2	1·2
Tabbita	920B	12	70	82	2	2	8				2	4	1·8
Tabbita	921	66	12	58	1	4	4	2	2	tr	3	6	0·44
Mountain Creek ..	901	45	41	93	2	1	1	8			tr	2	1·0

TABLE 2 (*Continued*)

Petrographic analyzes of sandstones of the Cocoparra Group. Each number is a percentage of the total count except the amount of undulatory quartz which is a percent of the monocrystalline quartz (M). Sample numbers refer to samples used by Conolly (1962) and stored in the School of Applied Geology at the University of New South Wales.

Locality	Sample Number	Monocrystalline Quartz (M)	Polycrystalline Quartz	Percent Undulatory Quartz in (M)	Chert	Volcanic Rock Fragments	Quartzose Sedimentary Rock Fragments	Shale Rock Fragments	Clay Pellets	Iron Oxides	Secondary Quartz	Matrix	Modal Grain Size (mm.)
Sequence Above Mailman Gap Conglomerate Member													
Mailman Gap ..	918	90	4	67		tr			4			2	0·11
Mailman Gap ..	917	61	20	51	1	1	10	2			3	2	0·9
Mailman Gap ..	916	72	8	62			10	3	2		2	3	0·5
Mailman Gap ..	915	77	12	76	tr	1	tr	1			7	2	0·55
Mailman Gap ..	914	78	16	83	1	1			1		1	2	0·36
Mailman Gap ..	913	70	7	58	4	2	3	4	2		tr	8	0·33
Mailman Gap ..	912	85	8	74	tr	1	tr	1	2		1	2	0·6
Sim's Gap	491	70	10	65	3	1	7	5			tr	4	0·4
Sim's Gap	490	77	12	68	tr	tr	1	2	1		2	5	0·35
Sim's Gap	489	83	8	77	1	1	2	1	1		1	2	0·22
Sim's Gap	488	44	6	72	5		4	15	10	3		13	0·23
Sim's Gap	487	33	14	79	5		8	10	15			15	0·25
Sim's Gap	486	68	16	65	4	1	3	3	1			4	0·7
Sim's Gap	485	37	44	63	4		7	2			2	4	0·8
Sim's Gap	1005	49	7	70	8	1	9	15	3	2		6	0·32
Sim's Gap	1006	47	10	94	8		12	13	3	1	tr	6	0·46
Tabbita	922	73	14	56	tr	1	1	1	5		3	2	0·3
West	811	52	34	79	2	3	1		1		4	3	0·5
West	872	68	23	75		2			2		2	3	0·6
West	873	58	13	88	3	1	1	11	8			5	0·42
West	874	58	14	75	2	8	1	7	5			5	0·45
West	499	55	10	81	2		4	8	7	4		10	0·31
West	498	59	25	94	4	1	2	4	1		1	3	0·63
West	497	55	22	66	3	2	6	6	2		tr	4	0·4
Pleasant Valley Region													
Top Member ..	464	50	12	45	3	1	4	10	10	3		7	0·34
Top Member ..	463	64	18	63	4	1	3	2	2		4	2	0·42
Top Member ..	462	70	9	38	4	1	2	2	1		5	6	0·46
Middle Member ..	461	52	20	81	4	3	4	4	6			7	0·35
Middle Member ..	460	36	22	60	16	3	11	4	2		tr	6	0·45
Middle Member ..	459	45	25	74	6	3	8	3	2			8	0·4
Middle Member ..	458	45	29	78	5	1	9	1	1			9	0·8
Middle Member ..	457	61	20	81	3	2	3	4	3		tr	4	0·5
Basal Member ..	456	50	15	76	2	2	6	8	4		tr	13	0·3
Basal Member ..	455	32	40	72	2	tr	5	4	2		1	14	0·7
Basal Member ..	923	46	11	68	2	10	3	9	2		1	6	0·4

Wales (Conolly, 1965*b*). The polycrystalline quartz content generally ranges from 10% for fine-grained sandstones to values as high as 60% of the total quartz content for coarse-grained sandstones (Table 2). No significant differences could be found in the amount of polycrystalline quartz in sandstones from different sample localities (Fig. 3). The polycrystalline quartz generally consists of a mosaic of interlocking quartz grains with no preferred grain orientation, but with undulatory extinction, and with sutured or smooth grain boundaries (Plate 1, Fig. 2), and is presumed to be derived from vein quartz and from recrystallized quartzose sediments similar in composition to those that occur so abundantly as rock fragments in the sandstones and as pebbles in the conglomerates.

The monocrystalline quartz consists of grains with undulatory or non-undulatory extinction. Generally 60 to 90 percent of the monocrystalline grains have undulatory extinction (Table 2). Most non-undulatory grains are characterized by rounded, smooth and frequently conchoidal grain boundaries or grain embayments, conchoidal fractures, and a general lack of gaseous, liquid, or mineral inclusions and are hence presumed to be derived from volcanic source rocks (Plate 1, Figs 1, 2, 4). High percentages of monocrystalline quartz with undulatory extinction could probably be caused by post-depositional folding or faulting (Conolly, 1965*b*).

Secondary quartz overgrowths on detrital grains is the dominant cement (Table 2). Dust particles, small mineral grains, or iron oxide commonly occur on the original detrital grain boundaries, and the secondary overgrowths are generally free of inclusions. A small percentage of detrital quartz in most sandstones shows two periods of secondary quartz outgrowth indicating derivation from old sedimentary source rocks.

The total amount of quartz, or, the quartz index, of the sandstones of the Barrat Conglomerate ranges from 84 to 66 percent of the total volume of the rock (Fig. 4). Generally, there is little difference in quartz index from one sample to another. A quartz index of 66 in the north-western sample area is probably a reflection of the less mature nature of the sandstones in that area, for these sands generally have a higher proportion of angular detrital grains. Conversely, the high quartz index of 84 for the sandstones from the Yalgogrin area is probably a reflection of their greater maturity, for these sands are generally much better sorted and consist of subrounded or rounded grains.

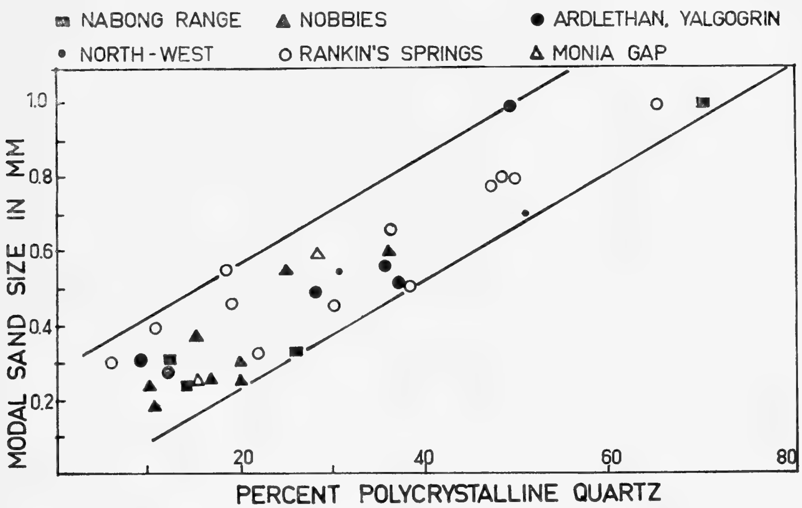

FIGURE 3—Percent polycrystalline quartz in the sandstones of the Barrat Conglomerate plotted against modal sand size. The percent of polycrystalline quartz increases with increase in grain size. No significant differences exist between sandstones from different localities.

Volcanic rock fragments

Volcanic rock fragments are generally of an acid volcanic type and the following three main varieties occur:

1. Mosaics of feldspar and quartz of devitrified rocks (Plate 1, Figs 3 and 4).

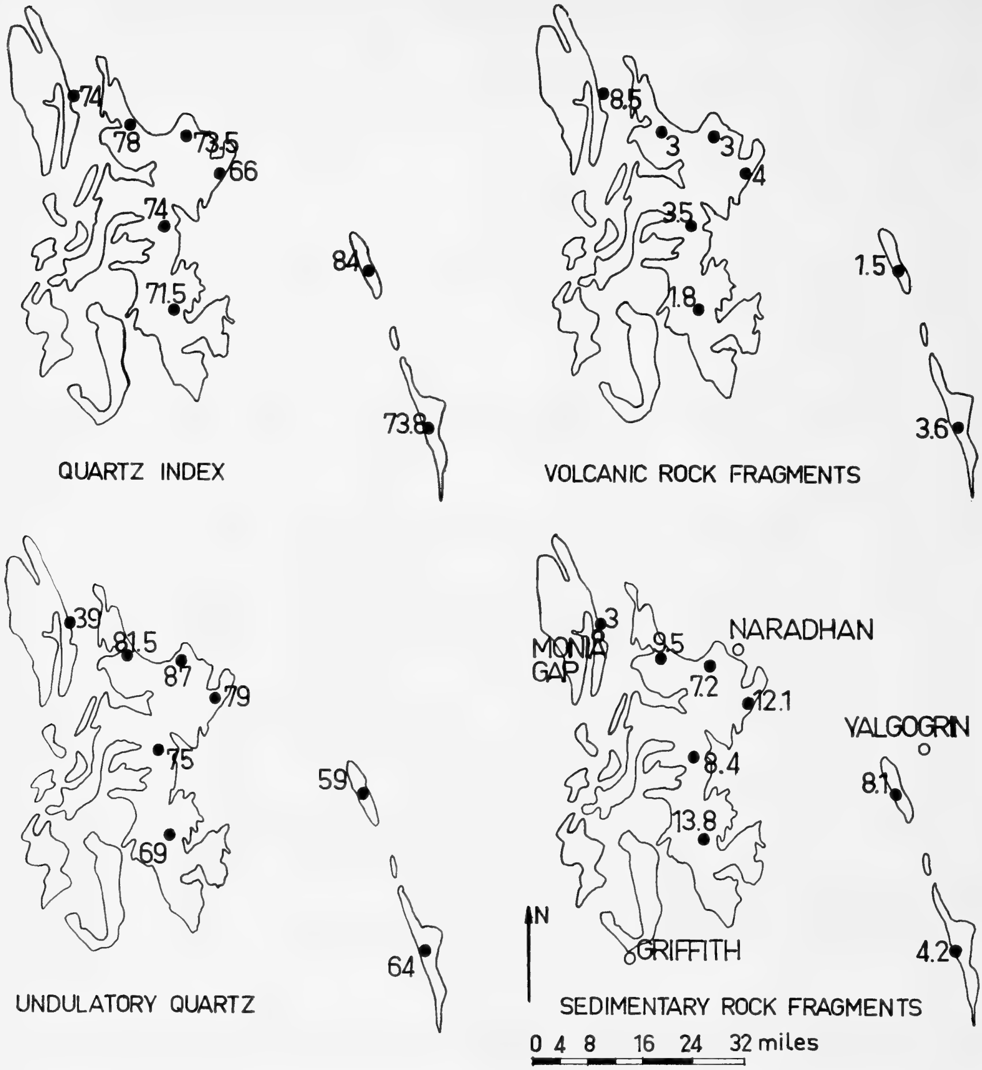

FIGURE 4—Quartz index, percent undulatory quartz in the monocrystalline quartz fraction, and percent volcanic and sedimentary rock fragments present in the sandstones of the Barrat Conglomerate. Values obtained by averaging the values obtained from petrographic analyzes from different sample areas.

2. Particles with relic quartz or feldspar phenocrysts (Plate 1, Fig. 1).
3. Particles having a "rhyolitic" or fluidal fabric (Plate 1, Fig. 3).

Mosaics of devitrified rocks are the commonest variety, and are generally altered to clay or iron oxide. Volcanic rock fragments generally make up two to nine percent of the total volume of the sandstone and 20 to 40 percent of the rock fragment content. High values of volcanic rock content occur in the northern-most sample areas probably indicating derivation of these particles from basement volcanic rocks, perhaps from part of the Ural Range Complex (Conolly, 1962).

Sedimentary rock fragments

Sedimentary rock fragments are normally more abundant than volcanic rock fragments and make up 60 to 80 percent of the total rock-fragment-content of the sandstones. The common varieties of sedimentary rock fragments are:

1. Quartzose siltstones and fine-grained sandstones. These are moderately sorted and consist of angular and subangular quartz set in a clay matrix (Plate 2, Fig. 1).

They are commonly partially or wholly recrystallized, and traversed by quartz veins.

2. Shale rock fragments, consisting of clay and fine silty quartz, and often very compact or cherty in appearance (Plate 2, Figs. 1 and 4).

The percentage of either type of sedimentary rock fragment varies considerably from one locality to another making it difficult to discern any obvious trends in distribution (Table 2). Generally, quartzose sedimentary rock fragments are as abundant as shale fragments except in the very northern outcrop areas west of Naradhan where they occur more abundantly than shale fragments. The breakdown of these shale fragments with increased transportation may be responsible for the slightly greater relative amounts of clay pellet fragments in the northern sandstones, or the high percentage of shale fragments in the southern sandstones may be caused by local source areas rich in shale fragments.

Clay pellets and clay matrix

Clay matrix and clay pellets make up a considerable portion (10 to 25 percent) of the sandstones of the Barrat Conglomerate. The clay which is mainly a meshwork of small illite grains, occurs infilling spaces between detrital grains. Discrete patches of kaolinitic clay are also quite common, but not nearly as abundant as illite. X-ray analyzes of the clay in the sandstones show that it consists of about 70% illite and 30% kaolinite (Conolly, 1965*d*). The percent of clay pellets tends to increase with decrease in the grain size of the sandstone (Fig. 5) due to the breakdown of these pellets with increase in distance of transportation and the necessary accumulation of the finer particles in the finer-graded sandstones.

Iron oxide and secondary quartz

Iron oxide in the form of hematite is the most abundant cement in the sandstones of the Barrat Conglomerate. It fills the pore spaces between grains, forms rims on detrital quartz grains and occurs as discrete particles. Hematite is most abundant in the more poorly-sorted sandstones, whereas secondary quartz overgrowths are more abundant in the better-sorted sandstones. Hence, it is uncommon to find large amounts of secondary quartz and hematite cement in the same sandstone. When the two cements occur together, it is common to find secondary quartz outgrowths covering iron oxide quartz rims, indicating formation of secondary quartz later in the diagenesis of the sandstones, and suggesting that most of the iron oxide is primary detrital material.

The percent of secondary quartz decreases with increase in the amount of matrix (Fig. 6), a relationship that has been shown before for the Upper Devonian Macquarie Park Sandstone of the Catombal Group (Conolly, 1963). The control of the amounts of secondary quartz present appears to be a function of the amount of space available for growth, and the porosity and permeability of the sandstones. With increased amounts of clay matrix, there is generally a decrease in sorting, permeability, pore-space and hence in the amount of secondary quartz overgrowths on detrital quartz grains.

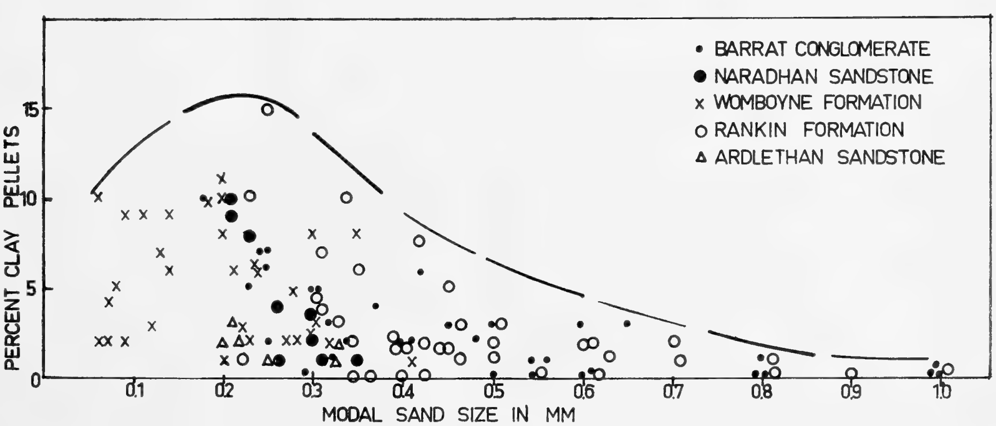

FIGURE 5—Comparison of percent clay pellets present in the sandstones of the Cocoparra Group with modal sand size. Clay pellets are most abundant in fine-grained sandstones. The percentage of clay pellets tends to decrease with increase in grain size.

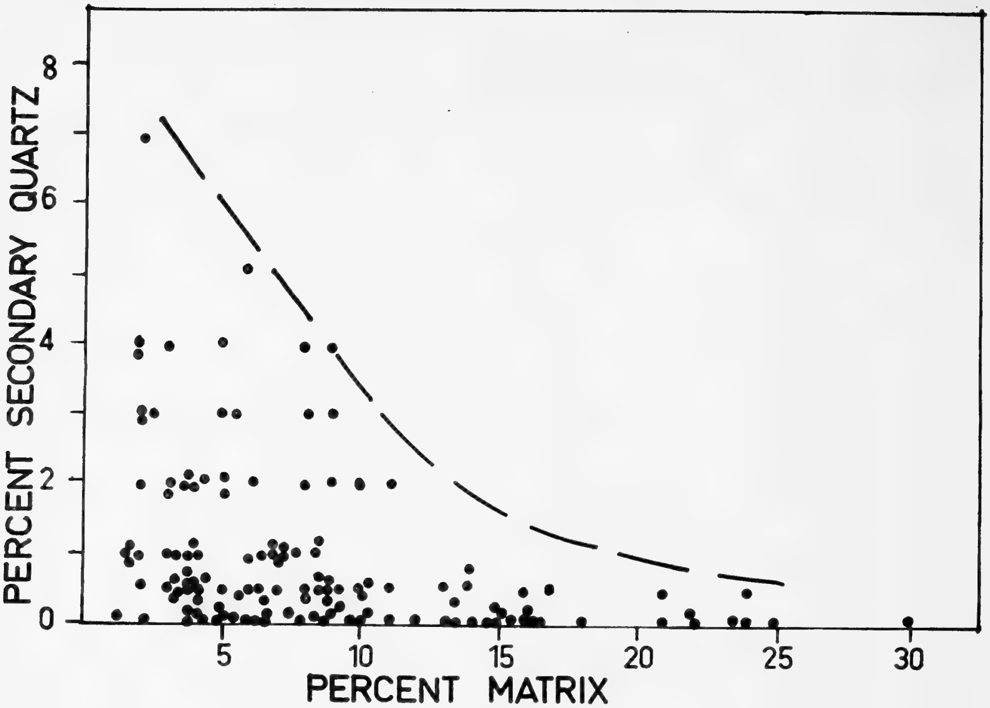

FIGURE 6—Percent clay matrix plotted against percent of secondary quartz for the sandstones of the Cocoparra Group. Secondary quartz is common in sandstones with small amounts of of clay matrix and rare in sandstones with high percentages of clay matrix.

Siltstones and Shales

Approximately 20 thin sections of these fine-grained sediments have been examined, showing that they are very similar in texture and composition to the siltstones and shales of the Hervey Group (Conolly, 1965*c*). Red siltstones are very abundant. They occur in thin (one to six inch) beds, and consist of 40 to 70 percent of angular silt-size quartz set in a matrix of illitic clay and clay pellets. Iron oxide occurs as iron patches, or colouring clay patches or pellets, and is probably mainly detrital in origin. Siltstones without high percentages of iron oxide fragments are much lighter coloured but occur more rarely.

Red shales are less common and contain less (10 to 30 percent) silt-size quartz, and a higher iron oxide content.

Formations of the upper part of the Cocoparra Group

General

The sequence above the Barrat Conglomerate consists of up to 15,000 feet of interbedded white to red quartzose sandstones, siltstones and, more rarely, shales. It has been subdivided into three formations in the Cocoparra Syncline, called from the base, the Naradhan Sandstone, Womboyne Formation, and the Rankin Formation, and lumped into one formation, the Ardlethan Sandstone, in the Ardlethan area (Table 1).

The Naradhan Sandstone is characterized by white protoquartzites and orthoquartzites (Conolly, 1962, 1967), the Womboyne Formation by a high proportion of red siltstones and fine-grained sandstones, and the Rankin Formation by abundant coarse-grained protoquartzites and lithic sandstones (Fig. 2). The Ardlethan Sandstone consists of lithologies similar to all of these, but is dominated by red sediments. The sandstones are either cross-stratified, or form laminar beds, and the siltstones are frequently rippled, mudcracked or form small sets of cross-strata. Details of the stratigraphy, lithology and sedimentary structures of these formations have been described previously (Conolly, 1962, 1967).

Petrology

Petrographic analyzes were made from 89 thin-sections of sandstones (Table 2). The detrital rock fragments in these sandstones are

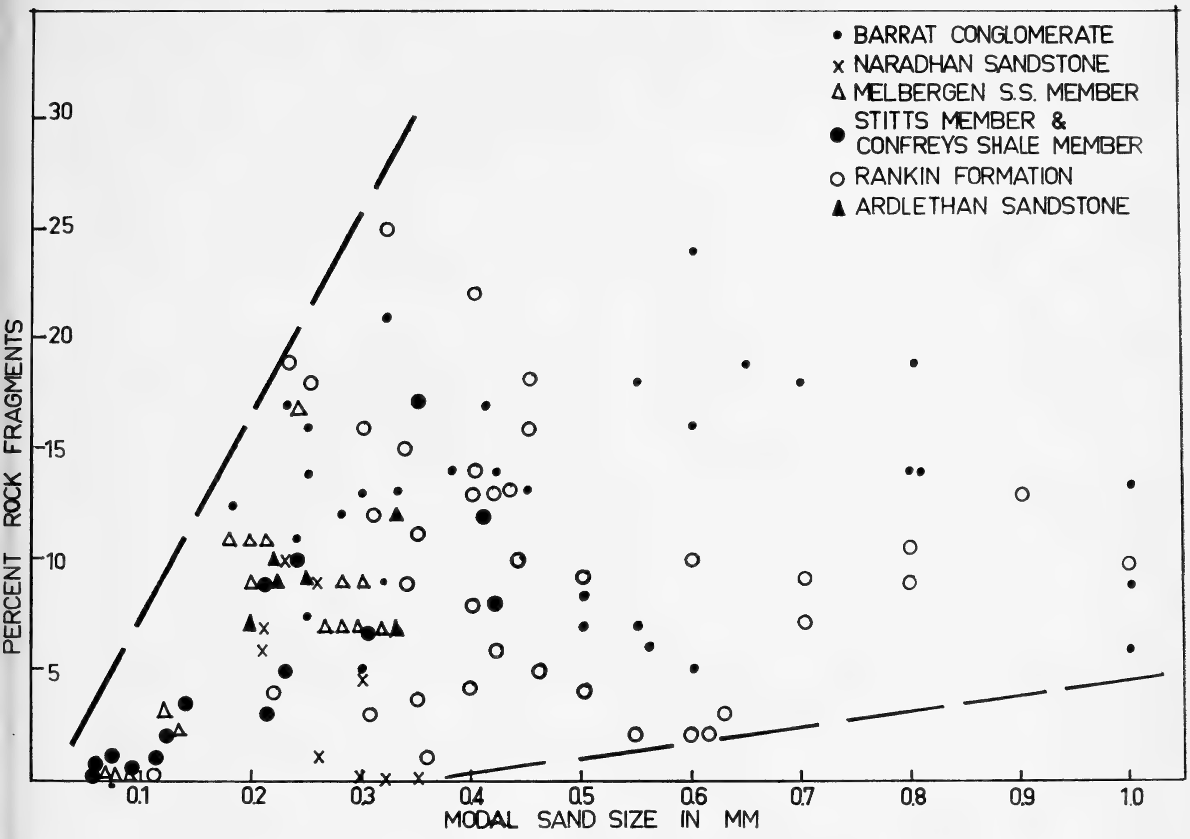

FIGURE 7—Percent rock fragments present in sandstones of the Cocoparra Group plotted against modal sand size. Although there is a wide distribution of plotted points, rock fragments are most abundant in coarse-grained sandstones. No significant differences in the amount of rock fragments occur between the different formations of the Cocoparra Group.

similar to those described for the sandstones of the Barrat Conglomerate; however, differences do exist in the amounts and distribution of these grains, and in the texture of the sandstones. These differences are best discussed by referring to the table of petrographic analyzes (Table 2) and to figures illustrating the distribution of percentages of different detrital grains from several main sample areas for each formation (Figs 8, 9, 10, 11 and 12).

Generally the percentage of rock fragments in a sandstone increases with increase in grain size (Fig. 7) and this rather feeble trend could control the percentages of rock fragments in a sample area, particularly if all the samples were either fine or coarse-grained. In this investigation the samples from any sample area cover a fairly large grain-size range, and hence the percentages of different rock fragments from each locality have been averaged.

Quartz

There is little difference in quartz indices from one formation to another. Most quartz indices range from 80 to 90, indicating extremely quartz-rich sandstones are characteristic of all formations. Quartz indices for the upper formations (Fig. 8) indicate that the most quartzose sandstones occur in the northern outcrop areas for all of the upper formations.

This trend suggests that the sediments are being transported northward and that with increase in transportation distance there is a corresponding increase in the quartz content of the sandstones. Polycrystalline quartz makes up a considerable portion of the detrital quartz fraction, and the amount of polycrystalline quartz has been shown (Conolly, 1965*b*) to increase with increase in grain size. When grain size is considered, no significant differences were found in the amount of polycrystalline quartz in either a lateral or vertical sense suggesting that changes in source rock composition and dispersal had little effect on the percentage of polycrystalline quartz in sandstones.

The percentage of undulatory quartz in the monocrystalline quartz fraction of the sandstones generally lies between 60 and 90 percent. This value is higher than that found by Blatt and Christie (1963) for orthoquartzites. Since orthoquartzite sandstones are credited with a concentration of non-undulatory quartz, the percentages of undulatory quartz in these sandstones must be caused by derivation from rocks rich in undulatory quartz, namely, metamorphozed and folded sediments, and granites. The rather low values of undulatory quartz in the northern sample areas for the Naradhan Sandstone and the Stitts Member of the Womboyne Formation, suggest that these rocks are more mature. The undulatory quartz should be destroyed with increase in transportation at the expense of the more mechanically unstable non-undulatory variety (Blatt and Christie, 1963).

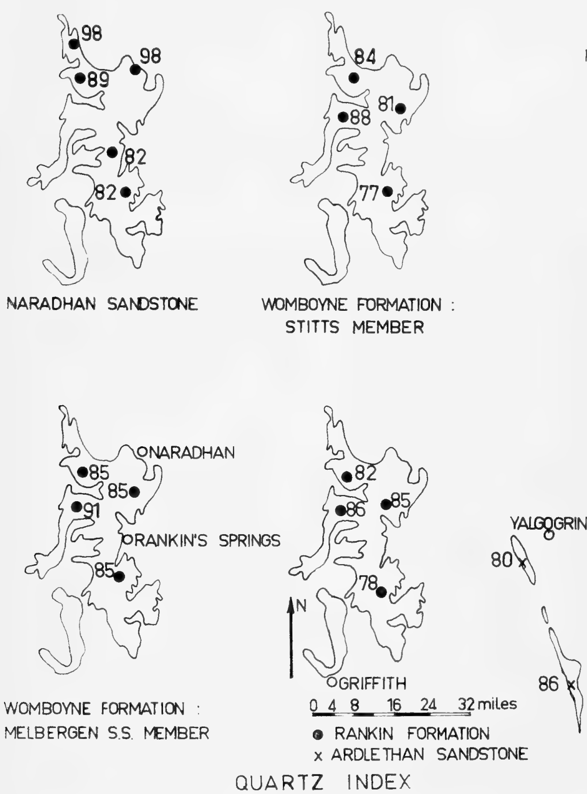

FIGURE 8—Quartz indices (percent quartz in the detrital grain fraction) for the upper formations of the Cocoparra Group. Values are averaged from petrographic analyzes from each sample area.

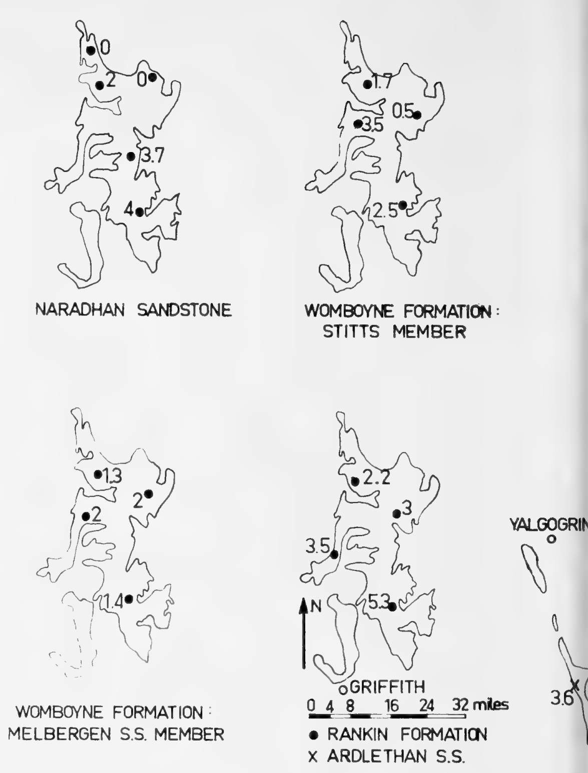

FIGURE 9—Percent quartzose sedimentary rock fragments present in the sandstones of the upper formations of the Cocoparra Group. Values are averages of the quartzose sedimentary rock fragment content from each sample area.

Quartzose sedimentary rock fragments

Quartzose sedimentary rock fragments occur throughout the upper formations of the Cocoparra Group (Plate II, 1). The percent of these fragments present in the sandstones varies considerably from sample to sample (Table 2), and average values for sample areas range from 0 to 5·3 percent of the total rock content (Fig. 9). High values of quartzose sedimentary rock fragments are characteristically found in the southern outcrop areas in the Cocoparra Syncline. This trend is similar to other trends already discussed, suggesting increased transportation and maturity of sandstones towards the north.

Shale and chert rock fragments

Shale rock fragments are more abundant in the southern area of outcrop than the north (Fig. 10) in the Naradhan Sandstone and the Stitts Member of the Womboyne Formation also suggesting transportation from south to the north during deposition of these two rock

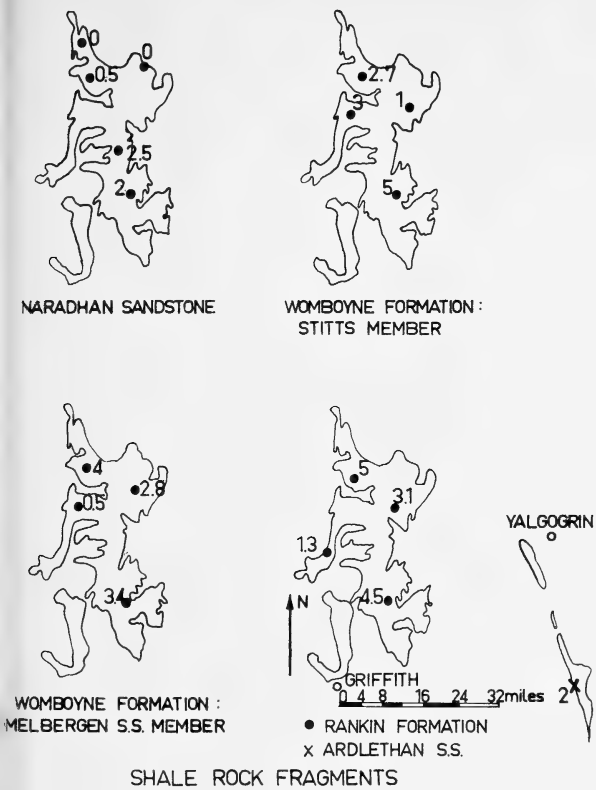

FIGURE 10—Percent shale rock fragments present in the sandstones of the upper formations of the Cocoparra Group. Values are averages of the shale rock fragment content from each sample area.

units. Shale rock fragments are particularly abundant in the Rankin Formation and occur associated with a high percentage of chert (Fig. 11). imparting a "spotted" texture to the sandstones as seen in hand specimen. Chert is relatively rare in all other formations in the Cocoparra Group.

Volcanic rock fragments

Devitrified acid volcanic rock fragments occur throughout the sequence (Plate II, 3). They are especially more abundant in the upper sequences of the Womboyne Formation and the Rankin Formation (Fig. 12). No other significant distribution can be found and the high percentages in the uppermost formations is probably a reflection of increase in the exposure of volcanic rocks in the source area.

Clay pellets and clay matrix

The clay in the sandstones predominantly consists of kaolinite and illite although chlorite and montmorillonite occur in small amounts. The kaolinite is mainly produced due to post-depositional alteration of existing detrital rock fragments and clay matrix, and frequently occur as discrete patches of small crystal or kaolinite "books" (Conolly, 1965*d*). The percentage of clay pellets tends to decrease with increase in grain size (Fig. 5). Very fine-grained sandstones and siltstones contain very few clay pellets, hence it appears that sandstones with modal sand sizes between 0·1 and 0·4 mm. tend to have high percentages of clay pellets. This tendency can be correlated with the author's observation that sandstones in this grain size range generally exhibit the best sorting. With increased transportation, and hence increased sorting, clay pellets are produced due to breakdown of clay-rich rock fragments and possibly, agglutination of detrital clay fragments.

Secondary quartz and iron oxide

Secondary quartz occurring as outgrowths on detrital quartz grains occurs as a cement in most sandstones and is only absent in the

FIGURE 11—Percent chert present in the sandstones of the upper formations of the Cocoparra Group. Values are averages of the chert content from each sample area.

FIGURE 12—Percent volcanic rock fragments present in the sandstones of the upper formations of the Cocoparra Group. Values are averages of the volcanic rock fragment content from each sample area.

presence of high amounts of clay matrix (Fig. 6) or high percentages of iron oxide. Secondary quartz cement makes up one to four percent of the Naradhan Sandstone and the Ardlethan Sandstone, but is less common in the relatively more poorly-sorted sandstones of the Womboyne and Rankin Formations. Iron oxide, mainly hematite, occurs abundantly in some parts of the Womboyne Formation, and in some fine-grained red sandstones in the Mountain Creek area makes up five to 10 percent of the rock. It generally occurs as discrete iron-rich particles that are normally alterations of volcanic or sedimentary rock fragments. Iron oxide occurs far less commonly as a cement.

Composition of the Source Rocks

Heavy Minerals

The heavy minerals separated[1] from the sandstones of the Cocoparra Group consist of tourmaline, zircon, rutile, muscovite, garnet, apatite, ilmenite, magnetite, and hematite-limonite, leucoxene-limonite mineral complexes (Table 3). All heavy minerals occur commonly except apatite and garnet, which have only been found in some poorly-sorted red lithic sandstones from the Womboyne Formation. The tourmaline, zircon, rutile, ilmenite and magnetite invariably occur as well-rounded grains. However, small percentages of angular tourmaline and zircon do occur and estimates of the rounded to angular grains have been made for each formation (Conolly, 1962).

Angular tourmaline and zircon are especially abundant in the lithic sandstones of the Barrat Conglomerate where approximately 30% of the tourmaline and 60% of the zircon is angular. These high percentages certainly suggest that most of the zircon and a great proportion of the tourmaline are derived from igneous or metamorphic rocks. The angular tourmaline is pleochroic (dark brown to green) and generally full of bubbles and cavities typical of the granitic variety described by Krynine (1946).

Only 5% of the tourmaline and 10 to 20 percent of the zircon is angular in the sandstones in the formations overlying the Barrat Conglomerate, suggesting that either rounding of the grains took place during transportation, or there was less material being derived from granitic rocks in the source area. Rounding during transportation is favoured, because, at the onset of deposition, the initial basal sediments of the Barrat Conglomerate were probably derived from nearby basement rocks. The remainder of the well-rounded tourmaline, zircon, rutile, ilmenite and magnetite grains were probably derived from reworked sedimentary source rocks. Apatite, which occurs as rounded and pea-shaped grains, and, associated garnet grains are also probably derived from reworked sedimentary rocks.

The occurrence of apatite and garnet in only the more immature red sandstones is common elsewhere in the Upper Devonian rocks of central New South Wales (Conolly, 1962) and apparently is due to the less mechanically and chemically resistant nature of the minerals. Magnetite is not abundant and makes up less than 5% of the ilmenite-magnetite fraction.

Hematite-limonite, and leucoxene-limonite mineral complexes make up the bulk of the heavy mineral fraction. The limonite probably owes its origin to post-depositional alteration in the porous sandstones during weathering. Leucoxene is the common heavy mineral of the white sandstones, whereas hematite is characteristic of the red sandstones. The leucoxene grains can be subdivided into ilmenite-leucoxene grains, white opaques, or amber-like

[1] Using bromoform (S.G. 2·8).

TABLE 3

Average heavy mineral composition of sandstones in the Cocoparra Syncline from Conolly, 1962.

Formation	Tourmaline	Zircon	Ilmenite and Magnetite	Hematite and Limonite	Leucoxene and Limonite	Rutile	Muscovite	Garnet	Apatite	Number of Analyzes
Barrat Conglomerate . .	5	4	7	76	4	1	3			4
Naradhan Sandstone . .	21	15	8	11	37	5	3			6
Womboyne Formation . .	25	16	3	7	40	6	3	Trace	Trace	20
Rankin Formation . .	21	17	3	7	44	4	4			8

grains using the classification proposed by Golding (1955). Most leucoxene belongs to the white-opaque and amber-like grain groups. A great deal of the leucoxene may be formed *in situ*, although some well-rounded ilmenite-leucoxene grains probably have been derived from sedimentary rocks in the source area.

Petrology

Barrat Conglomerate

The composition of the source rocks of the Barrat Conglomerate can be estimated from the mineralogy of the pebbles in the conglomerates and the detrital grains in the sandstones (Fig. 13). The mineralogy of the sediments suggests that three different groups of rocks are present in the source area:

1. A folded sedimentary sequence of quartzose sandstones, siltstones, shales and cherty shales. Ordovician and Silurian rocks of this composition outcrop over a large area of southern New South Wales and northern Victoria. The rocks are generally quite intensively folded, and characterized by a low grade of regional metamorphism. They are commonly traversed by quartz veins or partly recrystallized to form quartzites. The Quaternary soils produced on these rocks have a high content of white vein or polycrystalline quartz pebbles, quartz sand, quartz silt, and micaceous clays. Weathering of these rocks during the Devonian may have produced similar detritus that would then have been available for erosion, transportation, and deposition, to form part of the sediments of the Cocoparra Group. It is estimated that 50% of the detritus in the Barrat Conglomerate was derived from quartzose sandstones and siltstones, and 26% from shales and cherty shales (Fig. 13).
2. Granite was the next major source rock. Lower Palæozoic granites are abundant in southern New South Wales and northern Victoria, and outcrop over almost as great an area as do the Ordovician-Silurian sedimentary succession. Weathering of granitic rocks produces different soils under different climatic conditions, but undulatory quartz is almost always released (Blatt and Christie, 1963).
3. Acid volcanic rocks form the third source-rock suite. Rocks of this composition were formed during the Silurian and early Devonian throughout most parts of southern New South Wales and northern Victoria and they make up a much lesser proportion by volume of the basement complex. Most volcanic rocks have suffered extensive devitrification, but, in general, grains derived from these rocks are surprisingly hard and chemically inert. Acid volcanic rocks are estimated to have contributed 8·5% of the detritus of the Cocoparra Group and granitic rocks 15·5% (Fig. 13).

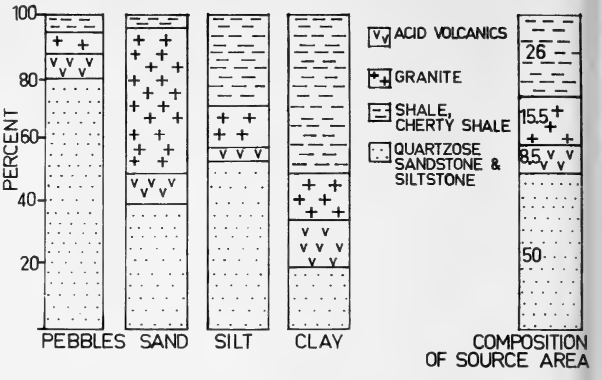

FIGURE 13—Estimates of the different source rocks contributing to the pebble, sand, silt and clay fraction of the Barrat Conglomerate, and an estimate showing the composition of the source rocks weighting pebble, sand, silt, and clay fractions in the ratios of 10 : 30 : 30 : 30.

The upper formations of the Cocoparra Group

Estimates of the composition of the source rocks for these formations could be made using a procedure similar to that discussed for the Barrat Conglomerate. By straightforward comparison of the mineralogy of the sandstone, it is seen that the source rocks must have been similar (Table 2). Differences in composition are probably mainly related to differences in textural maturity and not the product of significant changes in source rock composition. Chert and cherty shale fragments are the only detrital grains that become significantly more abundant in these upper formations (Stitts Member of the Womboyne Formation and the Rankin Formation). This change in sandstone mineralogy suggests an increase in the area of these rocks exposed in the source area.

Location of the Source Area

Regional Relations

When all areas that were surfaces of deposition during the late Devonian are excluded, the possible source areas for the Cocoparra Group lie to the west and south of its present location. To the west are the metamorphozed Precambrian and early Palæozoic rocks of the Broken Hill Block and its extension into South Australia (Packham, 1962). In as much as the metamorphic minerals, staurolite, andalusite, sillimanite and associated metamorphic rock fragments typical of this group of rocks have not been found in the Cocoparra Group, the high grade metamorphic rocks from this western area could be excluded as a possible source even though higher structural levels of the Precambrian and early Palæozoic metamorphic rocks could certainly have contributed lower metamorphic grade detritus during the Upper Devonian.

Stratigraphic evidence shows coarsening of presumably flood-plain deposits towards the south, and palæocurrent measurements also show that the sediments were deposited by northerly-flowing currents (Conolly, 1962, 1967). Evidence from stratigraphy and palæocurrents then supports a southern source land hypothesis.

Mineralogical Trends

Mineralogical trends interpreted as supporting derivation of the sediments from a southern land mass have already been described in some detail in the section on petrology but the sandstones and conglomerates of the Barrat Conglomerate are partly derived from local basement highs. For instance, high percentages of volcanic rock fragments in the northern outcrop area may indicate the influence of the volcanic basement rocks of the Ural Range to the north whereas high percentages of shale fragments in the south indicate that these particles may be derived from the south. In all other sequences above the Barrat Conglomerate there is an increasing mineralogical maturity of the sandstones towards the north. This trend certainly supports the hypothesis of derivation of these rocks from a southern land mass.

Sedimentation

Regional Relations

The basal sediments of the Cocoparra Group (the Barrat Conglomerate) were deposited on an eroded surface of granite, acid and intermediate volcanics and folded quartzose sediments of early Palæozoic age. The nature of the bedding, rapid change of thickness of individual beds along the strike, and the occurrence of fining-upward cycles of conglomerate, sandstone and siltstone, and lack of marine fossils suggest that these sediments were deposited by rivers and streams on a flood plain.

The upper half of the Barrat Conglomerate is characterized by large thicknesses of red siltstones and a lessening in the amount of coarse material perhaps indicating less deposition of sand and gravel by bed load, but rather, deposition of quartz silt and shale by more sluggish streams or as overbank deposits.

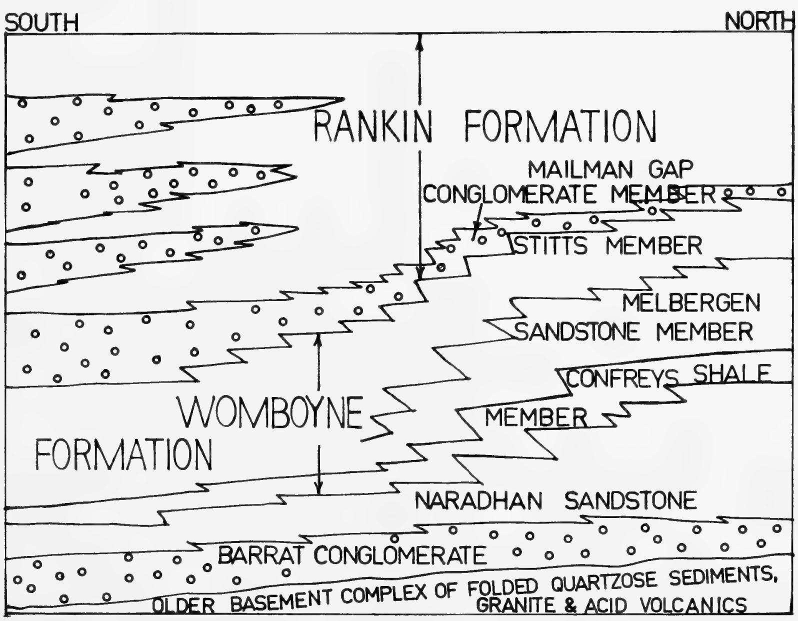

FIGURE 14—Sketch showing the general facies relationships of formations of the Cocoparra Group along a north-south section in the Cocoparra Syncline.

The deposition of the Naradhan Sandstone indicates another active period of sand accumulation. Deposition was greatest in an area in the north, near Naradhan and decreased towards the south. Upward-fining cycles of coarse to fine sediment (30 to 100 feet thick) are characteristic features of some sections and suggest deposition by streams. Elsewhere, large thicknesses (300 to 400 feet thick) of laminar and cross-stratified sands and silts may represent areas where sandy point bars and levee deposits have coalesced.

The sediments of the three members of the extremely thick Womboyne Formation resemble the sediments of the upper part of the Barrat Conglomerate and the Naradhan Sandstone. The basal Confreys Shale Member of the Womboyne Formation represents a stage similar to the upper fine-grained facies of the Barrat Conglomerate. The Melbergen Sandstone Member is a thick wedge of fairly well-sorted sand and silt that thins very rapidly south from the Naradhan area and is similar to the Naradhan Sandstone.

The Rankin Formation thickens southward whereas the formations overlying it thicken northward. This suggests the facies relation shown in Fig. 14 exists. Measurements of cross-stratification directions in the Rankin Formation indicate that palæocurrents came from the south and southwest (Conolly, 1962) supporting the hypothesis of deposition by northerly-flowing streams. Upward-fining cycles of cross-stratified beds of conglomerate or pebbly sandstone, into thinner beds of cross-stratified sandstone, and then into thin beds of siltstone are particularly characteristic of the Rankin Formation in the Pleasant Valley area. These cycles are similar to those described by Allen (1962, 1963) in the lower Old Red Sandstone of England and are probably deposited by offlap deposition by migrating rivers.

Acknowledgements

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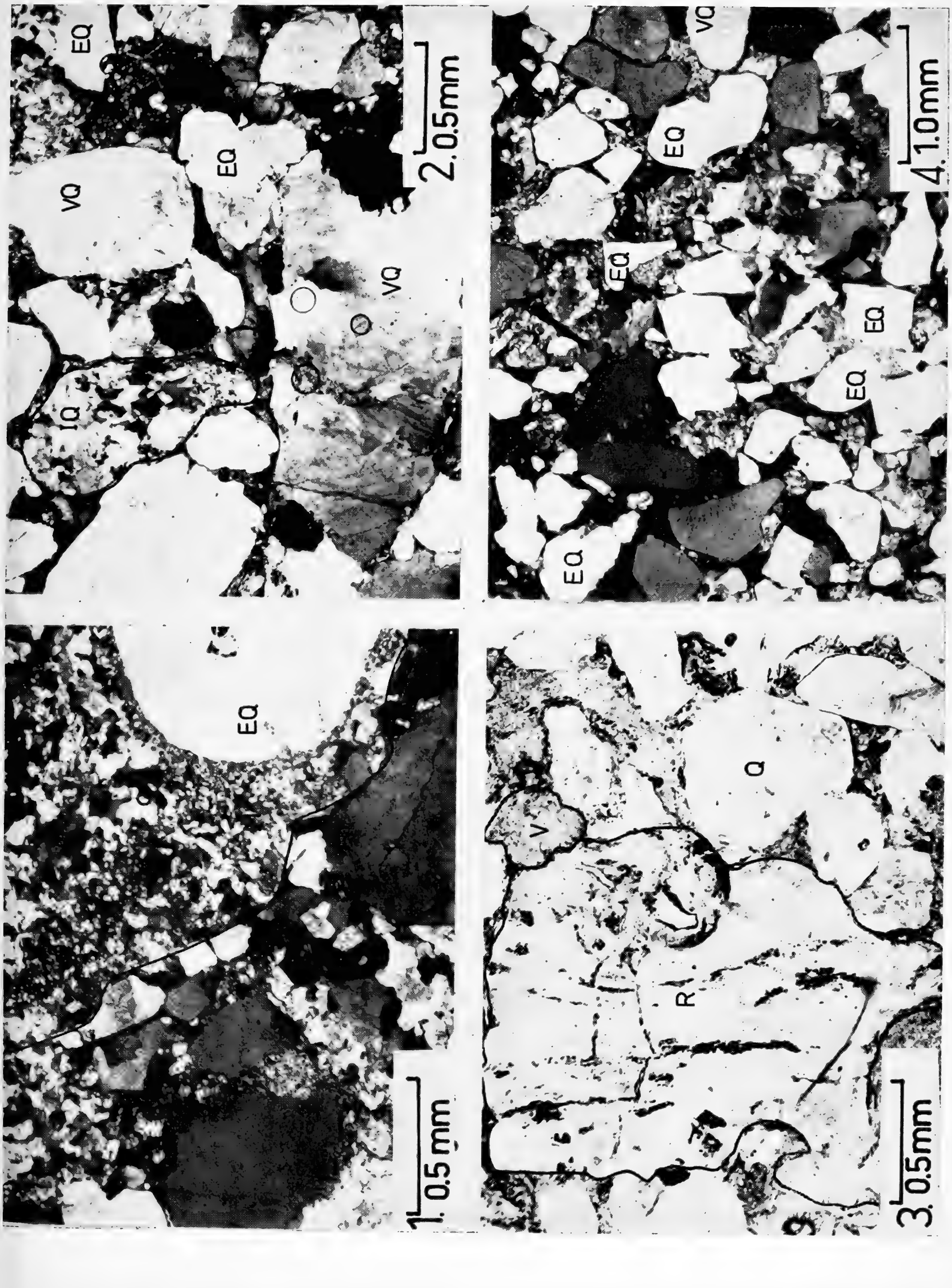
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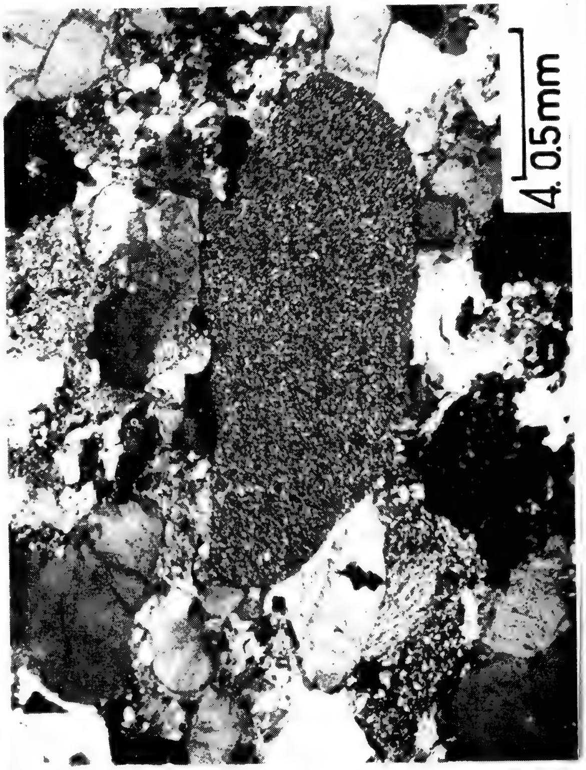
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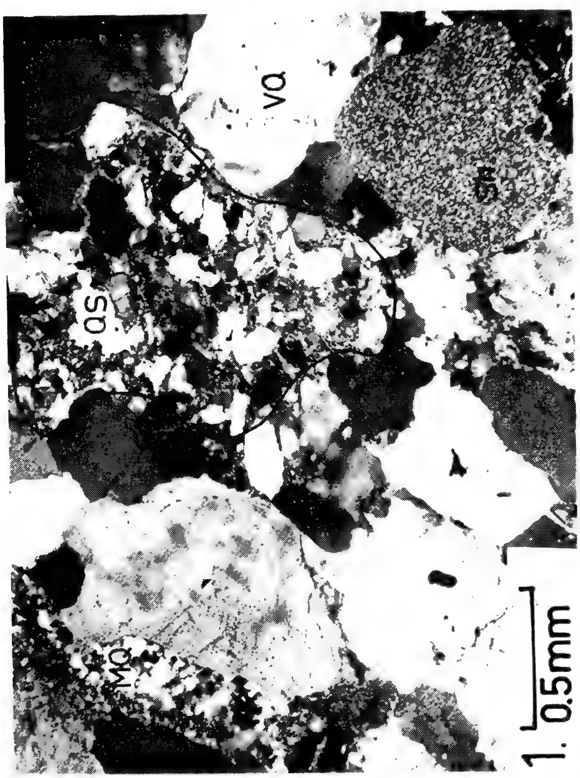
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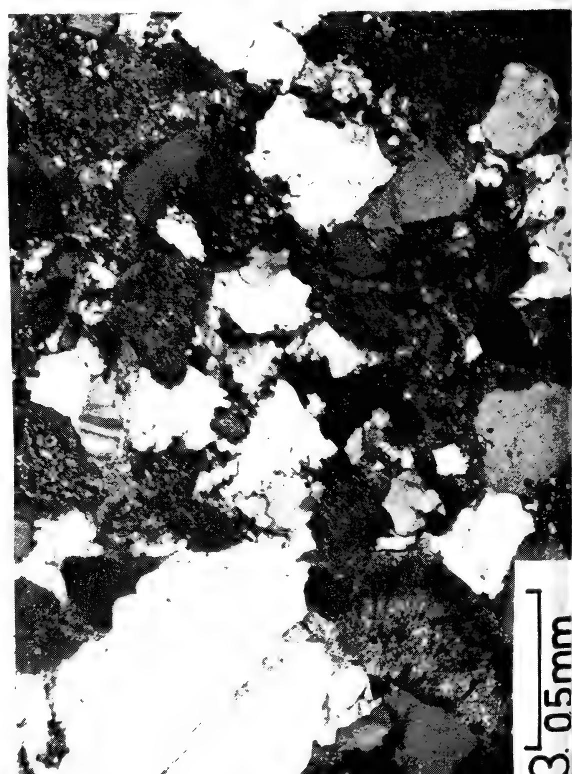
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Explanation of Plates

Plate I

Figure 1. Coarse lithic sandstone, Barrat Conglomerate, from the Nabong Range, west of Naradhan, No. 889. Crossed nicols. This microphotograph shows a poorly-sorted sandstone with a large dark acid volcanic fragment (top right) consisting of an irregular mosaic of feldspar (M) and with a large phenocryst of embayed quartz (EQ).

Figure 2. Coarse lithic sandstone, Barrat Conglomerate, west of Naradhan, No. 889. Crossed nicols. Consists of subangular polycrystalline quartz including vein quartz (VQ) and metaquartzite (IQ) varieties; monocrystalline quartz, some of which is clear of inclusions, embayed, and volcanic and sedimentary rock fragments in a dark clay matrix.

Figure 3. Coarse-grained lithic sandstone, Barrat Conglomerate, 17 miles south of Rankin's Springs, No. 931. Plane light. Consists of subangular quartz (Q) and volcanic rock fragments (V) in an iron-oxide-coloured clay matrix. A large fragment of rhyolite (R) has a fluidal fabric outlined by iron-oxide-stained feldspars concentrated along several flow bands.

Figure 4. Coarse-grained sandstone, Barrat Conglomerate, Nobbies Trig. south of Naradhan. No. 948. Crossed nicols. A fairly well-sorted protoquartzite consisting mainly of subangular and angular quartz, much of which is free of inclusions (EQ) and often embayed. Rock fragments consist mainly of devitrified acid volcanics and interstices between grains are filled with iron-oxide cement and clay.

Plate II

Figure 1. Coarse-grained sandstone, Rankin Formation, Mountain Creek, north of Rankin's Springs, No. 901. Crossed nicols. Moderately well-sorted, consisting of monocrystalline quartz, polycrystalline quartz (vein quartz —VQ, and metaquartzite—MQ), quartzose sedimentary (QS) and cherty-shale (Sh) rock fragments.

Figure 2. Naradhan Sandstone, No. 882, four miles south west of Rankin's Springs. Crossed nicols. Typical of the orthoquartzites in the Naradhan Sandstone with an interlocking grain texture due to interlocking of quartz grains or secondary quartz overgrowths.

Figure 3. Medium-grained lithic sandstone, Rankin Formation, Pleasant Valley, No. 923. Crossed nicols. Dark cherty shale and volcanic rock fragments have straight or sutured contacts with detrital quartz.

Figure 4. Pebbly sandstone, Barrat Conglomerate, Ardlethan, No. 471. Crossed nicols. Moderately sorted, with subangular to subrounded detrital quartz including many polycrystalline quartz grains, sedimentary rock fragments and one large fragment of siliceous shale showing poorly-defined bedding.

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Middle Devonian Conodonts from the Moore Creek Limestone, Northern New South Wales

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Abstract—The bar and platformed conodonts of the Moore Creek Limestone are described and illustrated. Thirty-two species are recognized. The conodont fauna is that of the Upper Eifelian *kockeliana*-Zone. This constitutes the first recognition of this zone (with its nominate species *Polygnathus kockeliana*) outside Western Europe.

Introduction

In this article the bar and platformed conodonts of the Middle Devonian Moore Creek Limestone of northern New South Wales are described. Particular attention has been paid to the stratigraphically important platformed elements and their significance. Excluded from this study are the simple, cone-like conodonts of the fauna. A more extensive study of the ranges of conodonts through the Middle Devonian limestones of the Tamworth Group in the Timor district (east of Murrurundi) is currently being undertaken by J. H. Jackson. The limestones of that area involve strata both older and younger than the Moore Creek Limestone, and, as a consequence, are more suitable for a zonal study of conodont faunas. The Moore Creek Limestone is developed north of Tamworth where it is the youngest limestone unit recognized within the Tamworth Group.

The faunas of the Moore Creek Limestone are comparatively well known (*fide* Brown, 1942, p. 172). Following the studies of Brown (1942, 1944) and Hill (1942) it has become customary to regard the Moore Creek Limestone as Givetian in age, and this has strongly influenced Devonian correlations, not only within the Tamworth Group, but also more generally throughout eastern Australia. Conodonts recovered from this horizon, however, are diagnostic of an Upper Eifelian age.

Acknowledgements

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Stratigraphy and Localities

Crook (1961) lists the name Moore Creek Limestone as proposed by Benson (1913) and designates as a provisional type section the limestone along the west side of Spring Creek, immediately north of Tamworth Common. However, Etheridge (1899) introduced the term Moore Creek Limestone and he employed this solely for the well-known locality immediately south of Moore Creek. The limestone along Spring Creek was designated the Woolomol Limestone by Etheridge (*op. cit.*). This confusion appears to be of little consequence, for Etheridge originally recognized the equivalence of the Moore Creek and Woolomol Limestones, and all subsequent workers have endorsed his conclusion. Indeed, A. E. H. Pedder's unpublished studies on Tamworth Group stratigraphy have shown that the Moore Creek Limestone is the most continuous limestone member of the Tamworth Group in the Attunga district, and that it was probably deposited as a continuous sheet over the Attunga, Moore Creek and North Tamworth areas.

The conodonts described in this article are from the Moore Creek Limestone at Moore Creek (30° 59·8′ S, 150° 54·6′ E). At this locality the structure of the limestone is not simple, as the outcrop forms a faulted anticline. Seven samples were taken through the limestone, but only one of these, in the core of the anticline and at the base of the formation, yielded a satisfactory abundance of conodonts. The conodonts described and figured in this article are from this locality, although it should be noted that *Polygnathus kockeliana*, the zonal index of the fauna, was recovered frcm the highest part of the unit, which here appears to be of the order of 200 feet thick. It would seem, therefore, that the Moore Creek Limestone lies wholly within the range of *Polygnathus kockeliana.*

Methods of Study

Methods of study have been outlined elsewhere (Philip, 1965). Approximately 100 kg. of limestone was processed from the locality at the base of the Moore Creek Limestone. This yielded some 1000 identifiable conodonts. The conodonts are black in colour and many are broken and deformed, apparently due to the shearing of the limestone in the vicinity of the conodont locality.

All photographed specimens are registered in the Palaeontological Collection of the University of New England, Armidale, N.S.W.

Stratigraphic Significance of Fauna

To date the most important published work on the sequence of Middle Devonian conodont faunas is that of Bischoff and Ziegler (1957), who examined the faunas of Eifelian and Givetian limestones, particularly of the Dill-Mulde, at the south-eastern margin of the Rheinisch Schiefergebirge. This region is intensely folded and faulted, and as a consequence the stratigraphy is not straightforward. However, correlation of the various limestones with the classical areas of the Eifel is well established, although some confusion has arisen concerning the stratigraphic position of the so-called Kalkigen Zwischenschicten (see below).

Bischoff and Ziegler's study has been much extended and revised by Wittekindt (1961) who has at press a revised zonal scheme for the Middle Devonian.* One change instituted by Wittekindt is of particular significance in the dating of the Moore Creek conodont fauna. Bischoff and Ziegler placed the Kalkigen Zwischenschicten above the Ballersbacher Kalk and below the Upper Eifelian Günteröder Kalk. Wittekindt has established the general equivalence of the Ballersbacher Kalk and the Greifesteiner Kalk and has maintained that the Kalkigen Zwischenschicten (with the highly diagnostic *Polygnathus kockeliana* fauna) is equivalent to the upper part of the Günteröder Kalk, i.e. it is of highest Eifelian age.

* See Addendum.

TABLE 1

Ranges of stratigraphically important conodonts common to the Moore Creek Limestone and Germany (after Wittekindt, 1961).

	Eifelian			Givetian			
	1	2	3	4	5	6	7
Polygnathus angustipennata		- -	—				
Polygnathus eiflia		—	—	—	- -		
Polygnathus kockeliana			—				
Polygnathus linguiformis	—	—	—	—	—	—	—
Polygnathus robusticostata		–	—	- -	—		
Polygnathus trigonica			—				
Polygnathus sp. nov. A (=*P. subserrata sensu* B. and Z.)		—	- -				
Polygnathus sp. nov. B (=*P. foliata sensu* B. and Z.)		–	—	—	—	—	—
Spathognathodus bidentatus		—	—	–			

Table 1 gives the ranges of the stratigraphically important conodonts common to the Moore Creek Limestone and Germany. The ranges are taken from Wittekindt (1961) and show the distribution of the species through his zonal scheme. It can be seen that the Moore Creek fauna is Wittekindt's zone 3, the *Kockeliana* Zone. It is the fauna of the Kalkigen Zwischenschicten, equivalent to the upper part of the Günteröder Kalk, of Upper Eifelian age.

The most important evidence in support of the older view of the Givetian age of the Moore Creek Limestone is the occurrence of a stringocephalid brachiopod (Brown, 1942). The form concerned was subsequently (Brown, 1944) described as *Bornhardtina coulteri*. Brown (*op. cit.*, p. 120) maintained that the occurrence of this genus was indicative of a Givetian age. It will be noted that, in the Eifel region, *Bornhardtina* appears first in the lowest part of the Junkerberg-Schichten (Struve, 1965, p. 462 ; Ochs and Wolfart, 1961) stratigraphically well below the entry of *Stringocephalus* which first occurs in the upper part of the Freilinger Schichten at the top of the Eifelian. The presence of the genus in the Moore Creek Limestone (apparently first occurring some 100 feet above its base) is therefore entirely consistent with the Upper Eifelian age indicated by conodonts.

Systematics

Genus ANGULODUS Huddle 1934

TYPE SPECIES : *Angulodus demissus* Huddle 1934.

Angulodus walrathi (Hibbard)

Plate 3, Fig. 3

Hindeodella walrathi Hibbard 1927, p. 205, Figs. 4*a-b*.

Angulodus walrathi (Hibbard) Huddle, 1934, pp. 77–78, Pl. 4, Fig. 15, Pl. 10, Fig. 5; Bischoff and Ziegler 1957, pp. 44–45, Pl. 8, Figs. 1–6 (5 ?), Pl. 20, Fig. 7.

Hindeodella catacta Huddle, 1934, p. 40, Pl. 4, Fig. 18.

Angulodus elongatus Stauffer, 1940, pp. 419–420, Pl. 58, Figs. 1, 8, 21–22.

Hindeodella ampla Cooper and Sloss, 1943, p. 173, Pl. 23, Fig. 20.

DIAGNOSIS: A species of *Angulodus* with deep, curved limbs, a small cusp and hindeodellid dentition.

FIGURED SPECIMEN: F9171/1.

REMARKS: This Middle and Upper Devonian form may well be directly derived from the late Silurian and Lower Devonian species *Plectospathodus alternatus* Walliser (1964, p. 64, Pl. 30, Figs. 23–25). The nature of the basal cavity possibly distinguishes the species, which otherwise appear to be very similar.

Genus BRYANTODUS Bassler 1925

TYPE SPECIES: *Bryantodus typicus* Ulrich and Bassler 1926.

Bryantodus sp. cf. biculminatus Bischoff and Ziegler

Plate 2, Figs. 13, 17

Cf. *Bryantodus biculminatus* Bischoff and Ziegler, 1957, p. 47, Pl. 13, Figs. 7–9.

FIGURED SPECIMENS: F9170/1–2.

REMARKS: The available specimens from Moore Creek are incomplete and so lack the diagnostic feature of this species, i.e., the enlarged anterior denticles. The specimen illustrated in Pl. 3, Fig. 13, however, closely resembles a specimen illustrated by Bischoff and Ziegler (*op. cit.*, Pl. 13, Fig. 8). For this reason the form is compared with *B. biculminatus*.

Bryantodus sp. cf. colligatus (Bryant)

Plate 2, Fig. 20

Cf. *Prioniodus colligatus* Bryant 1921, p. 17, Pl. 3, Figs. 1–2, 4; Pl. 5, Figs. 6, 10; Pl. 6, Fig. 8, Pl. 7, Figs. 2, 6.

Cf. *Bryantodus colligatus* (Bryant), Bischoff and Ziegler, 1957, pp. 47–48, Pl. 19, Fig. 39.

FIGURED SPECIMEN: F9170/3.

REMARKS: This species of *Bryantodus* approaches most closely *B. colligatus* (Bryant) as interpreted by Bischoff and Ziegler (*loc cit.*). It differs from this species in the fewer, more massive denticles and so approaches the Givetian form described by these authors as *B.* cf. *colligatus* (p. 48, Pl. 19, Fig. 42).

Bryantodus sp. cf. pravus (Bryant)

Plate 2, Figs. 15, 18, 19, ? 21

Cf. *Prioniodus pravus* Bryant, 1921, p. 18, Pl. 8, Fig. 5.

Cf. *Bryantodus pravus* (Bryant) Bischoff and Ziegler, 1957, pp. 51–52, Pl. 21, Fig. 19; Pl. 13, Fig. 5; Pl. 14, Figs. 1–2.

FIGURED SPECIMENS: 9170/4–6, 11.

REMARKS: This form agrees closely with *B. pravus*, although the anterior limbs appear to have fewer denticles than is usual for this species. One large specimen in the collection (Pl. 2, Fig. 21) has limbs with very strongly developed lateral flanges, which distinguishes it from smaller specimens. Bischoff and Ziegler (*op cit.*, Pl. 14, Fig. 1) include a similar specimen in *B. pravus*.

Bryantodus sp.

Plate 2, Fig. 22

FIGURED SPECIMEN: F9170/7.

REMARKS: This form is represented by one fragmentary specimen with prominent lateral flanges and flattened, fused denticles. The cusp is broad and spatulate. It resembles most closely the early Upper Devonian species *Bryantodus spatulatus* (Bryant 1921, p. 18, Pl. 8, Fig. 9).

Genus HIBBARDELLA Bassler 1925

TYPE SPECIES: *Prioniodus angulata* Hinde 1879.

REMARKS: Some confusion exists as to the generic name to be applied to conodonts which consist of a symmetrical anterior arch with a denticulated posterior bar. Ulrich and Bassler originally (1926) used the name *Hibbardella* for species apparently lacking a denticulated posterior bar, basing their concept of the genus on Hinde's (1879) original description of the type species *Prioniodus angulata*. However, the genus came to be employed for species with such a bar (e.g., Ellison, 1941; Branson and Mehl, 1944). In 1953 Hass proposed the genus *Roundya* (based on the Carboniferous species *R. barnettana* Hass) which he distinguished from *Hibbardella* in the "large, rather than a small sized, pulp cavity". Müller (1956*a*) proposed *Ellisonia* (type species: *E. triassica* Müller) for conodonts with a similar plan. Müller distinguished his genus from *Roundya* by "the lack of a basal cavity" and from *Hibbardella* by the "presence of a big denticulate posterior bar". Hass (1962) submerged *Ellisonia* in *Hibbardella*, noting that a "denticulated posterior bar" is "definitely present" and continued to distinguish *Roundya* by its "very large pulp cavity". More recently Lindström (1964) has regarded all these genera as synonymous, but utilized the name *Roundya*, observing that (p. 176) "*Hibbardella* is a doubtful name, since the posterior process of the type specimen is embedded in shale and unknown".

In order to clarify the status of *Hibbardella*, the holotype of Hinde's *Prioniodus angulata* was examined. It is from the Genesee Shale, North Evans, N.Y., and is now catalogued in the British Museum (Nat. Hist.) as A4180. The specimen is smeared with gum which makes detail difficult to discern. The following points were noted:

1. The specimen is an anterior arch, with most of the posterior surface exposed.

2. The underside of the cusp is deeply excavated to give a comparatively large basal cavity.

3. The base of the cusp is projected posteriorly and there is a definite facet developed on this projection. This is here interpreted as evidence that the specimen originally possessed a posterior process. It seems highly likely that this process would have been denticulated, but confirmation of this must come from new material of the species.

According to the observations and interpretations given above, it seems that *Hibbardella* should replace *Roundya* for forms with a well-developed basal cavity. For forms in which the basal cavity is lacking, *Ellisonia* could be applied if this feature were considered to be of generic importance.

Hibbardella sp. cf. wildungenensis
(Bischoff and Ziegler)
Plate 3, Figs. 9–11

Cf. *Roundya wildungenensis* Bischoff and Ziegler 1957, pp. 112–113, Pl. 11, Figs. 9–12.

Figured Specimens: F9171/12–14.

Remarks: In the available material the posterior bar is broken close to the cusp. In the anterior arch and its denticulation, as well as the rounded outline of the cusp, the species conforms closely with *H. wildungenensis*. The basal cavity is represented by a moderately large triangular pit beneath the cusp and extending outward beneath the posterior limb. In a small specimen (Pl. 3, Fig. 11) the limbs of the anterior arch are widely extended, but this appears to be a feature of the species (*cf.* Bischoff and Ziegler, *op. cit.*, Pl. 11, Fig. 11).

Genus HINDEODELLA Bassler 1925

Type Species: *Hindeodella subtilis* Bassler 1925.

Hindeodella sp.
Plate 3, Figs. 1–2

Figured Specimens: F9171/2–3.

Remarks: The specimens of *Hindeodella* in the collection are all broken; the two fragments illustrated are probably referable to *Hindeodella priscilla* Stauffer.

Genus ICRIODUS Branson and Mehl 1938

Type Species: *Icriodus expansus* Branson and Mehl 1938.

Icriodus sp.
Plate 2, Fig. 11

Figured Specimen: F9170/13.

Remarks: The single specimen of this genus in the collection is small and incomplete. It appears to be similar to *I. nodosus* (Huddle), but positive identification is not possible.

Genus LIGONODINA Bassler 1925

Type Species: *Ligonodina pectinata* Ulrich and Bassler 1926.

Ligonodina sp. A
Plate 3, Figs. 6–8

Figured Specimens: F9171/15–17.

Remarks: In this species the denticulation of the posterior bar is irregular, often with smaller denticles interposed between larger ones. The species resembles closely the form identified as *Ligonodina* cf. *franconica* Sanneman by Bischoff and Ziegler (*op. cit.*, Pl. 11, Figs. 5, 8) which, in turn resembles *L. armena* Stauffer (1940, Pl. 59, Figs. 62, 63, 65, and 71).

Ligonodina sp. B
Plate 3, Figs. 13–14

Figured Specimens: F9171/18–19.

Remarks: The posterior bar possesses widely separated, discrete denticles. In its general form the species thus resembles *Ligonodina delicata* Branson and Mehl 1933 (p. 199, Pl. 14, Figs. 22, 23).

Genus LONCHODINA Bassler 1925

Type Species: *Lonchodina typicalis* Bassler 1925.

Lonchodina discreta Ulrich and Bassler
Plate 3, Fig. 24

Lonchodina discreta Ulrich and Bassler 1926, p. 36, Pl. 10, Figs. 1–2 ; Sannemann, 1955, pp. 131–132, Pl. 4, Fig. 24 ; Bischoff and Ziegler, 1957, pp. 67–68, Pl. 10, Figs. 9, 11–13.

Subbryantodus humilis Branson and Mehl 1934, p. 328, Pl. 25, Fig. 4.

Lonchodina disjuncta Stauffer 1938, p. 435, Pl. 51, Fig. 7.

Lonchodina cf. *L. disjuncta* Stauffer, Rhodes and Dineley, 1957, pp. 363–364, Pl. 37, Fig. 14.

DIAGNOSIS: A species of *Lonchodina* in which the unit somewhat arched ; limbs short, coplanar and tapering to their extremities. Underside of unit excavated, with a tapering groove running from the basal cavity beneath each limb. Cusp and denticles discrete and well-separated ; rounded in cross section.

FIGURED SPECIMEN : F9171/8.

Lonchodina sp. A

Plate 3, Fig. 18

FIGURED SPECIMEN : F9171/9.

REMARKS : In the relationship of the limbs and the nature of the basal cavity this form closely resembles *Lonchodina richteri* Bischoff and Ziegler (1957, p. 70–71, Pl. 10, Figs. 4–5). The single specimen available is distinguished from the illustrated specimens of *L. richteri* by the denticles which in *L.* sp. A, are somewhat flattened and fused at their bases.

Lonchodina sp. B

Plate 3, Fig. 23

FIGURED SPECIMEN : F9171/10.

REMARKS: This is a strongly arched form with an inwardly projecting lip on the basal cavity. The limbs and the denticles are somewhat flattened. The nature of the basal cavity allies the form with *L. ramulata* Bischoff and Ziegler (1957, pp. 69–70, Pl. 10, Figs. 1–3) but it is distinguished by the limbs and the denticulation. It appears to resemble most closely the Givetian form illustrated as *Lonchodina* sp. C by Bischoff and Ziegler (*op. cit.*, Pl. 21, Fig. 28).

Lonchodina sp. C

Plate 3, Fig. 25

FIGURED SPECIMEN : F9171/11.

REMARKS : This is an unevenly denticulate species of *Lonchodina* with a downwardly flexed and twisted anterior limb. The denticles are rounded in cross section and those of the posterior limb have smaller ones interposed. It therefore approached closely *Lonchodina* sp. A of Bischoff and Ziegler (1957, Pl. 10, Figs. 6–7).

Genus NEOPRIONIODUS Rhodes and Müller 1956

TYPE SPECIES : *Prioniodus conjunctus* Gunnel 1931.

REMARKS : Forms apparently referable to *Neoprioniodus* in the Moore Creek Fauna are exceedingly variable. Two species are considered to be present, together with a third forms which can only questionably be referred to the genus. In view of the great number of names which have been applied to similar Devonian species overseas, no confident identification can be given of the forms.

The first species (described below as *Neoprioniodus* sp. A) appears to contain forms which Bischoff and Ziegler included in their species *Prioniodina schneideri* (Pl. 8, Figs. 10, 11) and in *Prioniodina prona* Huddle (Pl. 8, Figs. 12–14). Named species which could prove to be conspecific include :

Euprioniodina regularis Branson 1934, p. 330, Pl. 28, Fig. 1.

Euprioniodina fornicata Huddle 1934, p. 51, Pl. 6, Fig. 16.

Euprioniodina prona Huddle 1934, p. 52, Pl. 6, Fig. 19, ? Pl. 11, Fig. 8.

Euprioniodina devexa Huddle 1934, p. 52, Pl. 11, Fig. 4.

Euprioniodina debilis Huddle 1934, p. 53, Pl. 11, Fig. 6.

Euprioniodina falx Huddle 1934, p. 53, Pl. 11, Fig. 9.

Plectodina aculeata Stauffer 1938, p. 437, Pl. 51, Figs. 13, 28, and 33.

Synprioniodina gracilis Stauffer 1938, p. 441, Pl. 49, Figs. 12, 13.

Synprioniodina forsenta Stauffer 1940, pp. 432–434, Pl. 59, Figs. 31–33, 38–41.

Synprioniodina tropa Stauffer 1940, p. 434, Pl. 59, Fig. 60.

Prioniodina prona (Huddle) of Sannemann (1955) and *Synprioniodina forsenta* Stauffer of Rhodes and Dineley (1957) also belong to this species.

The second species (*Neoprioniodus* sp. B) apparently also involves specimens which Bischoff and Ziegler included in *Prioniodina prona* Huddle (e.g. *op. cit.*, Pl. 9, Fig. 1) and also in *Prioniodina* sp. (*op. cit.*, Pl. 9, Fig. 10).

Named species probably conspecific with it are:

Prioniodus bownockeri Stauffer 1938, p. 440, Pl. 49, Fig. 27.

Prioniodus idoneus Stauffer 1938, p. 440, Pl. 49, Fig. 19.

Neoprioniodus sp. A

Plate 3, Figs. 4–5

FIGURED SPECIMENS: F9171/20–21.

REMARKS: In this species the posterior bar is strongly recurved. An anticusp may be strongly developed; usually it is projected sharply downwards. A few germ denticles may be present on the anticusp. The basal cavity has an expanded asymmetrical inner lip and is not continued beneath the posterior bar as a groove. The denticulation of the posterior bar is variable; usually there are smaller denticles interposed between larger denticles but in some specimens there are comparatively large, regular, somewhat discrete denticles.

Bischoff and Ziegler proposed a new species for the forms with alternating denticulation (their *Prioniodina schneideri*) and it may be that this variant could be set apart as a separate subspecies.

This species resembles the Lower Devonian *Neoprioniodus bicurvatus* (Branson and Mehl) from which it differs in the more expanded basal cavity and the more strongly developed anticusp.

Neoprioniodus sp. B

Plate 3, Figs. 15–17

FIGURED SPECIMENS: F9171/22–24.

REMARKS: In this species the posterior bar tends to project at right angles to the cusp, which is rounded in cross section. The anticusp is variable in orientation; in some specimens it tends to project straight downwards (Pl. 3, Fig. 15); in others it projects outwards forming a short anterior limb. In such specimens it may bear several tiny denticles. The inner lip of the basal cavity is not prominent and the basal cavity tends to be continued posteriorly under the posterior limb, so that the underside of the unit may be excavated.

Neoprioniodus ? sp. C

Plate 3, Figs. 28–29

Prioniodina ? sp. Bischoff and Ziegler 1957, pp. 108–109, Pl. 9, Figs. 13–14.

FIGURED SPECIMENS: F9171/25–26.

REMARKS: This is a massive unit with a strongly developed, downwardly projected anticusp and a similarly shaped posterior process. The inner surface of the anticusp and posterior process is grooved. Both of the available specimens are broken, but it seems that the posterior process lacks denticles. For this reason the form cannot be referred to *Neoprioniodus*. It is identical with specimens illustrated by Bischoff and Ziegler (*loc. cit.*) from the Zwischenschichten of Blauer Bruch.

Genus OZARKODINA Branson and Mehl 1933

TYPE SPECIES: *Ozarkodina typica* Branson and Mehl 1933.

Ozarkodina plana (Huddle)

Plate 2, Figs. 10, 14

Bryantodus planus Huddle 1934, pp. 75–76, Pl. 10, Fig. 8.

Ozarkodina plana (Huddle), Bischoff and Ziegler 1957, pp. 78–79, Pl. 12, Fig. 15.

DIAGNOSIS: An only slightly arched species of *Ozarkodina* with the denticles usually discrete above their midheight and progressively reclined posteriorly.

FIGURED SPECIMENS: F9170/8–9.

REMARKS: The Moore Creek form closely resembles the specimen illustrated as this species by Bischoff and Ziegler (*loc. cit.*), although the Australian material tends to possess more denticles.

Ozarkodina sp. A

Plate 2, Fig. 12

FIGURED SPECIMEN: F9170/10.

REMARKS: The single specimen of this form differs from other species of *Ozarkodina* in the collection in the disposition of limbs and the closely adpressed denticles. It appears to resemble most closely *Ozarkodina ballai* Bischoff and Ziegler (1957, pp. 74–75, Pl. 13, Figs. 1–2) but, as the posterior limb is broken, it cannot be positively identified.

Ozarkodina sp. B

Plate 2, Fig. 16

FIGURED SPECIMEN: F9170/12.

REMARKS: This is a strongly arched species of *Ozarkodina* with a deep anterior bar. The denticles tend to be discrete. The basal cavity is large and possesses widely expanded lips. No obvious comparisons can be made with previously described Middle Devonian species of *Ozarkodina*.

Genus PLECTOSPATHODUS

Branson and Mehl 1933

TYPE SPECIES: *Plectospathodus flexuosus* Branson and Mehl 1933.

Plectospathodus heterodentatus Stauffer

Plate 3, Figs. 19–22

Cervicornoides heterodentatus Stauffer 1938, p. 424, Pl. 51, Fig. 11.

Hindeodella adunca Bischoff and Ziegler 1957, pp. 57–58, Pl. 7, Figs. 11–13.

DIAGNOSIS: A species of *Plectospathodus* with the unit distinctly bowed outwards and usually somewhat arched. Posterior limb usually longer than anterior limb, with the denticles progressively reclined distally. Denticulation irregular, often with small denticles interposed between larger ones. Cusp inwardly curved and with outer surface flattened. Underside of unit with basal groove; basal cavity with well-defined, inwardly projecting lip.

FIGURED SPECIMENS: F9171/4–7.

REMARKS: Stauffer (1938) originally proposed the genus *Cervicornoides* to include this species and *C. alternatus* from the Olentangy Shale. *Cervicornoides* was recognized by Hass (1962, p. W47) and placed in his subfamily Hindeodellinae (family Coleodontidae). Hass also recognized the genus *Plectospathodus* (included in the family Prioniodontidae). The above species has all the diagnostic features of *Plectospathodus,* and is here referred to that genus. *Cervicornoides* is therefore considered to be a junior synonym of *Plectospathodus*. *P. heterodentatus* is probably derived from the *P. flexuosus-extensus* plexus. Its variation is similar to that of the Lower Devonian group.

Genus POLYGNATHUS Hinde 1879

TYPE SPECIES: *Polygnathus dubia* Hinde 1879.

Polygnathus angustipennata Bischoff and Ziegler

Plate 1, Figs. 15–16

Polygnathus angustipennata Bischoff and Ziegler 1957, p. 85, Pl. 2, Fig. 16*a*, *b*; Pl. 3, Figs. 1–3; Bartenstein and Bischoff 1962, p. 47, Pl. 3, Figs. 22–24.

DIAGNOSIS: A species of *Polygnathus* with a long, deep blade and a very narrow platform, the outer margins of which bear strong, usually separate denticles. Platform deeply "U"-shaped in cross section and usually confined to the posterior half of the unit. Blade deep and coarsely denticulated, continued without change to posterior end of unit.

FIGURED SPECIMENS: F9168/1–2.

Polygnathus eiflia Bischoff and Ziegler

Plate 1, Figs. 5–6

Polygnathus eiflia Bischoff and Ziegler 1957, pp. 89–90, Pl. 4, Figs. 5–7.

DIAGNOSIS: A species of *Polygnathus* with posterior part of the platform flattened and bent inwards; in oral profile the outer margin of the platform is expanded at mid length. Oral surface of platform ornamented with closely spaced granules and irregular ridges; two small rostral ridges developed at anterior end of platform.

FIGURED SPECIMENS: F9168/3–4.

REMARKS: Typical specimens of *P. eiflia* are distinguished from typical specimens *Polygnathus* sp. nov. B (=*P. foliata* sensu Bischoff and Ziegler) by the occurrence rostral ridges, the granular ornament of the platform, and its shape. There is, however, a tendency for the two forms to intergrade (e.g., Pl. 2, Fig. 7).

It may be noted that the occurrence of rostral ridges is usually the main character used to distinguish the Lower Carboniferous genus *Siphonodella* from *Polygnathus*. Other species of *Polygnathus* (such as *P. inornata* Branson, *P. perplexa* Thomas and *P. hassi* Helms) beside *P. eiflia* show these ridges. Recently Klapper (1966) has considered that the nature of the aboral surface of the unit provides a better basis for distinguishing the genera.

Polygnathus kockeliana Bischoff and Ziegler

Plate 1, Figs. 8–11

Polygnathus kockeliana Bischoff and Ziegler 1957, p. 91, Pl. 2, Figs. 1–12; Bartenstein and Bischoff 1962, p. 48, Pl. 4, Figs. 2–5.

DIAGNOSIS: A species of *Polygnathus* with an extremely narrow, slightly "V"-shaped, unornamented platform which tapers to a pointed posterior end. Posterior end characteristically bent inwards and twisted. Blade high towards the anterior end with coarse, somewhat flattened denticles which give way to the more rounded denticles of the carina. Basal cavity large, with elevated asymmetrical lips, mounted beneath the posterior end of platform.

FIGURED SPECIMENS: F9168/5–8.

REMARKS: In Germany this species and *P. trigonica* have the most limited stratigraphical range of the forms present in the Moore Creek fauna.

Polygnathus linguiformis Hinde
Plate 1, Figs. 12–14

Polygnathus linguiformis Hinde 1879, p. 367, Pl. 17, Fig. 15; Fay 1952, p. 115 (*cum synon.*); Stewart and Sweet 1956, pp. 270–271, Pl. 34, Figs. 9–11 (*cum synon.*); Ziegler 1956, pp. 103–104, Pl. 7, Figs. 11, 12, 15–20; Müller 1956*b*, Pl. 145, Figs. 19–20; Bischoff and Ziegler 1957, pp. 92–93, Pl. 1, Figs. 1–13; Pl. 16, Figs. 30–35; Pl. 17, Figs. 1–8; Cloud, Barnes and Hass 1957, p. 812, Pl. 4, Fig. 1; Rhodes and Dineley 1957, pp. 365–366, Pl. 37, Figs. 17–19; Pl. 38, Fig. 3; Bischoff and Sannemann 1958, p. 102; Buedurov 1961, p. 264, Pl. 1, Figs. 5*a*-*b*, 7*a*–10*b*; Reichstein 1962, Pl. 1, Figs. 17–18; Haas 1962, p. W59, Fig. 36, 5*c*; Bartenstein and Bischoff 1962, p. 45, Pl. 3, Figs. 17–20; Walliser 1962, Fig. 1 (38); Orr 1964, pp. 16–17, Pl. 4, Figs. 8–9; Clark and Ethington 1966, pp. 683–684, Pl. 84, Figs. 7–9; Philip 1966, p. 448, Pl. 2, Figs. 29–40.

Polygnathus crassus Hinde 1879, p. 365, Pl. 17, Fig. 3.

Polygnathus ? *simplex* Hinde 1879, pp. 367–368, Pl. 17, Fig. 18.

Polygnathus sanduskiensis Stauffer 1938, p. 438, Pl. 53, Figs. 27, 36–37.

DIAGNOSIS: See Philip, *loc. cit.*

FIGURED SPECIMENS: F9168/9–11.

REMARKS: The progressive change in the character of the basal cavity, seen in Lower Devonian forms of this species, is described in detail elsewhere (Pedder, Jackson and Philip, 1967). The Moore Creek specimens have the tiny basal cavity characteristic of Middle Devonian representatives of the species.

Polygnathus robusticosta Bischoff and Ziegler
Plate 1, Figs. 17–19

Polygnathus robusticostata Bischoff and Ziegler 1957, pp. 95–96, Pl. 3, Figs. 4–10; Bartenstein and Bischoff 1962, p. 49, Pl. 4, Fig. 10.

DIAGNOSIS: A species of *Polygnathus* with a large platform which is strongly trough-shaped at its anterior end; posterior end usually pointed and somewhat flexed downwards. Platform ornamented with coarse transverse ridges which fade toward the carina. Blade high, with very large adpressed denticles.

FIGURED SPECIMENS: F9168/12–14.

REMARKS: The Moore Creek specimens tend to have a more rounded and flexed posterior end than is seen in the German material described by Bischoff and Ziegler. In other respects, however, the forms are identical.

Polygnathus trigonica Bischoff and Ziegler
Plate 1, Fig. 7

Polygnathus trigonica Bischoff and Ziegler 1957, pp. 97–98, Pl. 5, Figs. 1–6; Bartenstein and Bischoff 1962, p. 48, Pl. 4, Figs. 6–7.

DIAGNOSIS: A species of *Polygnathus* with a comparatively short blade and a triangular platform. Platform ornamented with rounded nodes, which may form irregular diagonal ridges, particularly toward the posterior end of the platform.

FIGURED SPECIMEN: F9168/15.

REMARKS: The one specimen recovered conforms closely with the broad-platformed variety of the species, as described by Bischoff and Ziegler. Both broad and narrow forms are represented in material from the Timor sections.

Polygnathus sp. nov. A
Plate 1, Figs. 1–4

Polygnathus cf. *subserrata* Branson and Mehl, Bischoff and Ziegler 1957, p. 97, Pl. 4, Figs. 10*a*-*b*, 11*a*-*b*.

Non Polygnathus subserrata Branson and Mehl 1934, p. 248, Pl. 20, Figs. 17–19.

DIAGNOSIS: A species of *Polygnathus* with the blade and platform approximately the same length. Platform arched and symmetrically triangular in shape with the anterior end trough-shaped. Oral surface ornamented with strong transverse ribs or nodes along the centre margins of the platform. Carina toward the posterior end consisting of prominent, often separated nodes. Blade high and coarsely denticulated.

FIGURED SPECIMENS: F9168/16–19.

REMARKS: *Polygnathus* sp. nov. A resembles most closely *Polygnathus robusticostata* from which it is to be distinguished principally by the smaller, narrower ribs of around the margin of the platform. In the Moore Creek specimens the platform tends to be somewhat more lanceolate than in the material figured by Bischoff and Ziegler (*loc. cit.*). The platform also appears to be less strongly arched than in the German material.

Polygnathus sp. nov. B
Plate 2, Figs. 4–9

Polygnathus foliata Bryant, Bischoff and Ziegler 1957, pp. 90–91, Pl. 4, Figs. 1–4; Bartenstein and Bischoff 1962, p. 48, Pl. 4, Fig. 1.

Non Polygnathus foliata Bryant 1921, p. 24, Pl. 10, Figs. 13–16.

DIAGNOSIS: A species of *Polygnathus* with platform and blade of approximately equal length. Platform comparatively wide posteriorly but tends to be constricted anteriorly where the platform becomes trough-shaped. Surface of platform ornamented with low, transverse ridges which may be replaced by irregular nodes.

FIGURED SPECIMENS: F9169/1–6.

REMARKS: This form differs from *P. foliata* Bryant essentially in the shape of the platform which is considerably narrower in this Upper Devonian species (*cf.* Müller and Müller 1957, pp. 1086–1087, Pl. 135, Fig. 1). Both Wittekindt (1961) and Ziegler (1962, p. 88) have noted that the Eifelian form should be set apart as a new species. Its relationship to *P. eiflia* is discussed under that species.

Polygnathus ? sp.
Plate 3, Fig. 27

FIGURED SPECIMEN: F9169/11.

REMARKS: This is a twisted, cap-shaped unit in which the aboral surface is completely excavated. The platform-like oral surface is marked by a sinuous row of large denticles, rounded in cross section.

The species resembles a form of *Bryantodus* with strongly developed lateral flanges. The completely excavated undersurface of the unit, however, prevents reference to that genus. It is therefore questionably referred *Polygnathus* where it appears to be better accommodated. In its general form it resembles *Polygnathus* ? *variabilis* Bischoff and Ziegler (pp. 99–100, Pl. 18, Figs. 8–17; Pl. 19, Figs. 10, 11, and 17), and *Polygnathus* ? n. sp. (*op. cit.*, p. 102, Pl. 19, Figs. 26, 36–37).

Genus SPATHOGNATHODUS
Branson and Mehl 1941

TYPE SPECIES: *Ctenognathus murchisoni* Pander 1856.

Spathognathodus bidentatus Bischoff and Ziegler
Plate 2, Figs. 1–3

Spathognathodus bidentatus Bischoff and Ziegler 1957, pp. 114–115, Pl. 6, Figs. 8–13; Bartenstein and Bischoff 1962, pp. 42–43, Pl. 3, Figs. 25–27.

DIAGNOSIS: A species of *Spathognathodus* with a long basal cavity developed in the posterior half of the unit. Oral margin sloping down to the posterior end and marked by different groups of denticles. Those at the posterior end above the basal cavity wide and separated; those at the anterior end narrow and fused.

FIGURED SPECIMENS: F9169/7–9.

Spathognathodus bipennatus
Bischoff and Ziegler

Spathognathodus bipennatus Bischoff and Ziegler 1957, pp. 115–116, Pl. 21, Fig. 31; Bartenstein and Bischoff 1962, p. 49, Pl. 4, Fig. 17.

Non Spathognathodus bipennatus nevadensis Clark and Ethington 1966, p. 687, Pl. 84, Figs. 1, 6, 8, 10, and 11 (=*Eognathodus sulcatus* Philip).

DIAGNOSIS: A species of *Spathognathodus* with the lips of the broad flat basal cavity strongly projecting on each side of the blade. Oral surface of posterior two-thirds of the unit broad with two marginal rows of nodes separated by a narrow trough. Anterior end of blade high with fused denticles.

Spathognathodus sp. cf. bipennatus
Bischoff and Ziegler
Plate 3, Fig. 12

Spathognathodus cf. *bipennatus* Bischoff and Ziegler 1957, p. 116, Pl. 6, Fig. 7*a-b*.

FIGURED SPECIMEN: F9169/10.

REMARKS: Bischoff and Ziegler (*op. cit.*) based the species *S. bipennatus* on nine specimens recovered from the early Upper Givetian *Spargenophyllum*-Kalk of Wenne-Tal. They also describe an isolated specimen from the Kalkige Zwischenschichten as *S.* cf. *bipennatus*. This differs from the Givetian form in lacking a trough dividing the nodes into two series along the oral surface. The two Moore Creek specimens recovered are intermediate between the two forms, for, although two rows of nodes are present, no medial trough is developed. The oral ornament has the appearance of transverse ridges which fade medially, and thus is closer to that of the Upper Eifelian form. It seems probable however, that all the above forms are variants of a single species.

ADDENDUM

While this article was at press, the paper of Wittekindt (1966: *Fortschr. Geol. Rheinl. Westf.*, 9, 621–646) came to hand. Wittekindt names two of the species of *Polygnathus* occurring in the Moore Creek fauna. These are:

Polygnathus sp. nov. A (=*P.* cf. *subserrata sensu* B. and Z.)=*P. angusticostata* Wittekindt.

Polygnathus sp. nov. B (=*P. foliata sensu* B. and Z.)=*P. pseudofoliata* Wittekindt.

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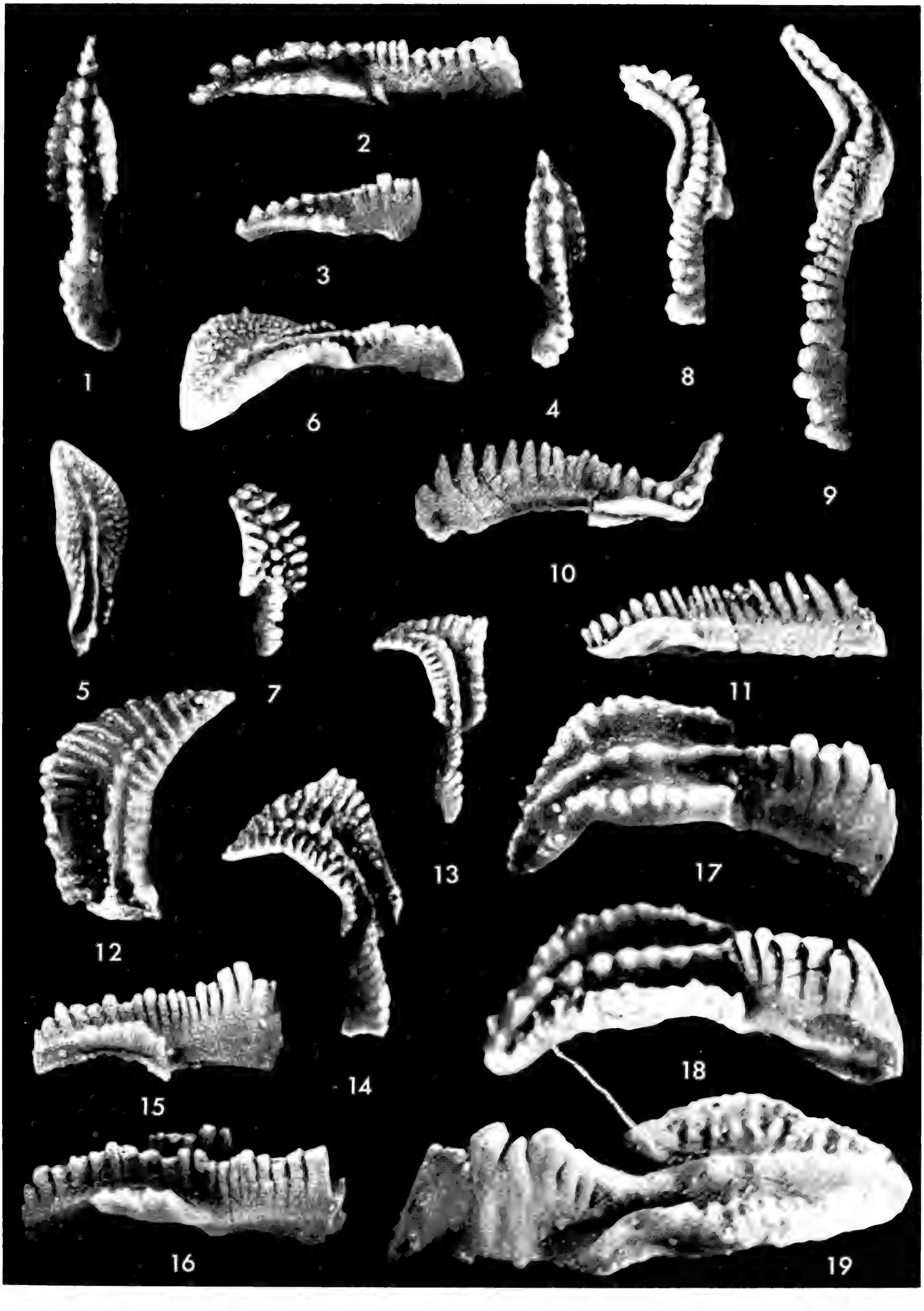
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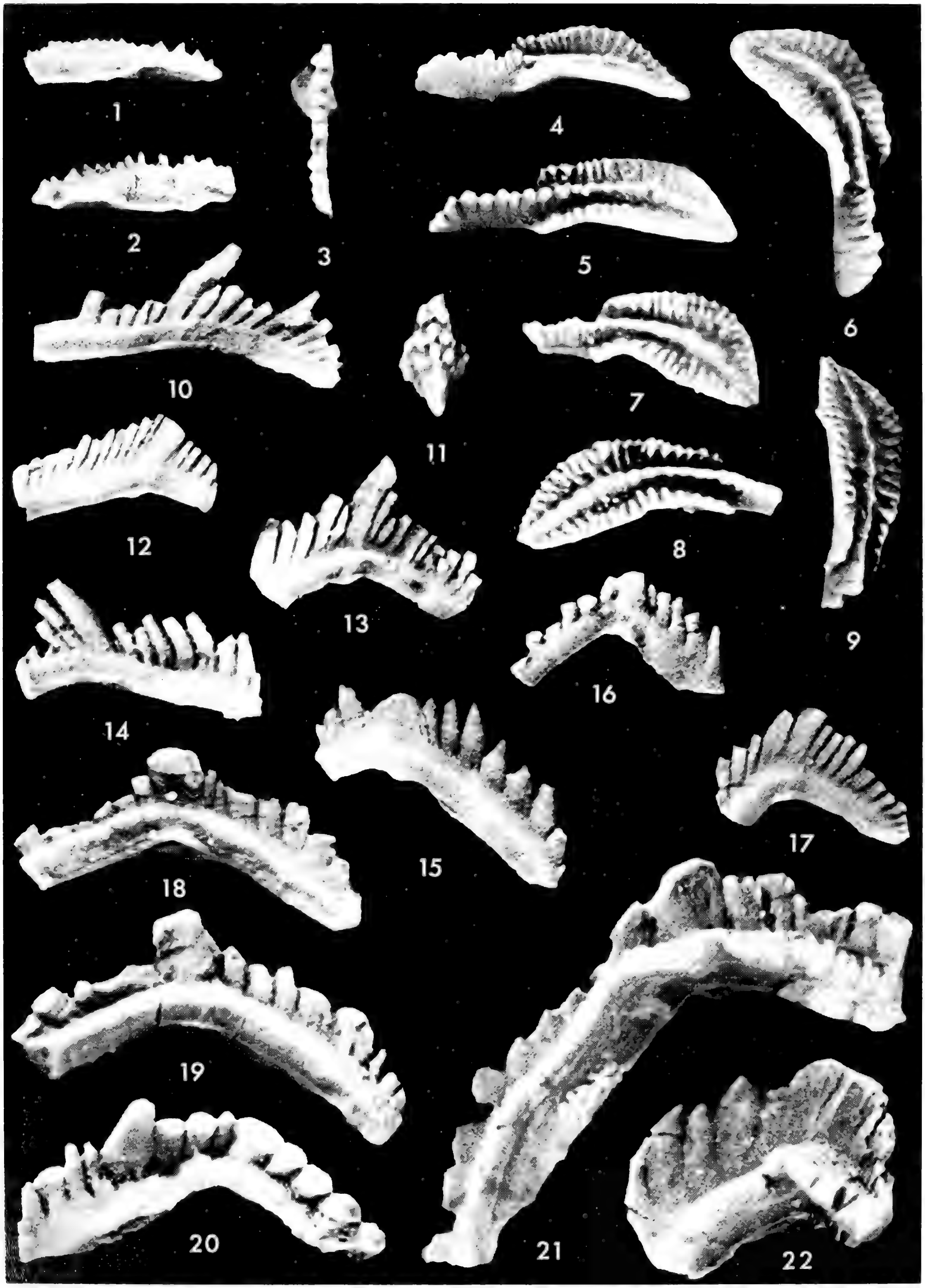
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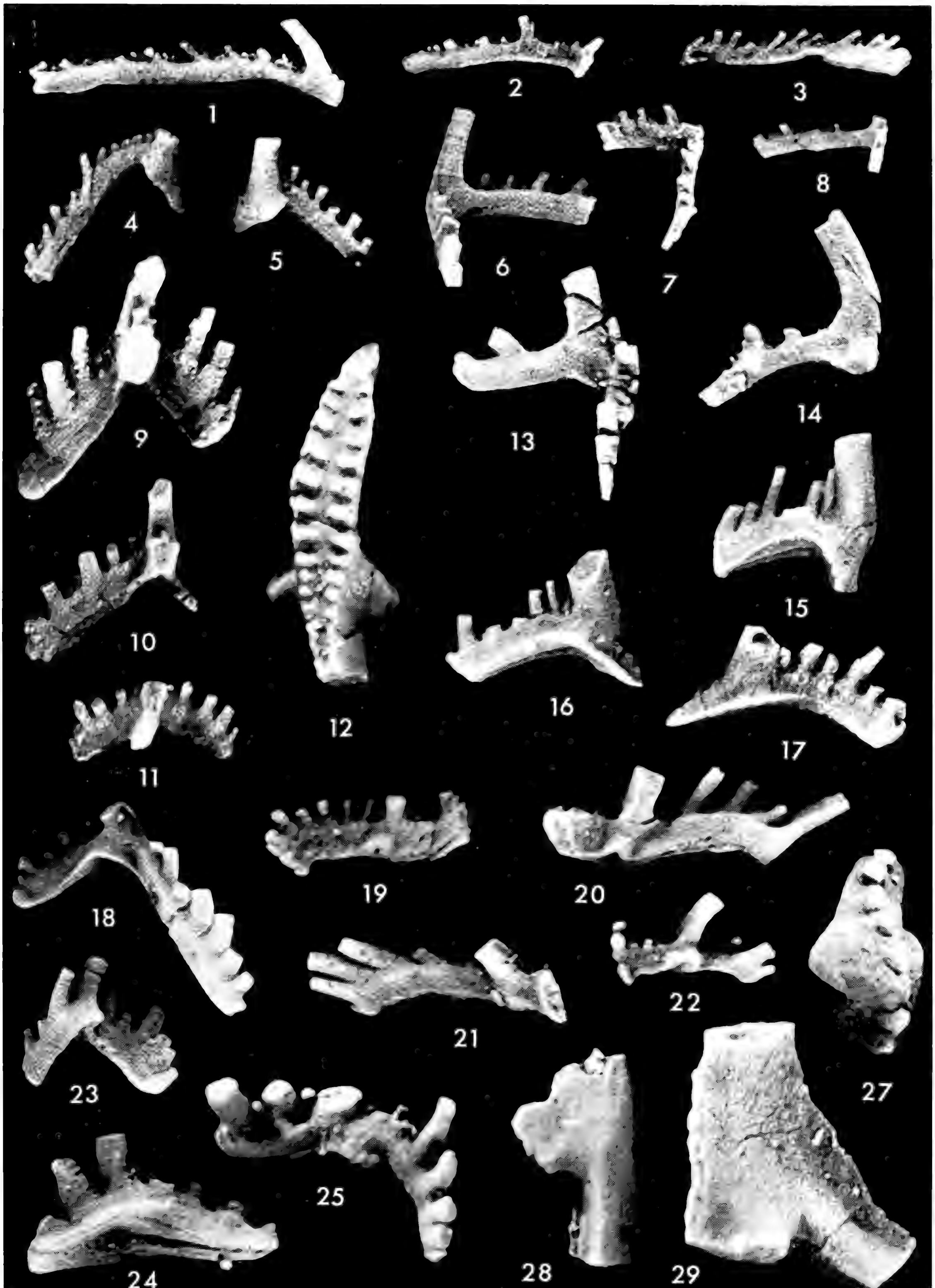
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Explanation of Plates

All figures ×40 and specimens registered in the University of New England Palaeontological Collection

PLATE 1

Figs. 1–4. *Polygnathus* sp. nov. A. 1, Oral view of F9168/16. 2, Lateral view of a large specimen F9168/17. 3, Lateral view of F9168/18. 4, Oral view of F9168/19.
Figs. 5–6. *Polygnathus eiflia* Bischoff and Ziegler. 5, Oral view of F9168/3. 6, Latero-oral view of F9168/4, a specimen with well developed rostral ridges.
Fig. 7. *Polygnathus trigonica* Bischoff and Ziegler. Oral view of F9168/15.
Figs. 8–11. *Polygnathus kockeliana* Bischoff and Ziegler. 8, Oral view of F9168/5. 9, Oral view of F9168/6. 10, Lateral view of F9168/7. 11, Lateral view of F9168/8, a specimen with a broken posterior end.
Figs. 12–14. *Polygnathus linguiformis* Hinde. 12, Oral view of a large broken specimen, F9168/9. 13, Oral view of a small specimen F9168/10. 14, Oral view of F9168/11.
Figs. 15–16. *Polygnathus angustipennata* Bischoff and Ziegler. 15, Lateral view of F9168/1. 16, Lateral view of F9168/2.
Figs. 17–19. *Polygnathus robusticostata* Bischoff and Ziegler. 17, Latero-oral view of F9168/12. 18, Latero-oral view of F9168/13. 19, Latero-oral view of F9168/14.

PLATE 2

Figs. 1–3. *Spathognathodus bidentatus* Bischoff and Ziegler. 1, Lateral view of F9169/7. 2, Lateral view of F9169/8. 3, Oral view of F9169/9.
Figs. 4–9. *Polygnathus* sp. nov. B. 4, Latero-oral view of F9169/1. 5, Oral view of F9169/2. 6, Oral view of F9169/3. 7, Oral view of F9169/4. 8, Oral view of F9169/5. 9, Oral view of F9169/6.
Figs. 10, 14. *Ozarkodina plana* (Huddle). 10, Lateral view of F9170/8. 14, Lateral view of F9170/9.
Fig. 11. *Icriodus* sp. Oral view of F9170/13.
Fig. 12. *Ozarkodina* sp. A. Lateral view of F9170/10.
Figs. 13, 17. *Bryantodus* sp. cf. *biculminatus* Bischoff and Ziegler. 13, Lateral view of F9170/1. 17, Lateral view of F9170/2.
Fig. 16. *Ozarkodina* sp. B. 16, Lateral view of F9170/12.
Figs. 15, 18, 19. *Bryantodus* sp. cf. *pravus* (Bryant). 15, Lateral view of F9170/11. 18, Lateral view of F9170/4. 19, Lateral view of F9170/5.
Fig. 20. *Bryantodus* sp. cf. *colligatus* (Bryant). Lateral view of F9170/3.
Fig. 21. *Bryantodus* sp. cf. *pravus* (Bryant) ? Lateral view of F9170/6.
Fig. 22. *Bryantodus* sp. Lateral view of F9170/7.

PLATE 3

Figs. 1–2. *Hindeodella* sp. 1, Inner lateral view of F9171/2. 2, Inner lateral view of F9171/3.
Fig. 3. *Angulodus walrathi* (Hibbard). Inner view of F9171/1.
Figs. 4–5. *Neoprioniodus* sp. A. 4, Inner view of F9171/20. 5, Inner view of F9171/21.
Figs. 6–8. *Ligonodina* sp. A. 6, Inner view of F9171/15. 7, Inner view of F9171/16. 8, Inner view of a small specimen, F9171/17.
Figs. 9–11. *Hibbardella* sp. cf. *wildungenensis* (Bischoff and Ziegler). 9, Posterior view of F9171/12. 10, Posterior view of F9171/13. 11, Posterior view of F9171/14.
Fig. 12. *Spathognathodus* sp. cf. *bipennatus* Bischoff and Ziegler. Oral view of F9169/10.
Figs. 13–14. *Ligonodina* sp. B. 13, Inner view of F9171/18. 14, Inner view of F9171/19.
Figs. 15–17. *Neoprioniodus* sp. B. 15, Inner view of F9171/22. 16, Inner view of F9171/23. 17, Inner view of F9171/24, a specimen with a strongly projected anticusp.
Fig. 18. *Lonchodina* sp. A. Inner view of F9171/9.
Figs. 19–22. *Plectospathodus heterodentatus* (Stauffer). 19, Inner view of F9171/4. 20, Inner view of F9171/5. 21, Inner view of F9171/6. 22, Inner view of a small specimen, F9171/7.
Fig. 23. *Lonchodina* sp. B. Inner view of F9171/10.
Fig. 24. *Lonchodina discreta* Ulrich and Bassler. Inner view of F9171/8.
Fig. 25. *Lonchodina* sp. C. Lateral view of F9171/11.
Fig. 27. *Polygnathus*? sp. Oral view of F9169/11.
Figs. 28–29. *Neoprioniodus*? sp. C. Inner view of F9171/25. 29, Inner view of F9171/26.

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Cambro-Ordovician Sediments from the North-Eastern Margin of the Frome Embayment (Mt. Arrowsmith, N.S.W.)

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Abstract—Middle Cambrian and Lower Ordovician sediments, recently discovered at Mt. Arrowsmith in north-western-most New South Wales, are of considerable importance for the evaluation of Lower Palaeozoic palaeogeography of the Frome Embayment and the Coopers Creek Sub-basin.

The total exposed thickness of the Middle Cambrian sequence at Mt. Arrowsmith is 1,900 feet, consisting of 575 feet of grey, silty shale, 385 feet of feldspathic and volcanic greywacke, 390 feet of interbedded siltstone and fossiliferous limestone, and 505 feet of red and green, silty shale. The Lower Ordovician sequence, whose total thickness is 1,060 feet, comprises 310 feet of quartzites and siltstones, 390 feet of thinly interbedded shale and richly fossiliferous carbonates, and 360 feet of green, clean shale.

Each sequence occurs in a separate, overturned syncline with steeply east-dipping axial plane. The deformation was the result of a post-Lower Ordovician orogeny.

The Middle Cambrian sequence is tentatively correlated with the Billy Creek Formation, the Wirrealpa Limestone and the lower Lake Frome Group in the Flinders Ranges, and with Middle Cambrian sediments encountered in D. S. Gidgealpa No. 1 well. The Ordovician sequence is of Tremadocian to Arenigian age and is in part comparable with sediments of similar age and lithology in the Mootwingee Ranges.

Interconnection is suggested between Flinders Ranges, Mt. Arrowsmith and the Coopers Creek Sub-basin in Cambrian time and between Mt. Arrowsmith and Coopers Creek Sub-basin in Ordovician time.

Introduction and Geological Setting

The Frome Embayment forms a SSW-trending lobe of the Great Artesian Basin extending from about south latitude 29°15′ to 31°45′. Its longitudinal boundaries are marked by the Flinders Ranges, situated in South Australia, and the Barrier Ranges, situated in the far west of New South Wales. The sedimentary section in the Frome Embayment consists of Upper Jurassic freshwater sands and Lower Cretaceous marine deposits attaining a thickness of about 2,000 feet in the northern portion of the embayment where it merges with the Great Artesian Basin, but thinning to the south where the Mesozoic sediments shelve onto the Precambrian rocks of the Broken Hill-Olary Block (see Fig. 1).

In parts of the Frome Embayment the Mesozoic strata are thought to rest on Lower Palaeozoic sediments which may be promising targets for petroleum exploration. This belief is based on tentative identifications of Cambrian sediments in some of the few deep water-bores (Ker, 1966) and on the presence of up to 20,000 feet of marine, partly bituminous sediments of Lower and Middle Cambrian age in the Flinders Ranges, the western margin of the Frome Embayment. There the Cambrian strata which rest on unmetamorphosed sediments of the Late Precambrian Adelaide Geosyncline, are gently folded and commonly dip beneath the younger sediments of the Frome Embayment (see Fig. 1).

Until recently, Lower Palaeozoic sediments were not known from the Frome Embayment's immediate eastern margin formed by the Precambrian Barrier Ranges north of Broken Hill and a NNE-trending chain of inliers protruding the Mesozoic sediment-blanket in the far northwest of New South Wales (see Fig. 1).

These inliers, identified from north to south as the Tibooburra inlier, Warratta inlier, Milparinka–Mt. Poole inlier, Mt. Shannon inlier and Mt. Arrowsmith inlier, are largely composed of Precambrian sediments interspersed with basic volcanics and, less commonly porphyries and felsites (Kenny, 1934). They are generally slightly altered, often severely sheared and are commonly cut by quartz " blows " and veins. These rocks have been referred to as the " Torrowangee Series " (Mawson, 1912) and they are fairly confidently correlated with portions of the Late Precambrian (Adelaidean) sedimentary sequence of the Adelaide Geosyncline.

The presence of Lower Palaeozoic sediments on the immediate eastern margin of the Frome Embayment was first established by R. L. Brunker of the N.S.W. Geological Survey, who discovered Ordovician fossils in a steeply dipping sedimentary section on the western flank of the Mt. Arrowsmith inlier early in 1965.

In May 1965 Messrs. G. Rose and R. L. Brunker of the Geological Survey of N.S.W. introduced the author to the sedimentary section at Mt. Arrowsmith, then believed to be entirely of Ordovician age. While measuring this section, the author and Mr. C. R. Dalgarno observed trilobite fragments, Hvolithes and Girvanella in the lower part, and therefore suggested a possible Middle Cambrian age for that interval. Samples from a limestone at 300 feet were forwarded (by courtesy of Delhi Australian Petroleum Ltd.) to Dr. B. Daily of the Adelaide University who identified the Middle-Cambrian trilobite *Xystridura* (pers. com.).

As this occurrence of Lower Palaeozoic rocks is most important for the evaluation of the petroleum potential of the Lake Frome Embayment, the author, with the consent of the Under Secretarv of the N.S.W. Department of Mines visited the Mt. Arrowsmith locality again in August, 1965, accompanied by Mr. A. J. Kapel of Delhi Australian Petroleum Ltd. This second trip was undertaken in order to investigate the relationship between the Cambrian and the Ordovician strata and to clarify the complex structural picture. Several additional sections were measured and the Palaeozoic rocks were mapped on aerial photographs. One hour of low-level aerial reconnaissance was also flown on that occasion.

The results of these investigations and their stratigraphic and palaeogeographic implication are the subiect of this paper.

STRATIGRAPHY

Precambrian Rocks

These rocks were not examined in detail and only a general description is given here. Three suites may be distinguished.

a. Basic volcanics. (Ꝑ u v on geologic map, Fig. 2).

These consist largely of green to dark green, amygdaloidal basalts, partly epidotised, and they form the " core " of the Mt. Arrowsmith inlier, including Mt. Arrowsmith itself. Andesites are reported to occur together with the basalts (Kenny, 1934, p. 51).

b. Altered sediments. (Ꝑ u a on geologic map, Fig. 2).

The volcanic " core " of the Mt. Arrowsmith inlier is surrounded by Precambrian quartzites, slates and sericite schists. These are succeeded by an interbedded sequence of black slate and greenish grey limestones with (?) sills of dark green volcanics with large feldspar-phenocrysts. Dykes of dark green, gabbroic rocks are also interspersed in this sequence. Sediments and igneous rocks are strongly sheared and cleaved and the limestone bands are commonly tightly folded.

c. Unaltered sediments (Ꝑ u u on geologic map, Fig. 2).

A sequence of unmetamorphosed rocks consisting of dark grey oolitic limestones, pinkish tan, thinly bedded dolomitic limestones, green siliceous dolomitic siltstones and shale, and dark green micro-amygdaloidal volcanics is exposed on the northwestern side of the inlier. No fossils have been discovered in these sediments. They unconformably underlie Lower Ordovician strata and are tentatively considered Proterozoic in age although they could conceivably be as young as Lower Cambrian.

Cambrian Sediments

Sediments of Cambrian age are exposed on the southwest margin of the Mt. Arrowsmith inlier, three miles ENE of Pincally Homestead.

Legend to Figure 1

Generalised geological map of Frome Embayment and geological units along its margin. The Lower Palaeozoic sequence in the Flinders Ranges consists of Lower to Middle Cambrian sediments, whilst the exposure at Mt. Arrowsmith comprises Middle Cambrian and Lower Ordovician deposits.

Oil exploration wells are identified by circles, and the respective stratigraphic section by letter symbols: (M=Mesozoic; P=Permian; O=Ordovician; ε=Cambrian; Ꝑ=Precambrian). Structural contour lines show depth below sea level of the base of the Cretaceous.

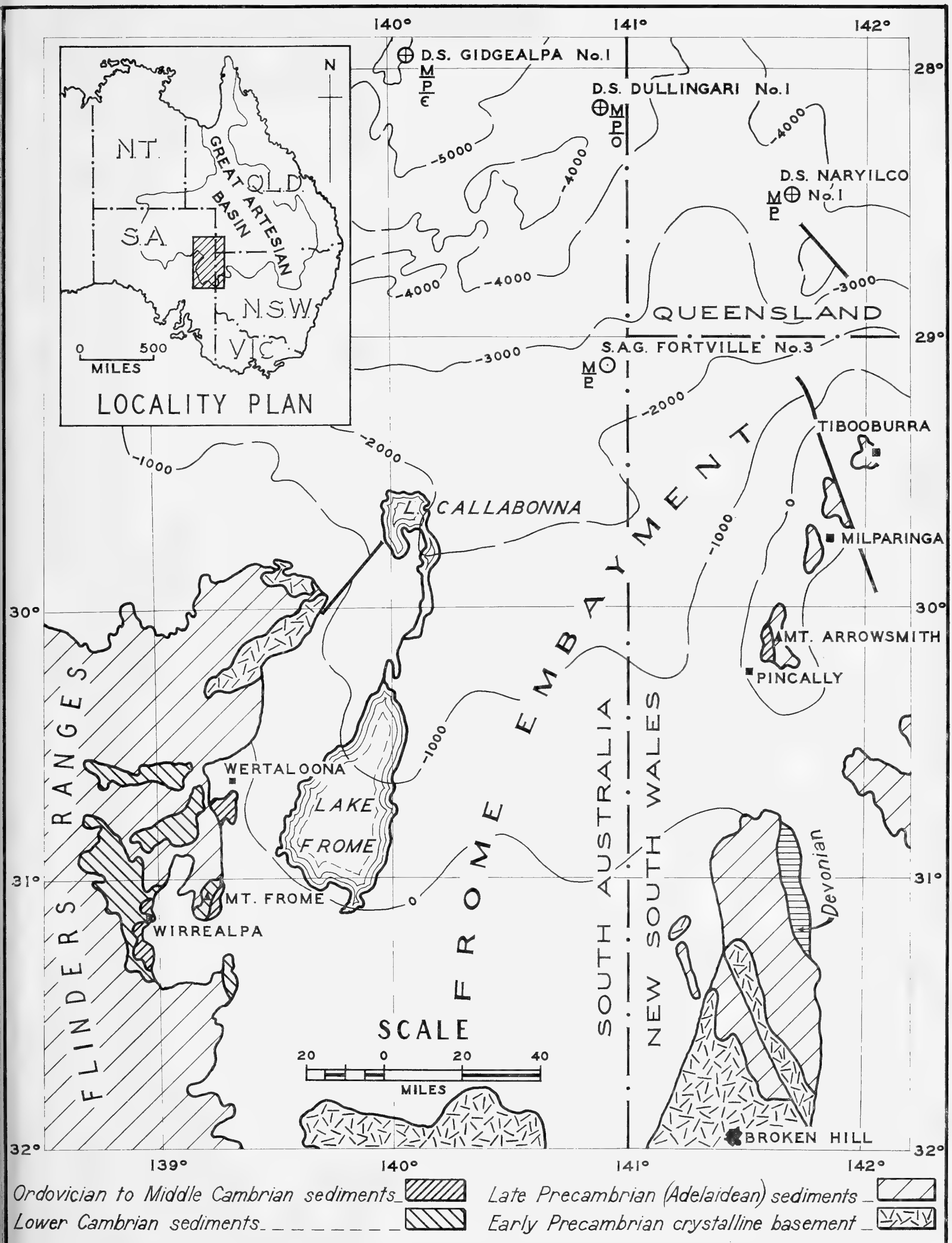

D.S. GIDGEALPA No.1
D.S. DULLINGARI No.1
D.S. NARYILCO No.1
S.A.G. FORTVILLE No.3
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
FROME EMBAYMENT
FLINDERS RANGES
L. CALLABONNA
LAKE FROME
WERTALOONA
MT. FROME
WIRREALPA
TIBOOBURRA
MILPARINGA
MT. ARROWSMITH
PINCALLY
BROKEN HILL
Devonian
LOCALITY PLAN
N.T.
QLD.
S.A.
N.S.W.
VIC.
GREAT ARTESIAN BASIN
0 500 MILES
SCALE
20 0 20 40
MILES
Ordovician to Middle Cambrian sediments
Lower Cambrian sediments
Late Precambrian (Adelaidean) sediments
Early Precambrian crystalline basement

Fig. 1

The area of exposure is about 8,500 feet long and has a maximum width of about 3,500 feet. (See Fig. 2 and Pl. 1). The stratigraphic thickness of the Cambrian section exposed is about 1,900 feet. The base of the section is concealed be recent deposits.

As shown on the composite section (Fig. 3) and the geological map (Fig. 2) the Cambrian sequence can be subdivided into four distinctive lithological units, here informally referred to in ascending order as members A, B, C and D. All boundaries except that between members C and D are transitional.

Member A consists of thinly bedded, brownish grey, slightly calcareous and finely micaceous silty shale with rare and thin, lenticular interbeds of carbonates, the latter constituting less than 2% of the unit. In the lowest exposed portion the carbonates are light grey, crystalline limestones. Between 250 and 300 feet above the lowest exposure, dark grey, current bedded, sandy, glauconitic limestone-interbeds contain fragments of trilobites including the Middle Cambrian genus *Xystridura* identified by Dr. B. Daily (pers. com.). A petrological description of these carbonate-interbeds is given in the appendix (P. 216/65, H.W. 100/2). The upper part of member A consists again of dark grey silty shale with interbeds of fine grained sandstone. Total exposed thickness of member A is 575 feet.

Member B is composed largely of fine to medium grained, silty, partly feldspathic sandstone and medium to coarse grained tuffaceous greywacke with infrequent lenticular bands of limestone and dolomite towards the top. The total thickness of member B is 385 feet whereof about 5% is composed of carbonates.

The lower portion of member B consists of interbedded siliceous, kaolinitic sandstones and fine-grained, maroon and grey spotted, slightly dolomitic greywacke. This sequence is overlain by maroon, richly feldspathic greywacke conglomerate and grit with green, micaceous lenses. Microscopic examination revealed shards of volcanic glass and other volcanic affinities suggesting a tuffaceous origin (see petrographic description P. 217/65, H.W. 100/5, in appendix). Conglomerates, consisting of well-rounded volcanic components are also present. Above 740 feet the dominant rock types are olive green, micaceous siltstone and splintery shale with thin, lenticular interbeds of carbonates. They are mainly limestones, although a few, thin dolomites are interspersed, and their thickness varies between six inches and 18 inches. The limestones are either dark grey, microcrystalline, or nodular and mottled, consisting of dark grey limestone nodules embedded in a yellow cr pink marly matrix. *Hyolithes* sp. is fairly common within these limestones.

The top of member B is formed by a thin band of pale green, feldspathic greywacke-grit with an average grain size of 2 to 4 mm and again showing tuffaceous affinities (see P. 218/65, H.W. 100/8, in appendix).

Member C which extends from 960 feet to 1,350 feet is largely composed of fine grained clastics but with a considerable increase in carbonate interbeds. Limestones and to a lesser degree dolomites constitute 15% to 20% of this particular member.

The clastics consist largely of green micaceous, feldspathic siltstones and silty shale (see P. 1355/65, H.W. 109, in appendix) with minor interbeds of fine grained, feldspathic sandstone. The clastics are thinly bedded to laminated but are more commonly finely current bedded, or current laminated. Festoon cross-bedding is also common. A well developed slump-horizon, about 12 to 18 inches thick occurs at 1,170 feet (see composite section, Fig. 3 and Pl. II–2).

The carbonates, which have an average bed-thickness of five to 10 feet, consist largely of grey and yellow mottled, dense to microcrystalline limestones with rare *Hyolithes* (Pl. II–1). Abundant Girvanella-type algal structures occur in a very dark grey and pink mottled limestone near the base of member C at 980 feet (see Fig. 3). Very characteristic yellow weathering, sandy and conglomeratic limestone with coarse, concave current bedding, overlies the slump horizon at 1,180 feet. The top of member C is formed by about 30 feet of sandy dolomite (see P. 219/65, H.W. 100/12, in appendix) and eight feet of dark brown, mottled limestone (1,310–1,350 feet). This latter unit is apparently lenticular and not persistent along the strike.

Member D is a silty shale unit, consisting of pale, olive green, micaceous silty shale with red shale interbeds (1,350–1,450 feet) grading to finely micaceous, splintery, maroon shale with green shale interbeds (see P. 220/65, H.W.

Legend to Figure 2

Geological map of Middle Cambrian and Lower Ordovician sediments on western side of Mt. Arrowsmith inlier. The measured sections are identified by roman numerals. Topographic base from uncontrolled air photo-plot.

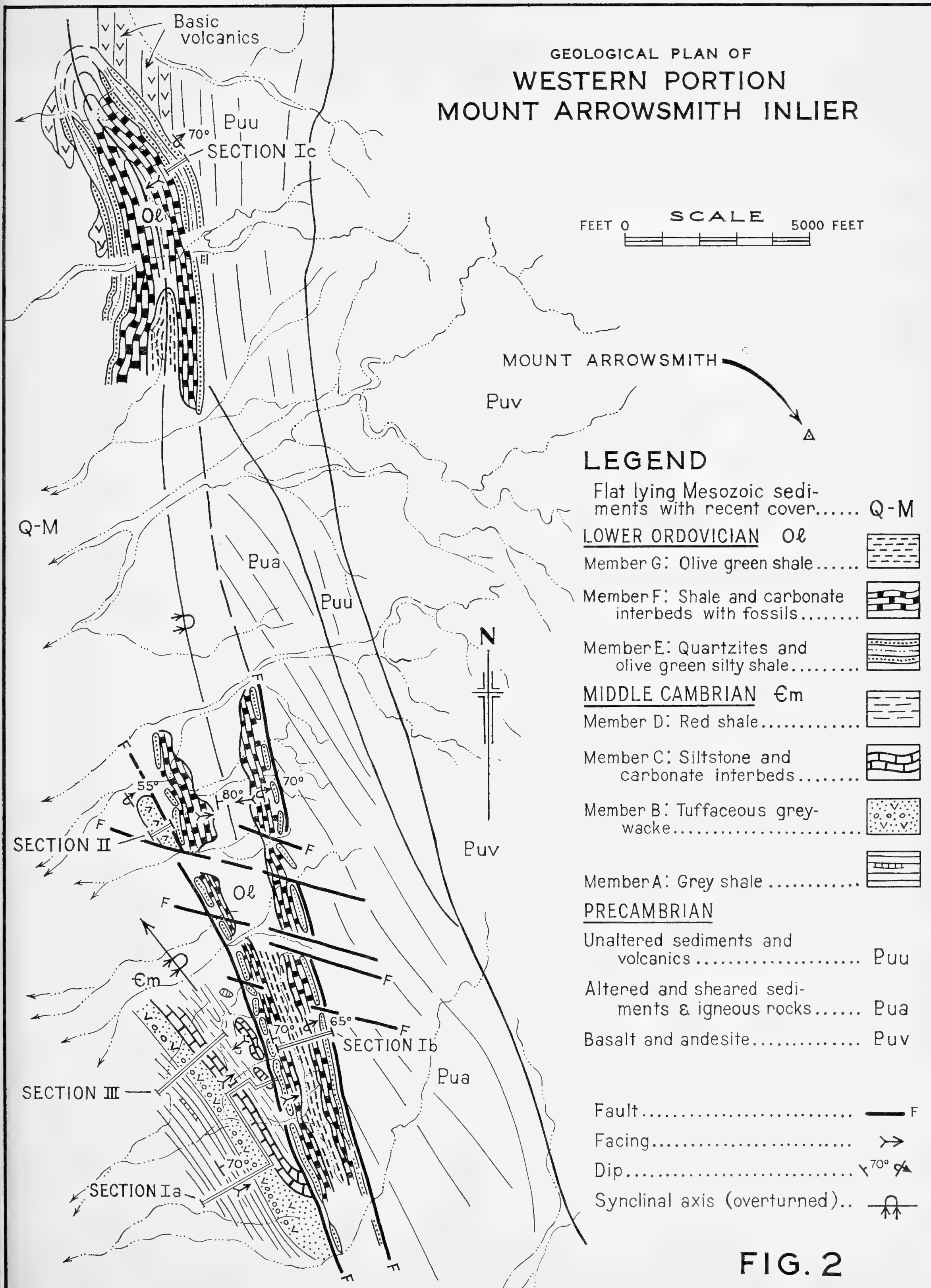

GEOLOGICAL PLAN OF
WESTERN PORTION
MOUNT ARROWSMITH INLIER
SCALE
FEET 0
5000 FEET
Basic volcanics
Puu
70°
SECTION Ic
Oℓ
MOUNT ARROWSMITH
Puv
Q-M
Pua
Puu
N
70°
55°
80°
SECTION II
F
Oℓ
€m
70°
65°
SECTION Ib
Pua
SECTION III
70°
SECTION Ia
LEGEND
Flat lying Mesozoic sediments with recent cover...... Q-M
LOWER ORDOVICIAN Oℓ
Member G: Olive green shale......
Member F: Shale and carbonate interbeds with fossils........
Member E: Quartzites and olive green silty shale.........
MIDDLE CAMBRIAN €m
Member D: Red shale............
Member C: Siltstone and carbonate interbeds........
Member B: Tuffaceous greywacke.....................
Member A: Grey shale...........
PRECAMBRIAN
Unaltered sediments and volcanics.................. Puu
Altered and sheared sediments & igneous rocks...... Pua
Basalt and andesite............. Puv
Fault........................ F
Facing........................
Dip........................... 70°
Synclinal axis (overturned)..

FIG. 2

100/13, in appendix). Lenses of grey, micaceous dolomite, rarely exceeding two feet in thickness, amount to less than 1% of this member.

Ordovician Sediments

The Ordovician sediments are exposed in a narrow strip 1,500 to 2,500 feet wide and about 5·3 miles long, to the east of the Cambrian sequence but west of the Precambrian rocks (see geological map Fig. 2 and photographs, Pl. I and Pl. III–1).

The contact with the known Cambrian sequence is faulted parallel to the strike of the Ordovician strata. In the northern part however, the Ordovician sediments rest unconformably on steeply dipping, unaltered sediments inter-bedded with basic volcanics (P u u in Fig. 2) which are assumed to be Late Precambrian or perhaps Early Cambrian in age. The composite columnar section presented in Fig. 3 was constructed from one section measured at the southern portion of the Ordovician outcrop (Section I*b*—Fig. 2) and a second section paced at the far northeast part of the exposure (Section I*c*—Fig. 2).

Total thickness of the Ordovician sequence is about 1,100 feet. In this paper three members are informally designated E, F and G in ascending order.

Member E is 310 feet thick and features a thick quartzite bed, both at the base and at the top. The interval between the two quartzites consists of green silty shale with carbonate nodules. Member E is best observed in the northern-most portion of the Ordovician exposure, as parts of member E have been faulted out further south (see Fig. 2).

The lower quartzite is a grey, massive to poorly bedded ortho-quartzite largely composed of medium grained, detrital quartz. Well-rounded pebbles, up to one inch diameter are scattered throughout the lower half of this unit. The sediments overlying the basal quartzite of member E consist of green to grey-green, micaceous shale with thin, wavy bedding. Thin and lenticular, silty, brittle carbonates, yellow to light brown and half to one inch thick, are irregularly interbedded. Carbonate nodules one-eighth to half inch average diameter, are scattered throughout. Some badly preserved (?) linguloid brachiopods were observed in the upper part of this unit. Some bands of dense, brown dolomite occur above this unit and immediately below the upper quartzite bed (see Fig. 3).

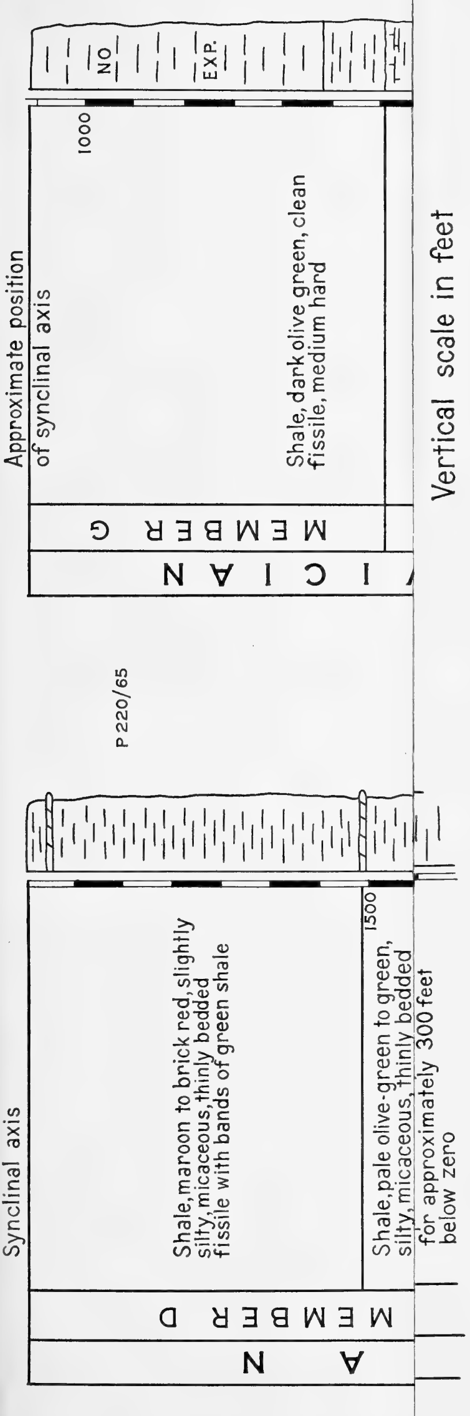
The upper quartzite bed forms the top of member E, and consists of white to very pale bluish grey, fine grained ortho-quartzite. The lower half is massive whilst the upper half is thinly bedded or exhibits well developed, concave current bedding with average foreset-angles of 10° to 15°. A detailed petrographic description of this unit is given in the appendix. (P. 221/65, H.W. 100/17).

Member F which overlies Member E with fairly sharp boundary (Pl. III–1), is comprised of 40 feet of greenish grey, micaceous, siliceous siltstone at the base followed by about 350 feet of thinly interbedded silty shales and carbonates. The shales are dark olive green to greenish grey, micaceous, silty and generally hard and splintery. Small flute casts are common throughout. The carbonates, which constitute about 10% to 15% of this interval are strongly lenticular, individual bed-thickness varying between one and six inches. The carbonates are generally brownish grey to pinkish brown, slightly sandy limestones, saccharoidal to crystalline and more or less dolomitic. Some thin bands of dense, yellow dolomite are interspersed. Wave ripple marks and current bedding are common (Pl. III–2). The limestone bands are usually richly fossiliferous, containing an abundance of nautiloids, brachiopods and brachiopod-lumachelle. The nautiloids *Pachendoceras* sp. and *Catoraphiceras* sp. have been identified by workers of the Geological Survey of N.S.W. (pers. com. R. Brunker). Flat-whorled gastropods (? *Raphistoma*), some bivalves, and trilobite-fragments have also been observed by the author. The fauna is of Early Ordovician age.

The general age indicated by the assemblage of macrofossils was subsequently confirmed by a conodont-fauna contained in a sample collected by Mr. Ph. Magnier of the French Pectroleum Co. (Aust.) Pty. Ltd. in 1966 and analysed by Mr. E. C. Druce of the Bureau of Mineral Resources (Druce, 1966).

The sample was collected about 50 feet above the upper quartzite unit corresponding to 351 feet on the composite stratigraphic section, figure 3 (pers. com. Ph. Magnier, March, 1966). Mr. Druce reports on the conodont-fauna as follows :

> " One sample, AD623 from near Mt. Arrowsmith has been submitted for examination. It has broken down in monochloracetic acid and yielded sixteen conodont specimens representing six species referable to four genera. The fauna consisted of :—
>
> *Drepanodus* n. sp.
> *Microcoelodus* n. sp.
> *Oistodus abundans* Branson and Mehl.
> *Oistodus inegualis* Pender.
> *Oistodus* n. sp.
> *Trichonodella* sp.



COMPOSITE STRATIGRAPHIC SECTIONS OF MIDDLE CAMBRIAN AND LOWER ORDOVICIAN SEDIMENTS AT MOUNT ARROWSMITH N.S.W.

Fig. 3

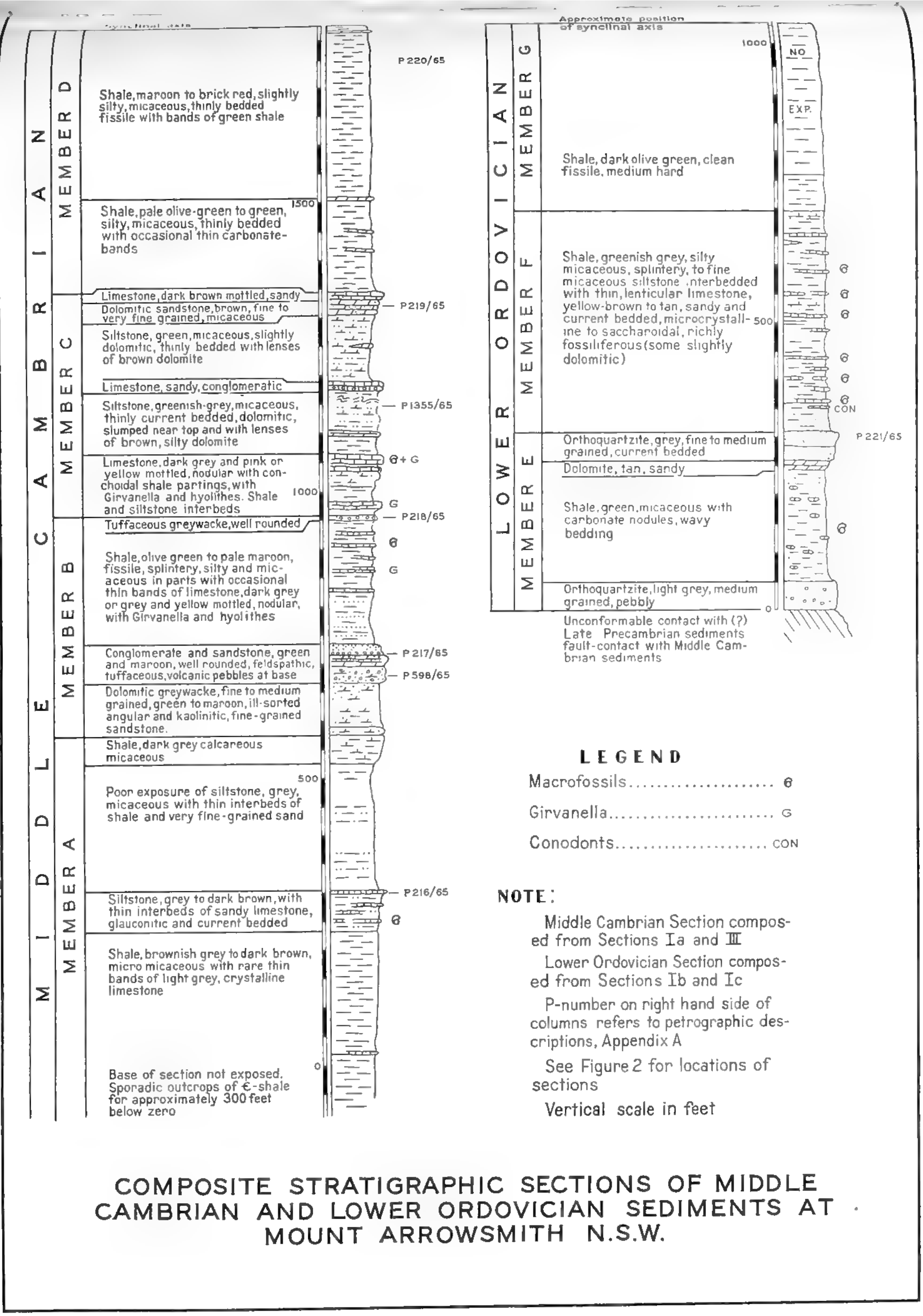

MIDDLE CAMBRIAN
MEMBER D
Shale, maroon to brick red, slightly silty, micaceous, thinly bedded fissile with bands of green shale
P 220/65
1500
Shale, pale olive-green to green, silty, micaceous, thinly bedded with occasional thin carbonate-bands
MEMBER C
Limestone, dark brown mottled, sandy
Dolomitic sandstone, brown, fine to very fine grained, micaceous
P219/65
Siltstone, green, micaceous, slightly dolomitic, thinly bedded with lenses of brown dolomite
Limestone, sandy, conglomeratic
Siltstone, greenish-grey, micaceous, thinly current bedded, dolomitic, slumped near top and with lenses of brown, silty dolomite
P1355/65
Limestone, dark grey and pink or yellow mottled, nodular with conchoidal shale partings, with Girvanella and hyolithes. Shale and siltstone interbeds
1000
G
P218/65
MEMBER B
Tuffaceous greywacke, well rounded
Shale, olive green to pale maroon, fissile, splintery, silty and micaceous in parts with occasional thin bands of limestone, dark grey or grey and yellow mottled, nodular, with Girvanella and hyolithes
G
Conglomerate and sandstone, green and maroon, well rounded, feldspathic, tuffaceous, volcanic pebbles at base
P 217/65
P 598/65
Dolomitic greywacke, fine to medium grained, green to maroon, ill-sorted angular and kaolinitic, fine-grained sandstone
MEMBER A
Shale, dark grey calcareous micaceous
500
Poor exposure of siltstone, grey, micaceous with thin interbeds of shale and very fine-grained sand
Siltstone, grey to dark brown, with thin interbeds of sandy limestone, glauconitic and current bedded
P 216/65
Shale, brownish grey to dark brown, micro micaceous with rare thin bands of light grey, crystalline limestone
0
Base of section not exposed. Sporadic outcrops of €-shale for approximately 300 feet below zero
Approximate position of synclinal axis
LOWER ORDOVICIAN
MEMBER G
1000
NO
EXP.
Shale, dark olive green, clean fissile, medium hard
MEMBER F
Shale, greenish grey, silty micaceous, splintery, to fine micaceous siltstone interbedded with thin, lenticular limestone, yellow-brown to tan, sandy and current bedded, microcrystalline to saccharoidal, richly fossiliferous (some slightly dolomitic)
500
CON
MEMBER E
Orthoquartzite, grey, fine to medium grained, current bedded
P 221/65
Dolomite, tan, sandy
Shale, green, micaceous with carbonate nodules, wavy bedding
Orthoquartzite, light grey, medium grained, pebbly
0
Unconformable contact with (?) Late Precambrian sediments fault-contact with Middle Cambrian sediments
LEGEND
Macrofossils
Girvanella ... G
Conodonts ... CON
NOTE:
Middle Cambrian Section composed from Sections Ia and III
Lower Ordovician Section composed from Sections Ib and Ic
P-number on right hand side of columns refers to petrographic descriptions, Appendix A
See Figure 2 for locations of sections
Vertical scale in feet
COMPOSITE STRATIGRAPHIC SECTIONS OF MIDDLE CAMBRIAN AND LOWER ORDOVICIAN SEDIMENTS AT MOUNT ARROWSMITH N.S.W.

Fig. 3

Oistodus abundans was first described from the Plattin Formation (Middle Ordovician) but is known from upper Canadian formations. *Oistodus inegualis* is known from Arenigian strata in Sweden.

The remaining species are known from the Horn Valley Formation of the Amadeus Basin which on graptolite, trilobite and conodont evidence is upper Arenigian ; they are not known from the Stokes Formation.

Thus the age of this sample is considered Upper Arenigian, and post Canadian, pre Chazyian."

(Published with the permission of the Assistant Director Geology, Bureau of Mineral Resources).

Member G situated in the centre of a syncline, is generally poorly exposed. It consists of dark olive green, clean, medium hard and fissile shale and attains a thickness of approximately 360 feet.

Structure

It is apparent from the geological map (Fig. 2) that the basic structural elements of the Cambrian and the Ordovician sediments at Mt. Arrowsmith are two near-isoclinal, overturned synclines.

The axis of the syncline formed by the Cambrian sediments trends 320° and has a north plunge of about 15° to 20°. The axial plane dips approximately 70° east (see Fig. 4). The overturned nature of the Cambrian syncline was verified by numerous, indisputable facings on both limbs. Excellent eastfacings were observed in the sandy carbonates in Member A (at 280–300 feet in composite section, Fig. 3) and within the slumped, ripple marked and current bedded siltstones in Member C (at 1,150 feet in composite section Fig. 3, and pictured in Plate II–2). These latter facings were confirmed by radiography, carried out on an orientated specimen by Mr. N. A. Trueman of AMDEL who reports as follows :

"The sample shows good cross-bedding. Asymptotic bottomset beds are visible in several places and top-set beds are truncated. The rock is therefore younger towards the top of the specimen. The direction of transport is evident on the section parallel to the dip and is in the up-dip direction. On the section parallel to the strike the direction is less evident and may be variable. From the slope of some channels there is a suggestion of transport from south to north." (Sample No. P.1355/65 ; H.W. 109).

West facings from the planar truncation of top-sets of concave current bedding in gritty limestones (equivalent to member C) were observed on the overturned limb. The facings observed in the field are also shown on the geological map, Fig. 2.

The axial trend of the Ordovician synclir sinuoid, changing from 340° in the soutl 360° and back to 330° in the north (see geolo map, Fig. 2). The axis appears to be flat ex for the northern-most part of the syncline w a southeasterly plunge is indicated. The plane dips about 60° to 65° to the east Fig. 4). The syncline appears to be very tig folded in the south, but opens towards northern end of the structure. Reliable facings based on truncations of top-set current bedding were observed within quartzite of member E and within s carbonates of member F. These were fu confirmed by small flute-casts in siltstones member F. West facings in the overt limb were obtained from current bedded s carbonates of member F exposed on the ea limb.

The compressive forces leading to deformation of the Cambro-Ordovician s are also evidenced in the fabric of some c arenaceous sediments. Elongation of q grains and orientation of mica has been obs in a sandy unit near the top of meml (see petrographic description P. 219/6 appendix), and slight elongation and unc extinction of quartz-grains occurs in the vician quartzite of member E (see P. 221/ appendix).

The basic structural features of the overt synclines are further complicated by v faults. Faulting is particularly severe i southern portion of Cambro-Ordovician ou but less noticeable in the northern exp of the Ordovician sediments.

The major fault in the southern part thrust-fault which more or less follow western margin of the Ordovician sedir separating them from the Cambrian succe This fault is evidenced by brecciation slicken-siding of the quartzite (member E by small slivers of fossiliferous memb sediments squeezed between the quartzit the fault (Fig. 4). It appears that the portion of member E has been faulted To the north the fault apparently dies o

A major fault or shear zone forms the c between the Ordovician sediments an Precambrian rocks and also delineate eastern margin of the Ordovician synclir Fig. 2 and Pl. I). This fault has caused brecciation and shearing within the Ordovician sequence (Pl. III–1) and rep of certain units is evident. This fault prominent only in the southern portion outcrop area.

Transverse faults occur commonly within the southern part of Cambro-Ordovician outcrop however, only the more important and obvious ones are shown on Fig. 2. They appear to post-date the major, longitudinal faults and their movements were largely transcurrent, leading to rotational displacements. This effect is particularly noticeable within the Ordovician quartzites.

No major faulting was observed within the northern part of the Ordovician syncline, where the Ordovician sediments rest unconformably on the steeply dipping sediments and volcanics of presumed Late Precambrian or Early Cambrian age.

ENVIRONMENT

In the following discussion of the depositional environments of the Lower Palaeozoic sediments at Mt. Arrowsmith, the authcr uses the subdivisions of marine environments as outlined by Krumbein and Sloss (1963, pp. 259–261).

Most of the Cambrian sediments exposed at Mt. Arrowsmith were deposited in a sublittoral environment. The grey shale sequence of member A with its occasional thin interbeds of current-bedded, sandy glauconitic carbonates appears to be a product of a sub-stable infra- to circa-littoral environment. The tuffaceous greywacke and conglomerates of member B are almost certainly infra-littoral with rapid sediment-intake resulting from unstable conditions. Most of the clastic material must have been derived from a nearby volcanic source which was intermittently uplifted. Water was the main transporting agency although direct intake of volcanic ash from contemporaneous volcanic activity is also indicated. The small scale current beds observed throughout the siltstones in member C again indicate an infra-littoral environment. This is further confirmed by the presence of Girvanella-type algae which, one might assume, would require a certain amount of light for their existence.

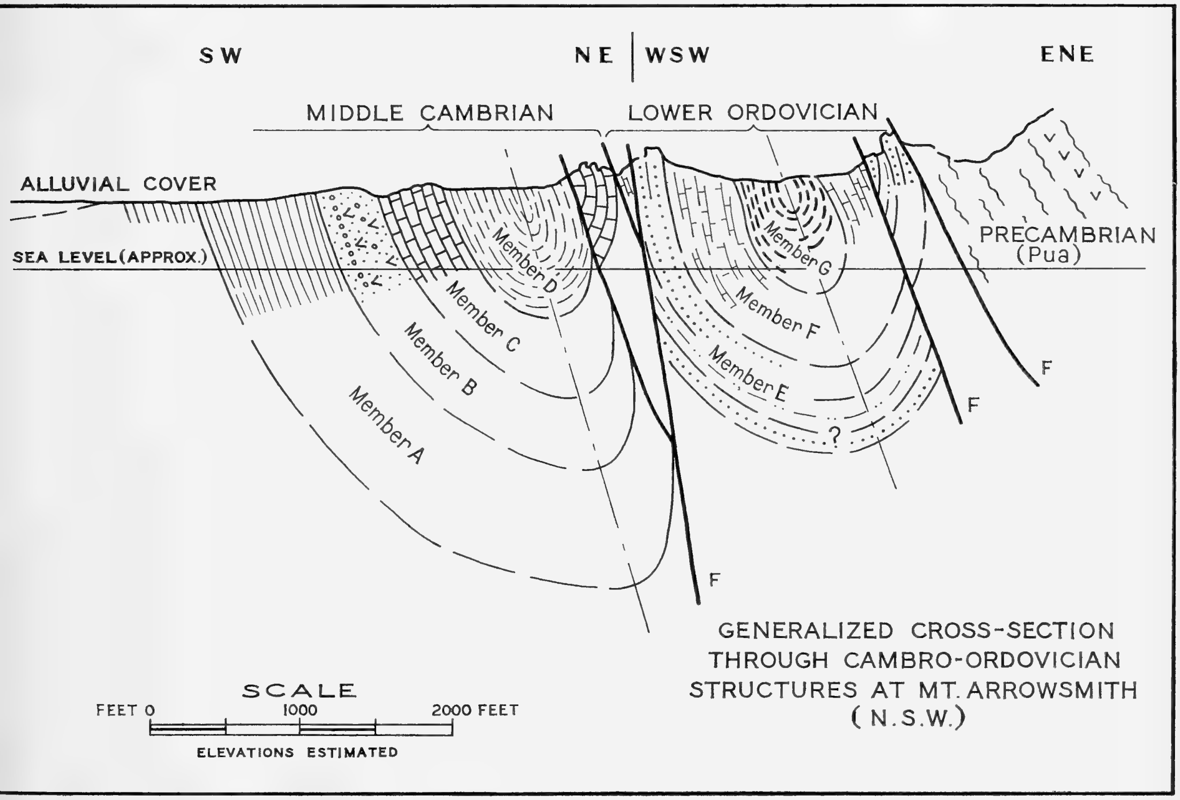


Fig. 4

Generalized geological cross-section showing relationship between Middle Cambrian and Lower Ordovician strata at Mt. Arrowsmith, approximately along section I*b* and I*a*.

Sediment-intake was generally moderate. Intermittent influx of medium to coarse clastic material indicates slight crustal instability.

The thinly bedded, red and green shales of member D with thin dolomite-bands are products of a stable, low-energy environment. They may either have been deposited in tidal mud flats or in a broad, restricted basin environment.

The unconformable relationship of the Ordovician sediments to the underlying rocks in the northern part of the syncline demonstrates the transgressive nature of the lower Ordovician sediments. The conglomeratic quartzites of the basal member E may therefore be interpreted as a close shore, transgressive facies.

The olive green micaceous and calcareous silty shales which are intercalated between the upper and the lower quartzite beds of member E, are suggestive of a lagoonal environment and the presence of inarticulate brachiopods would also be in keeping with shallow, quiet water conditions.

The shale-siltstone carbonate interbeds of member F are again infra-littoral. The abundance of concave and sinuoid current bedding and flute casting and the presence of lumachelle-carbonates suggests deposition under a medium high energy level. The abundance of nautiloid fossils indicates open, marine conditions. The dark green clean shale of member G was deposited in a low-energy environment and may be circa-littoral.

CORRELATION

The importance of the discovery of Cambro-Ordovician sediments at Mt. Arrowsmith lies largely in their geographic position. Located on the northeastern margin of the Frome Embayment, the Mt. Arrowsmith sections take a somewhat intermediate geographical position between the Cambrian sections in the Flinders Ranges and the subsurface occurrences of Cambrian and Ordovician sediments in the Cooper's Creek Sub-basin on the one hand and the Cambro-Ordovician sections in the Mootwingee-Gnalta area, northeast of Broken Hill, on the other.

However, before the full benefit of the Mt. Arrowsmith sections for stratigraphic evaluation can be realized they should be correlated with known Cambrian and Ordovician sections.

Some of the best-known Cambrian sections are exposed near the western margin of the Frome Embayment, about 140 miles WSW of Mt. Arrowsmith, in the Flinders Ranges. The Cambrian sequence in the Flinders Ranges consists, in ascending order, of Lower Cambrian carbonates and clastics (Hawker Group); an upper Lower Cambrian to lower Middle Cambrian red and green, partly tuffaceous shale and siltstone sequence (Billy Creek Formation); a lower Middle Cambrian carbonate band with *Girvanella*, *Hyolithes* and *Redlichia* (Wirrealpa Limestone), and a sparsely fossiliferous sequence of red shales, siltstones and sandstones, with some dolomites (Lake Frome Group) (Daily, 1956; Dalgarno, 1964).

With the occurrence of index fossils at Mt. Arrowsmith limited to *Xystridura* it would appear from present knowledge of the range of Cambrian trilobites, that member A is slightly younger than the *Redlichia*-bearing Wirrealpa Limestone.

On the other hand one cannot help noticing the striking similarities in lithology and succession between the Cambrian sequence at Mt. Arrowsmith and the sequence from the Billy Creek Formation to the lower part of the Lake Frome Group.

In the eastern Flinders Ranges the Billy Creek Formation consists of a lower member of grey-green siltstones with thin dolomite bands and an upper sequence of red-brown micaceous shale. White to pink tuffaceous bands are present in the middle portion of the Billy Creek Formation (Dalgarno, 1964). Tuffaceous greywacke occurs near the top of the Billy Creek Formation at Mt. Frome. Some of these tuffaceous bands are lithologically indistinguishable from the finer grained tuffaceous greywacke of member B of the Cambrian sequence at Mt. Arrowsmith.

Similarly the limestone bands of member C from Mt. Arrowsmith compare very favourably indeed with the lithology of the Wirrealpa Limestone. *Girvanella* and *Hyolithes* are abundant in both units.

The red and green sequence of silty shale with thin dolomite bands of member D is very similar to the red and green siltstone-sandstone sequence of the lower Lake Frome Group (Moodlatana and Balcoracana Formations).

One might therefore reason that the Cambrian sequence at Mt. Arrowsmith consists of equivalent lithosomes of Billy Creek Formation, Wirrealpa Limestone and lower Lake Frome Group but that the Mt. Arrowsmith equivalents are younger than the ones in the Flinders Ranges. Diachronism however appears to be unlikely in this type of sequence, particularly when considering the presence of lithologically similar tuffaceous beds in either succession.

Obviously more work is needed before these questions can be answered satisfactorily. The correlation presented in Table 1 is based on lithological considerations and should therefore be regarded as a tentative working hypothesis.

Accepting this correlation for the time being it seems apparent that members B and C were deposited closer to a volcanic source area but also closer to land than their lithologic equivalents on the western margin of the Frome Embayment. Member A on the other hand appears to have been laid down in more open marine conditions than the lower member of the Billy Creek Formation. Similar depositional environments are indicated for member D and the lower parts of the Lake Frome Group although the latter may have been deposited closer to land than member D.

Middle Cambrian sediments are also known from Delhi-Santos Gidgealpa No. 1 Well between 9,110 feet and approximately 10,000 feet below surface (Harrison and Higginbotham, 1964). There, grey, microcrystalline silty limestones and black, laminated, calcareous shale (9,110–9,390 feet) overlie grey-green tuffaceous shale, tuffaceous, fossiliferous limestone and conglomerate composed of volcanic rock fragments (9,390–9,535 feet). Tuffaceous shale and sandstone also occur intermittently throughout the interval 9,780 to 10,000 feet (Harrison and Higginbotham, *opus cit.*). Thus, it is tempting to correlate the main tuffaceous interval from Gidgealpa No. 1 (9,390–9,535 feet) with member B from Mt. Arrowsmith, and member C with the limestone-shale sequence between 9,110–9,390 feet. However neither the fauna obtained from the Middle Cambrian of Gidgealpa No. 1 nor the fauna from the Middle Cambrian at Mt. Arrowsmith is specific enough to allow accurate comparison and the correlation suggested above remains therefore conjectural.

The nearest known outcrops of rocks comparable to the Ordovician sediments at Mt. Arrowsmith occur in the Koonenberry Range and in the Mootwingee–Gnalta area.

The Ordovician sequence in the Mootwingee Ranges is well exposed along the old mail road from Mootwingee to White Cliffs, about eight miles from Mootwingee Homestead, where the road follows a strike valley developed in steeply dipping Ordovician sediments. The sequence consists of a lower, wormburrow quartzite, a fossiliferous silstone and dolomite unit and an upper quartzite containing some vertical worm burrows and *Cruciana*. The upper quartzite is unconformably overlain by coarse grained, current-bedded sandstones of Upper Devonian age. The siltstone-dolomite unit sandwiched between the two quartzites consists dominantly of dark green, thinly bedded, micaceous siltstones, interbedded with brown dolomites and some fine grained, silty, quartzitic

TABLE 1

Chart showing tentative rock-correlation of Middle Cambrian Sections of the eastern Flinders Ranges and Mt. Arrowsmith

Eastern Flinders Ranges			Mt. Arrowsmith	
	Rock Unit	Lithology	Rock Unit	Lithology
Lower Lake Frome Group	BALCORACANA FORMATION	Red and green micaceous siltstones and thin, grey dolomitic limestone.	MEMBER D	Red and green, micaceous, silty shale with thin bands of dolomite.
	MOODLATANA FORMATION	Red, micaceous siltstone and current bedded sandstone with thin bands of dolomite near top.		
WIRREALPA LIMESTONE		Gey and yellow mottled, nodular limestone with *Girvanella*, *Hyolithes* and trilobites (*Redlichia*). Also massive and oolitic limestones and some siltstone interbeds.	MEMBER C	Greenish grey, micaceous siltstone with interbeds of grey and yellow mottled, nodular limestone with *Girvanella* and *Hyolithes*.
BILLY CREEK FORMATION		Red-brown, micaceous sandstone and siltstone with thin bands of tuffaceous greywacke.	MEMBER B	Green or maroon feldspathic sandstone, tuffaceous greywacke and conglomerate composed of reworked volcanics.
		Red, grey and green silty shale with rare thin dolomite bands and thin, pink, tuffaceous beds.	MEMBER A	Grey silty shale with thin bands of glauconitic, feldspathic carbonates containing *Xystridura*.

sandstones. The dolomite-interbeds are more frequent near the top of the unit. Inarticulate brachiopods occur abundantly in this unit which, in the past, has been referred to informally as the "lingula beds".

Fletcher (1964) identified *Obolus mootwingeensis*, *Lingulella* (*Leptembolon*) *gnaltaensis* and *Ectenoglossa brunnschweileri* and assigned a Tremadocian age to the fauna.

Member E of the Mt. Arrowsmith section is strikingly similar to the Ordovician sequence in the Mootwingee Ranges, and the author is fairly confident in correlating the green, micaceous silstones, containing inarticulate brachiopods with the Tremadocian "lingula beds" of the Mootwingee Ranges. Druce's (*op. cit.*) Arenigian age for the sediments of member F would also be in agreement with this correlation.

Lower Ordovician to lower Upper Ordovician sediments, consisting largely of very dark grey, hard, pyritic shale with bands of fine grained pyritic sandstone were encountered in Delhi-Santos Dullingari No. 1 Well between 9,050 feet and the total depth of the well at 11,588 feet (Harrison and Greer, 1963). Portion of this sequence would appear to be equivalent in time to the Ordovician sediments at Mt. Arrowsmith, but deposited in deeper parts of the Ordovician sea.

The correlation of member F of the Ordovician at Mt. Arrowsmith with the Horn Valley Formation of the Amadeus Basin as suggested by Druce (*op. cit,*) is particularly noteworthy. The two stratigraphic units are lithologically very similar, although the nearest outcrop of Horn Valley Formation is situated nearly 650 miles northwest of the Ordovician exposure at Mt. Arrowsmith.

No sediments of documented Ordovician age are known in the Flinders Ranges.

Conclusions

The Middle Cambrian sediments at Mt. Arrowsmith may be correlated lithologically with the Middle Cambrian succession in the Flinders Ranges, and certain similarities also exist with the Middle Cambrian section encountered in Delhi-Santos Gidgealpa No. 1 Well. One may conclude therefore that the Middle Cambrian sea extended from the Flinders Ranges across the Frome Embayment into New South Wales and northward into the area of the Coopers Creek Sub-basin. A not too distant shoreline might have existed to the south or south-southwest of Mt. Arrowsmith, formed by a northern salient of the Broken Hill–Olary Block. This salient also would have separated the Cambrian basin of the Flinders Ranges from the Cambrian trough in the Mootwingee–Gnalta area.

According to presently accepted views (Daily, 1956; Campana, 1958; Thomson, 1965), the Cambrian sediments of the Flinders Ranges were deformed together with the Adelaidean strata, in late Middle Cambrian to Early Ordovician time, resulting in the formation of long, comparatively simple fold-chains, complicated only along major fault-zones.

At Mt. Arrowsmith the main orogenetic movements took place in post-Early Ordocivian time, although the presence of an angular unconformity at the base of the Lower Ordovician sediments indicates tectonic movements prior to their deposition. From evidence in the Mootwingee-Gnalta area, a Late Ordovician to Silurian age is suggested for the main orogeny in the Mt. Arrowsmith area.

The Cambrian strata have been preserved extensively in the Flinders Ranges whence they dip easterly beneath the Frome Embayment.

As the Middle Cambrian facies of the Flinders Ranges can be compared with the Middle Cambrian strata at Mt. Arrowsmith, one can assume that the Middle Cambrian sea extended uninterrupted between the two outcrop areas. Middle Cambrian sediments are therefore likely to have been preserved extensively beneath the deeper parts of the Frome Embayment. Indeed bore data strongly suggest the presence of Cambrian strata in the western and central portion of the Frome Embayment (Ker, 1966).

Since Ordovician strata are not known in the Flinders Ranges one may predict an Ordovician shore line to the west of Mt. Arrowsmith, in an area now covered by the younger sediments of the Frome Embayment. The black, marine shale facies of Lower to Middle Ordovician age beneath the Coopers Creek Sub-basin must have had a corresponding near-shore development and it seems logical to interpret the Ordovician sediments at Mt. Arrowsmith as a remnant of such a near shore facies.

The once existing connection between the Lower Palaeozoic sediments beneath the Coopers Creek Sub-basin on one side and the Lower Palaeozoic basins of the Mt. Arrowsmith–Mootwingee trend and of the Flinders Ranges on the other however, has since been severed. This is shown by sub-surface information from the northeastern-most Frome Embayment, where Upper Jurassic and Lower Cretaceous sediments rest directly on truncated crystalline basement (Wopfner and Cornish, 1966). The break in the Lower Palaeozoic sedimentary cover in this area was caused by strong, Late Palaeozoic to Early Mesozoic uplifts of the Tibooburra–Milparinka Block, from which the Lower Palaeozoic sediments were stripped by the ensuing erosion.

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APPENDIX

Petrographic Descriptions of Rocks from Mt. Arrowsmith

The following petrographic descriptions were carried out by the Mineralogy Section of the Australian Mineral Development Laboratories in Adelaide. The samples were investigated by Mr. A. R. Turner (P. 216/65 to P. 221/65), Mr. I. F. Scott (P. 598/65 to P. 600/65) and Mr. D. Smale (P. 1355/65).

The footage-numbers refer to the position of the sample in the stratigraphic column as shown in the composite sections, Figure 3.

a. Cambrian Rocks from Normal (West)-Limb of Syncline

Member A; 300 feet.

P. 216/65; H.W. 100/2; TS 16145.

This specimen is a calcareous, feldspathic, greywacke which in hand-specimen displays a poorly defined laminated texture and has a dark greyish brown colouration flecked by minute grains of a green mineral.

The rock is composed of sub-angular to sub-rounded quartz grains, altered feldspar grains, rock fragments and opaque mineral grains set in a matrix of chemically precipitated and recrystallized calcite, chlorite, glauconite and recrystallized clay minerals. The detrital components have a size distribution in the range 0·35 to 0·05 mm. and are poorly sorted. The quartz grains are few in number, randomly distributed and inclusion free. The major proportion of the detrital fraction is composed of feldspar; both alkaline and plagioclase. The alkali feldspar is orthoclase and the plagioclase is predominantly sodic and twinned according to the albite law. Sericitization and chloritization of the feldspars is extensive; some grains being almost completely replaced. The rock fragments have also been subjected to extensive alteration and appear to have been variable in composition. The fragments have been subjected to various degrees of rounding; the more rounded grains are sedimentary and composed predominantly of clay minerals and the more angular grains appear to have had a fine-grained igneous origin.

The matrix is composed predominantly of calcite (in some areas replaced by (?) dolomite) together with masses of chlorite and pellets of glauconite. Rare laths of sericite and chlorite are randomly distributed throughout the rock.

The origin of this specimen is difficult to determine petrographically however, it appears likely that it has been deposited in a marine environment nearby to an eruptive volcanic source or alternatively nearby to volcanic lava flows which on erosion formed the clastic material constituting the bulk of the sample.

Member B; 670 feet.

P. 598/65; H.W. 107; TS 17011.

This is a coarse grained conglomerate exhibiting graded bedding. The rock fragments grade from sand size to cobble size with a maximum diameter of 1 cm.

Most of the fragments are fine grained volcanics, sometimes exhibiting primary flow banding while others are porphyritic in nature. One fragment consisted of recrystallized spherulites. None of the flow banded fragments appear to have a "typical" welded tuff texture. Secondary silicification has eliminated many of the clear cut grain boundaries and, except for the rounded nature of the grains as well as the distinct graded bedding, the rock closely resembles a tuff.

The volcanic rock fragments are sometimes red in hand specimen due to the presence of magmatically derived iron oxides. Rounding of the components varies from well rounded in the coarser fragments to sub-angular in some of the smaller grains.

Stringers of quartz transect the rock as a late stage phenomenon. No definite tuffaceous fragments were observed.

Member B; 720 feet.

P. 217/65; H.W. 100/5; TS 16147.

This specimen is a (?) tuffaceous greywacke which in hand-specimen is massive and a dark yellowish brown in colouration.

The rock is composed predominantly of clastic material, which shows a moderately high degree of packing, cemented together with recrystallized clay minerals and minor silica. The clastic fraction has a size distribution in the range 7·5 to 0·1 mm. and is poorly sorted. The majority of the grains are fine-grained, porphyritic, volcanic rock fragments composed of phenocrysts of intensely altered plagioclase feldspar set in a crypto-crystalline groundmass of silica and alkali feldspar. The phenocrysts have been largely altered to sericite. The grains show a degree of rounding which suggests that they have been subjected to mechanical transportation before deposition and are not direct pyroclastic ejecta. The groundmass of the fragments appears to be devitrified glass which exhibits incipiently developed flow structures. The remainder of the clastic fraction is composed of angular to sub-rounded quartz grains, which generally have a finer-grained size distribution than the fragments of igneous origin. Minor sedimentary rock fragments are also found. Opaque minerals, zircon and apatite are found in accessory amounts within the rock fragments.

The matrix of the rock is formed of sericite, chlorite and other minor clay minerals which coat each of the clastic grains in a fine veneer.

This specimen could be a tuff although no direct evidence is apparent with which to support this statement. The writer tends to favour deposition by normal sedimentary processes of either formerly tuffaceous material or of eroded volcanic lava flows.

Member B; 950 feet.

P. 218/65; H.W. 100/8; TS 16148.

This specimen is a (?) tuffaceous greywacke which in hand-specimen is greenish brown in colouration and extremely friable due to excessive weathering.

The rock is similar to specimen P. 217/65 in a number of respects but the following differences were observed:

1. Grain size smaller and in the range 3·0 to 0·1 mm. The grains are poorly sorted.
2. Calcite is the main cementing agent together with minor limonite.
3. Composition of pebbles:
   - *a.* devitrified siliceous glass with alkaline feldspar.
   - *b.* (?) welded tuff fragments; devitrified glass included with glass shards elongated in such a way as to produce the effect of flow.
   - *c.* plagioclase (sodic) fragments.
   - *d.* quartz fragments.
   - *e.* sedimentary grains composed primarily of finely divided quartz grains, micas and clay minerals.
   - *f.* rounded grains of andesite composed of numerous microlites of plagioclase set in quartz and devitrified glass which has been stained deep brown by finely disseminated limonite.
   - *g.* grains of probable trachytic material also occur.
   - *h.* opaque mineral grains.

Much of the interstitial cementing material has been removed by subsequent weathering. The grains in the main show a degree of rounding which together with the mixture of volcanic, (?) tuffaceous and sedimentary grains suggests it has been mechanically deposited as a sediment. Providing the identification of tuffaceous fragments is correct the writer is of the opinion that this rock is probably a reworked tuff. However, it is possible that it is a water-laid sediment deposited close to the "primary source area" of the volcanic material.

Member C; 1,150 feet.

P. 1355/65; H.W. 109.

This is a well-sorted siltstone with a grain size of 0·03 to 0·09 mm. Quartz is the dominant mineral, but other minerals together form nearly as much of the rock; the other minerals are feldspar (some of which is microcline and some plagioclase of intermediate composition), muscovite flakes, brownish weathering products that may have formed from biotite, and minor detrital siderite grains. Secondary calcite or dolomite is fairly common. Detrital tourmaline, opaques and rounded zircon are accessory.

The matrix consists largely of clay and some sericite, but secondary enlargement of the quartz grains has been responsible for some of the cementation.

Member C; 1,325 feet.

P. 219/65; H.W. 100/12; TS 16149.

This specimen is a massive, partially recrystallized, feldspatic sandstone which displays a dark buff-coloured colouration in hand-specimen. A curiosity present in the hand-specimen is the presence of a layer of opaque minerals concentrated approximately 1 to 2 cm., towards the centre, from the surfaces of the specimen. It appears probable that the concentration has occurred by weathering processes which have penetrated the rock surface to this depth.

The specimen is fine-grained and composed of numerous grains of quartz which are angular to sub-rounded and grains of plagioclase feldspar which have a similar habit set in a matrix of authigenic silica, recrystallized clay minerals, carbonate, muscovite laths and aggregates of finely disseminated opaque minerals. Accessory tourmaline and zircon constitute the remainder of the detrital fraction.

Many of the quartz grains have been subjected to recrystallization and tend to be elongated in a direction perpendicular to that of a compressive stress. The muscovite laths tend to have an orientation parallel to this elongation. The feldspar is plagioclase, commonly twinned according to the albite law, and has a composition of approximately oligoclase (An_{10-30}). The grains are randomly distributed and have a similar habit to those of the detrital quartz. Carbonate, chlorite, sericite and finely disseminated opaque minerals occupy interstitial positions. The grain size of the rock is in the range 0·2 to 0·03 mm.

Locally the rock has been fractured at an angle of approximately 90° to the primary elongation of the grains and along these zones secondary precipitation and recrystallization of quartz has occurred. The fracturing has had little effect on the remainder of the rock.

The ring of accumulated opaque minerals apparent in the hand-specimen is a concentration of opaque minerals and interstitial carbonate leached from the outermost zones of the rock and deposited at the limits of penetration of the weathering solutions.

Member D; 1,750 feet.

P. 220/65; H.W. 100/13; TS 16150.

This specimen is a laminated, ferruginous siltstone. In hand-specimen the rock displays a dark red colouration, poorly defined graded bedding and is markedly fissile along planes parallel to the laminations.

The rock is composed of numerous fine-grained quartz and plagioclase grains, abundant clay minerals and ferruginous material together with elongated, parallel orientated laths of a mica. The fineness of grain in these areas does not permit additional observations to be made. Throughout the rock, orientated parallel to the laminations, are coarser-grained lenses and layers which have a similar mineralogic composition although there is a pronounced decrease in the percentage of ferruginous material. Altered rock fragments of an unknown composition and altered sodic plagioclase form the coarsest grains in the coarse-grained layers. They have been substantially replaced by chlorite, sericite and other clay minerals together with opaque mineral grains.

The mica formed in this rock is very fresh which together with its habit suggests it may have formed in-situ by diagenetic processes.

b. Cambrian Rocks from Overturned (East)-Limb of Syncline

(These samples were collected from Section II, whose position is shown on Figure 2).

Member B:

P. 599/65; H.W. 108/II/4; TS 17012.

This rock is a well sorted (fine sand size) feldspathic sandstone in which a foreign fragment (2·5 cm. diameter) of crystal tuff is present. This tuff fragment contains euhedral feldspar crystals and irregular quartz crystals set in a very iron oxide rich siliceous matrix which is highly contorted. The matrix is typical of welded tuffs.

The components of the body of the rock are mainly feldspar, both recrystallized and relatively fresh (twinned), opaques and associated quartz grains (15–20% of the rock). The grains are commonly thinly coated with limonitic material which acts as a cementing agent in association with sericite. The grains vary in roundness from angular to sub-rounded.

Secondary carbonate has replaced much of the interstitial material so that now it also acts as a cement. Veins of carbonate were also observed in thin section especially in the tuff fragment itself.

Member B:

P. 600/65; H.W. 108/II/5.

This specimen is a volcanic greywacke. It contains proportionally more volcanic rock fragments than H.W. 108/II/4 and is therefore more comparable with H.W. 100/5. The largest fragment in this thin section is, in particular, very similar to the crystal tuff fragment seen in H.W. 108/II/4. There are also other fragments which appear to be welded tuff as well as flow banded volcanic fragments (some porphyritic) and crystals of quartz and feldspar.

Sericite, limonite and a little silica are the common cementing agents, the latter probably being of secondary origin as are also minor carbonate grains throughout the rock.

Fragmental components are rounded to angular in shape in this rock.

Sample H.W. 108/II/5 is very similar to H.W. 100/5 and H.W. 100/8.

c. Ordovician Quartzite from Normal (West)-Limb of Syncline

Member E; 300 feet.

P. 221/65; H.W. 100/17; TS 16151.

This specimen is a recrystallized orthoquartzite which in hand-specimen is a pale buff colour and displays a laminated texture due to concentrations of darker material along planes approximately 0·5 to 1 cm. apart.

The rock is composed of numerous, recrystallized, detrital quartz grains which have a size distribution in the range 0·48 to 0·05 mm. set in a matrix of authigenic silica, minor clay minerals, rare muscovite and finely disseminated limonite. Accessory grains of tourmaline and rock fragments complete the detrital fraction. The quartz has recrystallized under the influence of a minor uni-directional stress system which has caused slight elongation of some grains parallel to the lamination and the development of undulose extinction. The detrital grain shape of the component minerals has been preserved by a fine veneer of opaque and clay minerals which coat their surfaces. Authigenic silica is abundant and occupies the majority of interstitial spaces with recrystallized clay minerals occupying the remainder. The clay minerals have recrystallized to chlorite, sericite and minor muscovite and along some planes are associated with limonite. Finely disseminated opaque minerals are included within the detrital fraction.

The rock has been fractured at angles approximately perpendicular to the laminations. The fracturing is local and has caused disruption and some granulation of the grains, however, these have been healed by the recrystallization. Limonite has been deposited along some fracture zones.

Explanation of Plates

Plate I

Oblique aerial photograph looking NNW over Cambrian and Ordovician outcrops on western side of Mt. Arrowsmith inlier. Cambrian section is on left of picture, showing sequence from member A, on far left of picture, to member D in centre of overturned syncline. The eastern, overturned limb of the syncline is marked by faulted, west facing, sandy carbonates of member C.

The Ordovician syncline, edged by parallel strike-ridges of boldly outcropping quartzites of member E is shown in the centre of the photograph. Member G, occupying the centre of the syncline is distinguished from member F by smoother and somewhat lighter photo-pattern.

The far right of the photograph shows strongly sheared Precambrian Sediments (Ꝑua).

Plate II—1

Typical outcrop-pattern of member C (Middle Cambrian) consisting of steeply dipping limestone and siltstone interbeds. The characteristic mottling of the limestone can be observed in the centre foreground of picture. The hill in the far right background is formed by volcanic greywacke of member B.

Plate II—2

Thinly parallel and current bedded, dolomitic siltstone from central portion of member C, capped by slump-horizon. Exposure is to the left of outcrops shown in Pl. II—1 and on west-limb of syncline, showing normal, east-facing strata. Sample P.1355 was obtained from this outcrop. Scale on hammer in inches.

Plate III—1

View across Ordovician syncline looking west. Ridge forming quartzite (member E) and fossiliferous siltstone-limestone interbeds (member F) on far side of strike-valley. Strongly sheared and brecciated, basal Ordovician quartzite of the overturned limb of the syncline is shown in the right-hand foreground of picture.

Plate III—2

Wave ripple-marks on Lower Ordovician, current bedded, sandy limestone of member F. Scale on hammer in inches.

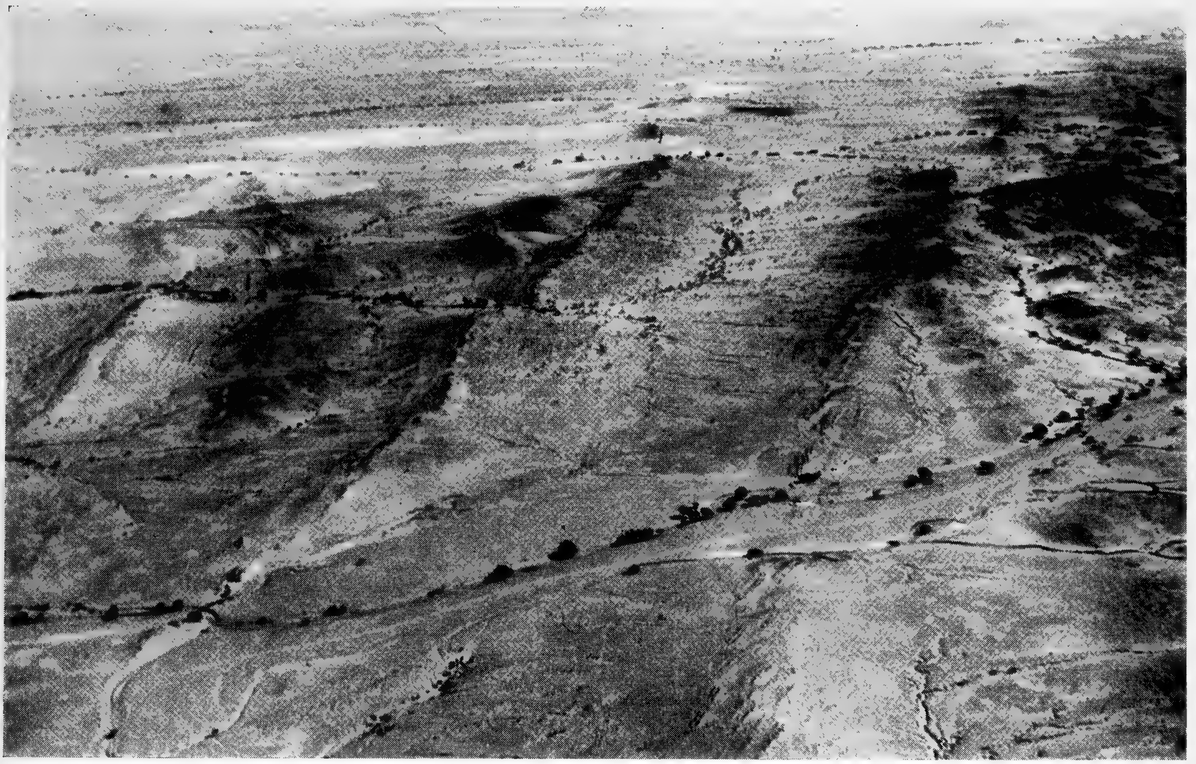


Plate I

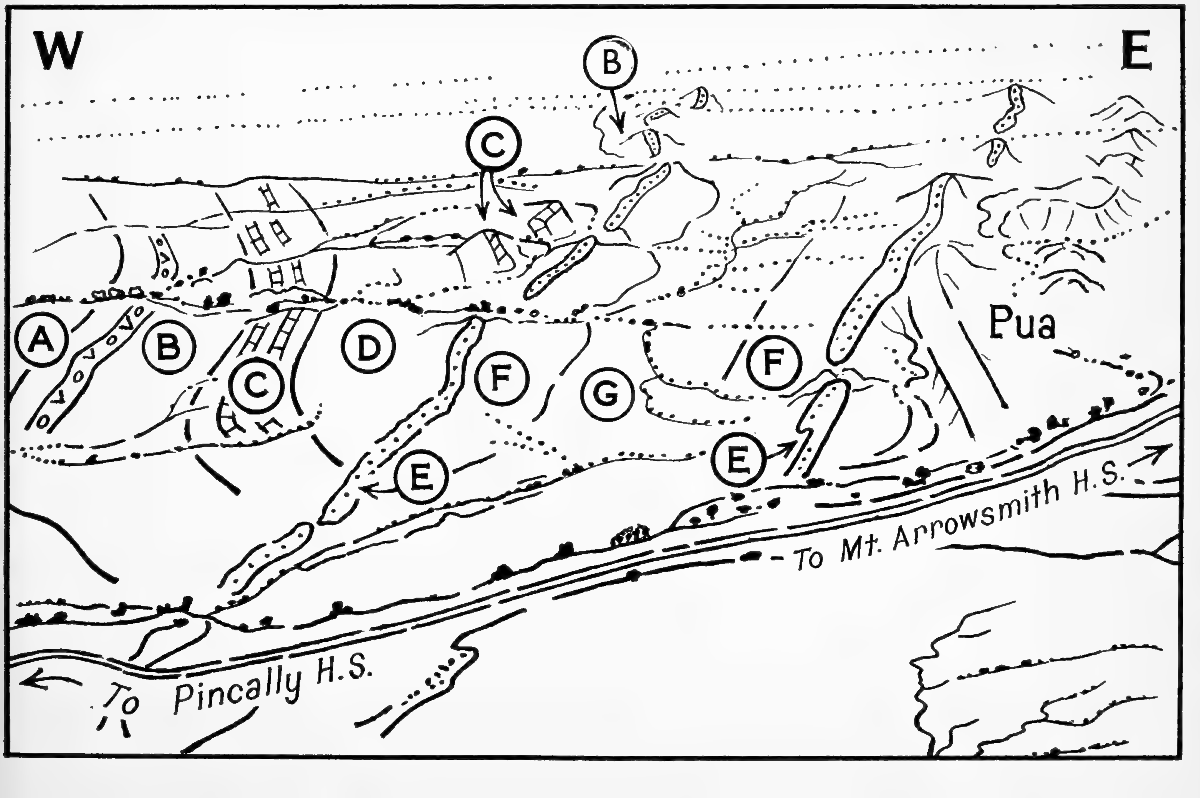
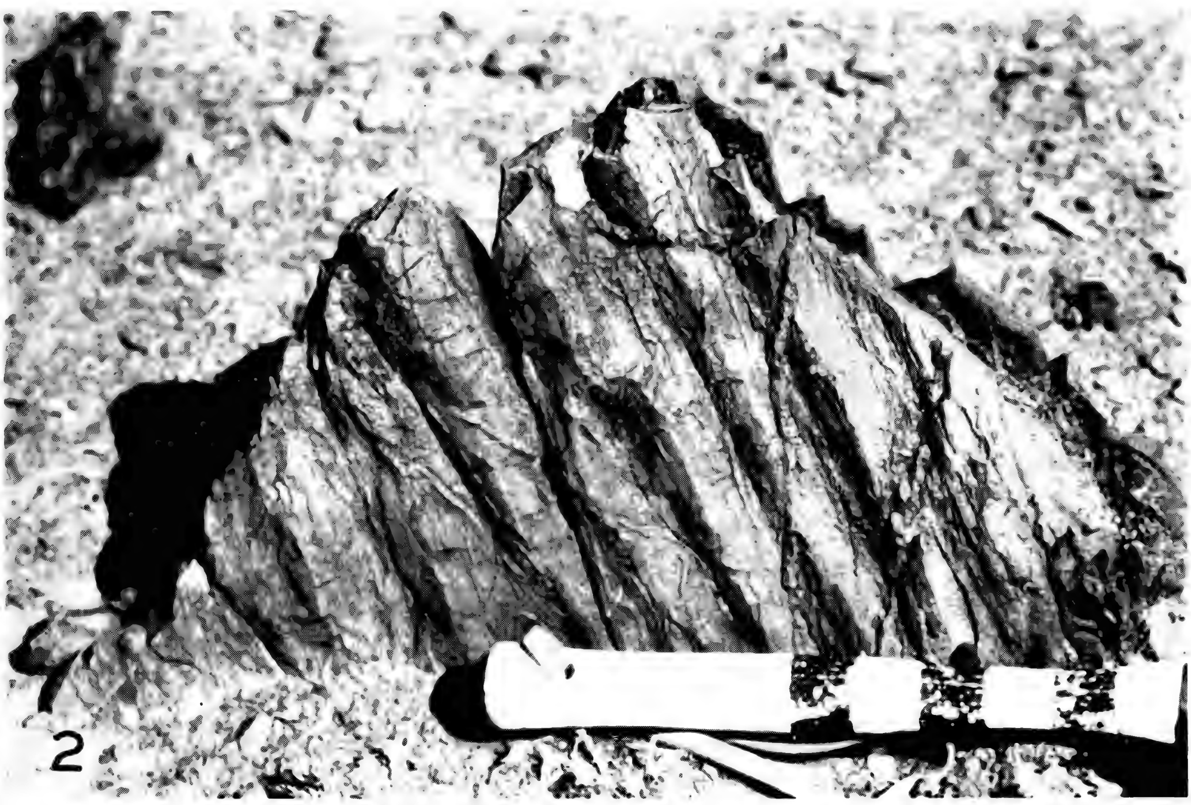


Plate II—1

PLATE III—1



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Autocondensation of Urea at 105-110°C.

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Abstract—Prolonged heating of urea at 105–110°C results in the formation of biuret and triuret. Cyanuric acid is formed in subordinate amounts only.

The uncatalysed thermal autocondensation of urea at atmospheric pressure has been studied only at and above 120°C. Depending on the reaction conditions employed biuret, triuret, cyanuric acid and ammelide are formed (Sonn, 1942 ; Kamlet, 1956 ; Spasskaya and Kazarnovskii, 1962 ; Ostrogovich and cow., 1962).

This communication reports some results obtained on heating urea at 105–110°C for a prolonged period of time. Biuret, triuret and cyanuric acid were obtained in varying yields ; no ammelide was found in the reaction mixtures. Apart from the temperature and the length of the heating period, the thickness of the urea layer in the reaction dish had a marked influence on the course of the reaction. Since deamination is the main process an increased surface area facilitates the escape of ammonia, thus speeding up the reaction. A simple, albeit approximate way of expressing the relationship between thickness and surface area exposed to the atmosphere was to relate the cross-sectional area of the reaction dish A (in cm^2) to the weight of urea W (in g) in the following manner: $X=A/W$.

Results obtained by varying the heating time are summarised in Table 1.

Table 1

Heating of Urea at 105±1°C. $X=1\cdot26$ cm^2g^{-1}

Time in hours	Loss in weight	Yield of biuret	Yield of triuret	Yield of cyanuric acid (anhydrous)
275	14%	12·8%	9·3%	trace
365	19%	23·3%	18·5%	trace
420	22%	24·4%	14·2%	0·7%
480	25%	25·6%	32·1%	2·2%
770	32%	37·3%	8·6%	3·6%

The results of two separate experiments showing the influence of X on the rate of the reaction are presented in Table 2.

Table 2

Heating of Urea at 109±1°C.

X in cm^2g^{-1}	Time in hours	Loss in weight	Yield of biuret	Yield of triuret	Yield of cyanuric acid (anhydrous)
0·63	184	12·1%	21·3%	9·1%	5·4%
3·28	115	33·5%	9·4%	24·0%	6·6%

Apart from the observation that urea should not be dried by heating, the high yields of triuret are noteworthy.

Experimental

Urea (10 g in each experiment), evenly spread in beakers of suitable dimensions, was heated for varying periods of time in an ordinary laboratory drying oven. As the reaction proceeded shrinking and later partial melting followed by resolidification of the samples was observed. A strong odour of ammonia was noticed in the early stages of the reaction.

The working-up procedure was in all cases identical. The reaction product was triturated once with water (30 ml) at 90°C and filtered quickly through a preheated Buchner funnel. The filtrate deposited almost pure biuret on cooling. The hot-water insoluble residue was dispersed in cold 15% aqueous ammonia solution (20 ml) and left to stand overnight at room temperature. Crude triuret, forming the insoluble residue, was filtered cff and the filtrate acidified with dilute hydrochloric acid. After standing in the refrigerator for one day the crystalline precipitate of crude cyanuric acid was filtered off. The crystals of the hydrated acid were dried at 105°C to yield anhydrous cyanuric acid.

Biuret and triuret were identified by comparison with authentic substances (m.p., mixed m.p. and infra-red spectrum) prepared by the method of Haworth and Mann (1943). Cyanuric acid was identified by comparison with a purified commercial sample (acid value and infra-red spectrum).

Acknowledgement

The author wishes to express his thanks to Mr. H. H. G. McKern for helpful comments.

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Minor Planets Observed at Sydney Observatory during 1966

W. H. Robertson

The following observations of minor planets were made photographically at Sydney Observatory with the 23 cm Taylor, Taylor and Hobson lens. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were automatically recorded on a chronograph by a contact on the shutter.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in No. 2122, where the result is from only one image owing to a defect in the other. No correction has been applied for aberration, light time or parallax but in Table 1 are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1966). The observers named in Table 2 are W. H. Robertson (R), K. P. Sims (S) and H. W. Wood (W). The measurements were made by Miss R. Bull, Miss J. Doust and Miss B. Frank, who have also assisted in the computation.

Reference

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Table I

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
1993	10	1966	March	28·56250	11	30	27·77	—02	51	32·2	+0·05	—4·5
1994	26	1966	June	30·59191	18	26	49·08	—28	02	48·6	+0·05	—0·9
1995	28	1966	June	01·63080	17	50	17·60	—11	08	00·3	0·00	—3·4
1996	28	1966	July	07·51905	17	20	39·65	—11	48	13·4	+0·02	—3·3
1997	34	1966	August	09·51002	19	31	04·35	—14	22	14·7	—0·01	—2·9
1998	37	1966	June	30·64816	19	54	23·10	—25	27	32·0	+0·04	—1·3
1999	37	1966	August	11·50177	19	16	14·66	—26	34	04·8	+0·02	—1·1
2000	66	1966	July	26·68648	22	10	30·80	—15	09	48·6	+0·09	—2·8
2001	77	1966	June	27·67233	20	15	05·52	—23	20	11·6	+0·04	—1·6
2002	77	1966	July	14·59790	20	00	57·55	—24	04	47·8	—0·02	—1·5
2003	77	1966	July	26·63115	19	49	23·00	—24	31	44·7	+0·23	—1·7
2004	97	1966	July	13·68061	21	39	27·49	—05	42	10·6	+0·02	—4·1
2005	109	1966	August	09·58772	21	04	44·92	—26	58	00·5	+0·04	—1·1
2006	110	1966	July	27·57665	19	53	04·50	—29	42	19·9	+0·05	—0·6
2007	110	1966	August	10·51345	19	41	12·98	—30	09	51·2	—0·01	—0·6
2008	111	1966	July	27·64349	21	05	43·16	—16	00	23·5	+0·10	—2·7
2009	115	1966	May	26·66694	17	55	31·98	—36	52	59·4	+0·06	+0·5
2010	115	1966	June	27·55682	17	18	47·25	—35	35	16·0	+0·07	+0·3
2011	115	1966	July	05·52812	17	10	23·12	—34	50	58·8	+0·07	+0·2
2012	126	1966	April	14·59791	14	12	38·51	—14	02	59·8	—0·04	—3·0
2013	126	1966	April	28·57502	13	59	11·95	—13	09	08·3	+0·04	—3·1
2014	127	1966	March	22·66206	13	48	03·78	—08	07	51·4	+0·02	—3·8
2015	127	1966	April	21·54526	13	22	27·00	—07	07	46·1	—0·04	—3·9
2016	142	1966	May	26·60598	16	17	36·45	—24	28	42·4	+0·08	—1·4

Table I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
2017	144	1966	June	30·59191	18	22	43·10	—26	04	09·4	+0·06	—1·2
2018	144	1966	July	05·57606	18	17	33·09	—26	16	03·8	+0·07	—1·2
2019	150	1966	April	14·59797	14	08	27·71	—12	43	16·1	—0·03	—3·1
2020	150	1966	April	21·57782	14	03	08·59	—12	11	13·9	—0·02	—3·2
2021	164	1966	June	16·68299	19	42	34·96	—38	27	37·5	+0·06	+0·7
2022	164	1966	July	07·59984	19	23	29·51	—45	17	45·1	+0·01	+1·8
2023	164	1966	July	28·53760	18	54	28·28	—50	24	38·1	+0·09	+1·5
2024	169	1966	May	24·65731	17	46	54·21	—32	58	56·8	+0·03	—0·1
2025	169	1966	June	21·56024	17	17	35·91	—33	18	32·2	+0·03	—0·1
2026	172	1966	May	23·66326	17	17	50·30	—40	10	51·6	+0·12	+0·9
2027	172	1966	June	27·52570	16	38	09·00	—38	40	00·1	+0·06	+0·7
2028	182	1966	July	28·58864	20	25	04·60	—20	18	11·1	+0·02	—2·0
2029	197	1966	Sept.	07·66364	00	47	02·14	—11	04	39·8	+0·04	—3·4
2030	201	1966	May	10·60238	15	30	59·41	—09	58	36·3	+0·03	—3·5
2031	201	1966	May	19·55874	15	23	03·55	—09	22	10·3	—0·02	—3·6
2032	205	1966	July	13·55352	19	20	44·94	—05	33	00·9	—0·08	—4·2
2033	209	1966	March	22·60270	12	15	22·60	—02	11	16·3	+0·03	—4·6
2034	209	1966	April	12·54973	11	59	17·94	—01	11	00·8	+0·08	—4·7
2035	219	1966	April	14·66890	15	42	07·63	—12	46	11·9	—0·01	—3·1
2036	219	1966	May	19·55874	15	13	53·70	—07	53	04·6	0·00	—3·8
2037	222	1966	April	21·57782	14	04	56·48	—10	00	16·7	—0·03	—3·5
2038	222	1966	May	10·57144	13	50	37·23	—08	55	16·5	+0·14	—3·7
2039	230	1966	June	01·60454	17	27	37·60	—18	20	53·4	—0·03	—2·3
2040	230	1966	June	16·58097	17	12	34·97	—17	02	36·5	+0·06	—2·5
2041	239	1966	August	11·65102	22	41	50·52	—03	00	34·2	+0·04	—4·5
2042	239	1966	Sept.	19·50509	22	16	07·07	—07	18	00·7	—0·03	—3·9
2043	258	1966	March	22·63134	12	46	43·67	—11	37	30·7	+0·05	—3·3
2044	258	1966	April	13·52696	12	29	46·44	—08	33	51·9	—0·05	—3·7
2045	266	1966	March	21·59290	12	12	15·04	—17	20	41·7	0·00	—2·5
2046	266	1966	March	29·59440	12	06	02·60	—16	26	44·2	+0·09	—2·6
2047	282	1966	Sept.	22·64952	01	47	03·03	—01	26	38·8	—0·01	—4·7
2048	282	1966	Oct.	10·61308	01	34	19·09	—04	15	26·4	+0·06	—4·3
2049	309	1966	August	22·62680	22	10	16·49	—14	30	11·6	+0·13	—3·0
2050	338	1966	August	10·60293	21	25	08·21	—10	04	06·4	+0·05	—3·5
2051	338	1966	August	22·57938	21	15	11·91	—10	32	55·2	+0·10	—3·5
2052	346	1966	August	04·60776	21	22	39·84	—25	15	41·4	+0·02	—1·3
2053	347	1966	May	25·58388	15	50	09·86	—11	13	10·1	+0·06	—3·4
2054	349	1966	August	04·63056	22	09	49·52	—24	25	06·3	—0·02	—1·4
2055	352	1966	August	08·58046	20	52	00·32	—11	18	38·2	+0·03	—3·4
2056	359	1966	May	10·63407	16	14	11·35	—29	54	45·1	+0·04	—0·6
2057	359	1966	May	26·57506	15	58	27·23	—29	49	39·6	+0·02	—0·6
2058	366	1966	May	11·59105	14	45	29·77	—31	31	22·6	—0·04	—0·3
2059	366	1966	May	26·52478	14	32	56·73	—29	45	13·6	+0·05	—0·6
2060	369	1966	May	11·62327	15	52	52·83	—07	17	38·7	+0·05	—3·9
2061	369	1966	May	24·59213	15	40	40·15	—07	17	47·2	+0·09	—3·9
2062	374	1966	May	09·62366	15	55	56·00	—16	06	51·9	+0·03	—2·7
2063	374	1966	May	23·59726	15	44	29·63	—14	35	00·7	+0·09	—2·9
2064	377	1966	March	22·56822	11	38	58·71	—03	40	14·9	0·00	—4·4
2065	377	1966	March	28·56250	11	34	23·75	—02	56	19·2	+0·05	—4·5
2066	378	1966	July	11·61506	19	44	35·78	—11	31	43·4	+0·05	—3·3
2067	380	1966	June	21·66657	19	25	03·32	—23	08	48·6	+0·08	—1·7
2068	380	1966	June	27·63213	19	20	20·73	—23	36	07·8	+0·03	—1·6
2069	389	1966	March	28·59386	12	56	57·99	—20	44	58·4	—0·03	—2·0
2070	389	1966	April	12·57320	12	43	45·24	—19	30	02·1	+0·06	—2·2
2071	403	1966	May	23·68650	18	23	47·84	—18	51	04·9	+0·03	—2·3
2072	403	1966	June	27·59214	17	55	39·78	—17	16	57·3	+0·09	—2·5
2073	404	1966	May	23·68650	18	29	05·71	—18	34	59·3	+0·01	—2·3
2074	404	1966	June	16·60922	18	09	53·77	—21	46	18·2	+0·02	—1·8
2075	404	1966	July	05·55258	17	50	38·19	—24	20	45·4	+0·05	—1·4
2076	407	1966	May	09·59324	15	32	53·63	—29	41	14·9	—0·02	—0·6
2077	407	1966	May	23·56396	15	19	17·55	—28	39	22·7	+0·05	—0·8
2078	416	1966	April	28·67641	15	46	45·44	—16	00	36·5	+0·12	—2·7
2079	416	1966	May	19·58563	15	26	44·27	—17	40	51·8	+0·06	—2·4
2080	418	1966	May	12·57410	15	02	22·61	—20	49	10·7	+0·05	—2·0
2081	438	1966	April	20·67493	15	28	30·68	—17	52	44·1	+0·09	—2·4
2082	438	1966	April	28·65052	15	21	53·28	—17	56	22·2	+0·10	—2·4

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
2083	441	1966	March	21·63292	13	16	51·77	−19	08	18·0	−0·01	−2·2
2084	441	1966	April	20·53719	12	53	40·52	−16	16	35·2	−0·04	−2·6
2085	443	1966	August	10·60293	21	34	25·24	−09	51	53·8	+0·03	−3·6
2086	445	1966	June	21·59616	17	54	18·34	−36	56	08·6	+0·07	−0·5
2087	445	1966	July	11·51418	17	34	57·82	−34	52	48·0	+0·01	+0·2
2088	472	1966	July	27·64349	20	59	49·48	−17	57	08·1	+0·11	−2·5
2089	472	1966	August	11·58299	20	46	42·32	−20	24	25·4	+0·08	−2·0
2090	485	1966	May	11·62327	16	00	59·61	−06	18	29·8	+0·03	−4·0
2091	485	1966	May	24·59213	15	50	17·25	−05	08	29·6	+0·07	−4·2
2092	488	1966	Sept.	22·61432	01	27	10·39	−07	02	54·8	−0·07	−4·0
2093	488	1966	Oct.	20·58791	01	07	03·81	−08	51	50·5	+0·12	−3·7
2094	498	1966	July	19·54248	18	28	35·69	−25	39	17·8	+0·06	−1·2
2095	498	1966	July	27·51932	18	22	34·43	−26	23	39·4	+0·07	−1·1
2096	508	1966	July	14·63268	20	51	28·49	−37	22	17·8	−0·02	+0·6
2097	508	1966	July	27·60673	20	40	04·99	−38	21	24·7	+0·04	+0·7
2098	510	1966	March	29·65742	13	53	07·75	−11	57	27·8	+0·05	−3·3
2099	510	1966	April	20·57053	13	36	41·65	−08	46	52·2	0·00	−3·7
2100	511	1966	July	19·56925	19	15	49·04	−22	59	37·1	+0·04	−1·6
2101	514	1966	June	20·60504	18	14	41·74	−23	09	03·7	+0·03	−1·6
2102	514	1966	July	14·52150	17	54	58·83	−22	45	58·6	+0·02	−1·7
2103	521	1966	August	11·61730	22	01	14·52	−27	00	55·1	+0·02	−1·0
2104	532	1966	Oct.	10·64687	02	07	23·55	−11	57	00·5	+0·10	−3·3
2105	535	1966	May	19·64188	17	03	42·74	−19	56	56·7	+0·03	−2·1
2106	535	1966	May	26·63838	16	57	21·08	−20	04	03·4	+0·09	−2·1
2107	540	1966	March	17·59655	11	57	06·11	−04	23	57·7	+0·01	−4·3
2108	540	1966	April	12·50331	11	37	42·43	−00	20	40·7	−0·02	−4·8
2109	544	1966	June	30·64816	19	50	56·41	−23	58	55·3	+0·04	−1·5
2110	544	1966	July	27·54972	19	24	39·40	−22	41	27·3	+0·02	−1·7
2111	558	1966	June	21·63354	18	31	09·73	−13	45	18·4	+0·09	−3·0
2112	558	1966	July	11·54683	18	14	40·44	−14	31	40·8	+0·03	−2·9
2113	567	1966	May	12·61246	15	46	13·00	−19	19	12·4	+0·04	−2·2
2114	567	1966	May	24·55419	15	35	42·17	−19	21	58·9	−0·02	−2·2
2115	575	1966	August	10·63110	21	52	57·11	−27	51	49·6	+0·08	−0·9
2116	576	1966	April	14·63667	15	03	09·16	−32	13	57·8	−0·05	−0·2
2117	576	1966	April	28·61195	14	52	01·45	−31	55	07·9	+0·04	−0·3
2118	576	1966	May	26·52478	14	27	40·92	−29	42	17·7	+0·06	−0·6
2119	579	1966	May	09·67767	17	02	32·85	−18	14	20·5	+0·06	−2·4
2120	579	1966	June	16·55722	16	31	02·84	−19	22	26·3	+0·07	−2·6
2121	584	1966	May	12·64401	16	48	29·80	−32	48	22·5	+0·01	−0·1
2122	584	1966	May	25·60225	16	35	13·06	−32	04	00·4	+0·02	−0·3
2123	593	1966	Sept.	19·61828	00	54	53·46	−21	52	49·4	−0·02	−1·8
2124	593	1966	Oct.	11·55823	00	34	21·01	−23	11	49·8	+0·03	−1·6
2125	599	1966	April	13·64562	14	47	27·57	−12	24	49·0	+0·03	−3·2
2126	599	1966	May	11·52184	14	19	44·15	−12	22	53·8	−0·06	−3·2
2127	626	1966	April	20·61130	14	30	17·38	−49	09	38·5	+0·02	+2·3
2128	626	1966	May	11·55634	14	01	39·60	−48	59	36·9	+0·13	+2·1
2129	628	1966	May	11·64974	16	41	35·83	−07	51	34·8	+0·03	−3·8
2130	628	1966	May	23·63352	16	31	18·83	−07	46	41·0	+0·10	−3·9
2131	634	1966	July	14·56006	18	52	44·68	−13	44	00·9	+0·01	−3·0
2132	634	1966	July	26·54989	18	43	36·31	−14	54	07·0	+0·10	−2·9
2133	638	1966	May	25·67896	18	02	34·20	−18	07	46·1	+0·07	−2·4
2134	638	1966	June	22·57313	17	39	06·18	−19	38	01·3	+0·03	−2·1
2135	663	1966	March	17·55823	10	49	26·30	−19	11	40·2	+0·04	−2·2
2136	674	1966	May	09·65063	16	38	49·56	−24	16	27·7	+0·02	−1·4
2137	674	1966	May	24·62156	16	25	38·00	−24	36	21·2	+0·09	−1·4
2138	675	1966	March	28·62399	13	09	51·70	−21	05	15·8	+0·03	−1·9
2139	675	1966	April	20·53719	12	51	15·75	−18	53	01·4	0·00	−2·2
2140	677	1966	April	21·61556	14	31	29·86	−26	00	02·7	+0·04	−1·2
2141	677	1966	May	12·53492	14	14	31·74	−24	03	11·5	0·00	−1·5
2142	680	1966	Sept.	21·61679	01	17	53·97	−07	16	18·1	−0·05	−3·9
2143	680	1966	Sept.	22·61432	01	17	00·43	−07	17	47·1	−0·05	−3·9
2144	702	1966	April	21·65682	15	01	27·51	−43	58	40·4	+0·13	+1·5
2145	702	1966	May	19·53386	14	36	12·81	−41	53	44·3	+0·01	+1·3
2146	702	1966	May	24·52256	14	32	13·38	−41	14	35·6	+0·03	+1·2
2147	712	1966	April	13·61181	14	30	12·34	−20	03	17·9	−0·04	−2·1
2148	712	1966	May	09·56419	14	08	25·09	−16	50	56·2	+0·08	−2·6

TABLE I—*continued*

No.	Planet	U.T.			R.A. (1950·0) h	m	s	Dec. (1950·0) °	′	″	Parallax Factors s	″
2149	757	1966	July	13·64172	20	58	34·89	—31	00	44·2	—0·02	—0·4
2150	776	1966	May	19·64188	17	03	21·66	—18	28	38·2	+0·03	—2·3
2151	776	1966	May	26·63838	16	57	19·24	—18	46	51·1	+0·09	—2·3
2152	780	1966	August	09·55574	20	44	38·01	—11	14	21·4	—0·02	—3·4
2153	780	1966	August	22·53446	20	35	56·22	—13	16	51·1	+0·05	—3·1
2154	786	1966	July	14·66300	21	24	39·60	—28	59	09·9	0·00	—0·7
2155	834	1966	June	27·59214	18	07	17·34	—16	41	21·6	+0·07	—2·6
2156	834	1966	July	07·54408	17	59	48·96	—16	47	42·0	+0·02	—2·6
2157	856	1966	June	22·64264	19	26	18·16	—12	18	17·2	+0·01	—3·2
2158	877	1966	Sept.	21·57938	23	45	44·11	—09	01	15·1	+0·03	—3·7
2159	906	1966	May	24·65731	17	39	23·10	—34	16	28·4	+0·05	+0·1
2160	906	1966	June	21·56024	17	11	48·57	—35	42	20·2	+0·04	+0·3
2161	912	1966	Sept.	21·65215	01	33	23·45	—00	05	47·5	+0·02	—4·9
2162	925	1966	July	14·59790	20	05	54·63	—22	15	14·9	—0·03	—1·8
2163	925	1966	July	26·63115	19	52	43·48	—21	33	59·0	+0·21	—2·1
2164	980	1966	June	16·64409	19	02	18·00	—27	13	02·1	+0·02	—1·0
2165	980	1966	July	07·57102	18	40	28·03	—25	21	05·8	+0·01	—1·3
2166	983	1966	April	13·57514	13	35	06·63	—26	16	34·4	—0·04	—1·1
2167	983	1966	April	28·54089	13	24	10·02	—24	20	34·3	+0·01	—1·4
2168	986	1966	August	09·66004	22	52	28·48	—27	54	25·4	+0·03	—0·9
2169	986	1966	Sept.	19·54439	22	24	40·55	—32	10	20·7	+0·09	—0·3
2170	1018	1966	July	14·66300	21	20	11·45	—28	52	43·5	+0·02	—0·8
2171	1018	1966	July	26·65802	21	11	15·25	—29	17	40·0	+0·13	—0·8
2172	1044	1966	August	08·61020	21	39	57·51	—21	57	27·9	+0·02	—1·8
2173	1063	1966	May	19·61540	16	29	58·76	—16	07	09·5	+0·02	—2·7
2174	1063	1966	June	21·51980	15	58	23·61	—16	36	12·3	—0·07	—2·6
2175	1096	1966	Sept.	07·62733	23	57	09·84	—19	43	28·0	+0·03	—2·1
2176	1137	1966	June	22·60512	18	19	48·76	—25	15	52·4	+0·04	—1·3
2177	1137	1966	July	13·51732	17	58	31·31	—26	00	56·2	—0·01	—1·2
2178	1146	1966	March	21·67392	13	28	44·71	—17	42	32·6	+0·09	—2·4
2179	1146	1966	April	14·56606	13	13	14·48	—13	58	52·8	—0·01	—3·0
2180	1153	1966	June	20·60504	18	21	31·63	—24	27	48·8	+0·02	—1·4
2181	1153	1966	June	22·60512	18	19	28·72	—24	23	01·6	+0·04	—1·4
2182	1186	1966	Sept.	21·54154	22	11	01·16	—27	00	18·5	+0·12	—1·1
2183	1196	1966	June	21·66657	19	21	20·88	—22	12	14·9	+0·09	—1·8
2184	1196	1966	June	27·63213	19	16	19·78	—23	08	38·4	+0·04	—1·6
2185	1216	1966	June	20·64335	19	15	54·06	—15	35	22·2	+0·02	—2·7
2186	1246	1966	June	27·67233	20	14	00·21	—21	17	25·6	+0·04	—1·9
2187	1246	1966	July	13·59104	19	59	08·91	—18	37	33·5	—0·05	—2·3
2188	1246	1966	August	09·51002	19	30	00·78	—13	48	25·9	0·00	—3·0
2189	1390	1966	August	09·62310	21	39	05·21	—43	07	13·8	+0·09	+1·4

TABLE II

No.	Comparison Stars	Dependences			
1993	Yale *17* 4329, 4348, *21* 3270	0·42171	0·44259	0·13569	S
1994	Yale *13* II 11955, 12004, 12025	0·30191	0·29397	0·40412	S
1995	Yale *11* 6088, 6101, 6106	0·32426	0·41232	0·26342	R
1996	Yale *11* 5928, 5939, 5953	0·37370	0·30390	0·32240	W
1997	Yale *12* I 7330, 7341, 7353	0·35551	0·38704	0·25745	S
1998	Yale *14* 13871, 13897, 13921	0·30791	0·41048	0·28162	S
1999	Yale *14* 13418, 13443, 13450	0·24406	0·47757	0·27837	S
2000	Yale *12* I 8289, 8311, 8317	0·35338	0·38115	0·26547	W
2001	Yale *14* 14071, 14086, 14099	0·25236	0·27673	0·47091	S
2002	Yale *14* 13942, 13962, 13986	0·20355	0·51420	0·28225	R
2003	Yale *14* 13806, 13833, 13863	0·26737	0·33501	0·39762	W
2004	Yale *16* 7783, 7790, 7802	0·36738	0·25643	0·37619	R
2005	Yale *13* II 13869, 13891, 13903	0·14187	0·17899	0·67914	S
2006	Yale *13* II 13066, 13081, 13114	0·48176	0·16694	0·35130	W
2007	Cape *17* 10746, 10752, 10774	0·42826	0·41897	0·15277	S

TABLE II—*continued*

No.	Comparison Stars	Dependences			
2008	Yale *12* I 7948, 7967, 7979	0·42248	0·41460	0·16291	W
2009	Cape *18* 9116, 9132, 9165	0·30028	0·32362	0·37610	W
2010	Cape *18* 8645, 8677, 8681	0·21731	0·25964	0·52304	S
2011	Cape *17* 9046, 9066, 9093	0·48955	0·08315	0·42730	W
2012	Yale *11* 5010, 5024, 5027	0·34052	0·38166	0·27782	R
2013	Yale *11* 4945, 4947, 4959	0·38904	0·10727	0·50368	W
2014	Yale *16* 4917, 4928, 4943	0·34586	0·29983	0·35431	R
2015	Yale *16* 4786, 4796, 4809	0·38399	0·27746	0·33855	S
2016	Yale *14* 11430, 11433, 11454	0·35280	0·38709	0·26012	W
2017	Yale *14* 12752, 12755, 12774	0·20292	0·26622	0·53086	S
2018	Yale *14* 12678, 12690, 12742	0·52354	0·23384	0·24262	W
2019	Yale *11* 4995, 5004, 5017	0·46040	0·34892	0·19068	R
2020	Yale *11* 4962, 4975, 4987	0·43605	0·30264	0·26130	S
2021	Cape *18* 10226, 10236, 10254	0·33533	0·28768	0·37698	W
2022	Cape Z. 18137, 18166, 18222	0·24638	0·47440	0·27922	W
2023	Cape Z. 17772, 17831, 17865	0·34620	0·26132	0·39248	W
2024	Cape *17* 9468, 9470, 9492	0·29929	0·14060	0·56012	W
2025	Cape *17* 9121, 9154, 9173	0·23548	0·41633	0·34819	R
2026	Cape *18* 8639 Z. 16066, 16109	0·30536	0·41984	0·27480	W
2027	Cape *18* 8236, 8240, 8284	0·40370	0·30070	0·29560	S
2028	Yale *13* I 8764, 8766, 8792	0·17221	0·54818	0·27961	W
2029	Yale *11* 149, 159, 172	0·52779	0·16617	0·30604	S
2030	Yale *16* 5424, 5433, 5443	0·40280	0·22811	0·36909	R
2031	Yale *16* 5382, 5384, 5394	0·23980	0·43329	0·32691	S
2032	Yale *17* 6600, 6617, 6627	0·25586	0·40339	0·34075	R
2033	Yale *21* 3383, 3394, *17* 4551	0·24611	0·43328	0·32061	R
2034	Yale *21* 3331, 3335, 3348	0·34861	0·40274	0·24866	R
2035	Yale *11* 5474, 5476, 5491	0·29962	0·32284	0·37754	R
2036	Yale *16* 5320, 5342, 5346	0·33574	0·36009	0·30417	S
2037	Yale *16* 5004, 5023, *11* 4979	0·42816	0·37365	0·19819	S
2038	Yale *16* 4927, 4943, 4944	0·22579	0·40448	0·36973	R
2039	Yale *12* II 7160, 7168, 7175	0·25264	0·24222	0·50514	R
2040	Yale *12* I 6157, 6179, 6190	0·20059	0·63906	0·16035	W
2041	Yale *17* 7872, 7883, 7887	0·12368	0·60995	0·26636	S
2042	Yale *16* 7984, 7986, 7995	0·31349	0·45733	0·22918	R
2043	Yale *11* 4611, 4616, 4628	0·31306	0·24478	0·44216	R
2044	Yale *16* 4585, 4586, 4592	0·43452	0·22219	0·34329	R
2045	Yale *12* I 4718, 4736, 4738	0·50695	0·24949	0·24356	R
2046	Yale *12* I 4693, 4703, 4708	0·22898	0·29774	0·47329	S
2047	Yale *21* 345, 368, *17* 423	0·20923	0·46102	0·32974	R
2048	Yale *17* 363, 369, 384	0·23418	0·55256	0·21326	R
2049	Yale *12* I 8289, 8302, 8319	0·31126	0·35298	0·33576	R
2050	Yale *11* 7603, 7610, 7614	0·21053	0·34497	0·44449	S
2051	Yale *11* 7541, 7547, 7553	0·35770	0·33534	0·30696	R
2052	Yale *14* 14727, 14767, 14774	0·37192	0·24505	0·38303	R
2053	Yale *11* 5505, 5511, 5524	0·32250	0·36902	0·30847	W
2054	Yale *14* 15116, 15142, 15143	0·42228	0·28973	0·28799	R
2055	Yale *11* 7395, 7402, 7417	0·21673	0·60594	0·17733	S
2056	Yale *13* II 10189, 10202, 10208	0·39780	0·28921	0·31299	R
2057	Yale *13* II 10036, 10051, 10079	0·38154	0·29512	0·32334	W
2058	Cape *17* 7623, 7633, 7658	0·12051	0·52914	0·35034	R
2059	Yale *13* II 9193, 9212, 9218	0·35360	0·29404	0·35235	W
2060	Yale *16* 5533, 5546, 5555	0·53167	0·17964	0·28869	R
2061	Yale *16* 5476, 5481, 5493	0·23974	0·30130	0·45896	W
2062	Yale *12* I 5822, 5823, 5836	0·31080	0·28790	0·40130	R
2063	Yale *11* 5479, 5495, 5767	0·20878	0·35530	0·43592	W
2064	Yale *17* 4372, 4390, 4397	0·35758	0·31087	0·33156	R
2065	Yale *21* 3270, *17* 4360, 4376	0·20539	0·54911	0·24551	S
2066	Yale *11* 6941, 6943, 6974	0·33284	0·49244	0·17472	R
2067	Yale *14* 13526, 13555, 13557	0·22939	0·33269	0·43792	R
2068	Yale *14* 13488, 13497, 13505	0·44546	0·39022	0·16432	S
2069	Yale *13* I 5579, 5590, 5599	0·31950	0·34950	0·33100	S
2070	Yale *12* II 5504, 5510, 5534	0·20350	0·40092	0·39558	R
2071	Yale *12* II 7681, 7702, 7706	0·33894	0·19697	0·46409	W
2072	Yale *12* I 6462, 6469, 6487	0·46547	0·48021	0·05433	S
2073	Yale *12* II 7729, *12* I 6796, 6847	0·46363	0·33819	0·19818	W
2074	Yale *14* 12564, *13* I 7530, 7563	0·39707	0·24263	0·36030	W
2075	Yale *14* 12243, 12251, 12260	0·22220	0·55128	0·22652	W

Table II—*continued*

No.	Comparison Stars	Dependences			
2076	Yale *13* II 9731, 9767, 9774	0·39703	0·20257	0·40040	R
2077	Yale *13* II 9626, 9631, 9683	0·35951	0·41233	0·22816	W
2078	Yale *12* I 5774, 5777, 5793	0·40935	0·22197	0·36868	W
2079	Yale *12* I 5668, 5686, 5694	0·32739	0·38577	0·28683	S
2080	Yale *13* I 6223, 6253, 6260	0·34319	0·14691	0·50990	R
2081	Yale *12* I 5684, 5686, 5697	0·39383	0·12100	0·48517	S
2082	Yale *12* I 5641, 5652, 5671	0·30317	0·35607	0·34075	W
2083	Yale *12* II 5672, 5691, 5711	0·32629	0·24507	0·42864	R
2084	Yale *12* I 4923, 4939, 4952	0·39120	0·31929	0·28952	S
2085	Yale *11* 7655, 7674, *16* 7757	0·46865	0·34402	0·18733	S
2086	Cape *18* 9100, 9127, 9132	0·26912	0·32598	0·40489	R
2087	Cape *17* 9325, 9384, *18* 8849	0·41870	0·30762	0·27368	R
2088	Yale *12* II 9003, 9028, 9035	0·21128	0·42574	0·36299	W
2089	Yale *13* I 8915, 8929, 8940	0·12370	0·54215	0·33414	S
2090	Yale *16* 5576, 5588, *17* 5552	0·28095	0·41645	0·30260	R
2091	Yale *17* 5503, 5517, 5518	0·32609	0·33916	0·33476	W
2092	Yale *16* 299, 306, 310	0·36422	0·44352	0·19226	R
2093	Yale *16* 225, 238, 245	0·45026	0·22806	0·32168	S
2094	Yale *14* 12813, 12860, 12861	0·41462	0·28367	0·30172	S
2095	Yale *14* 12748, 12774, 12781	0·43791	0·24197	0·32012	W
2096	Yale *18* 10790, 10807, 10828	0·21321	0·40769	0·37911	R
2097	Cape *18* 10713, 10718, 10744	0·26784	0·35239	0·37977	W
2098	Yale *11* 4917, 4926, 4938	0·28337	0·47396	0·24267	S
2099	Yale *16* 4860, 4872, 4873	0·36736	0·32771	0·30493	S
2100	Yale *14* 13409, 13427, 13458	0·25185	0·37817	0·36998	S
2101	Yale *14* 12643, 12647, 12680	0·34520	0·37978	0·27502	R
2102	Yale *14* 12273, 12289, 12327	0·21264	0·35215	0·43521	R
2103	Yale *13* II 14355, 14365, 14379	0·16276	0·34406	0·49318	S
2104	Yale *11* 487, 490, 513	0·43653	0·37591	0·18756	R
2105	Yale *12* II 6972, 6976, *13* I 7001	0·24213	0·53906	0·21881	S
2106	Yale *13* I 6920, *12* II 6922, 6952	0·33548	0·29484	0·36968	W
2107	Yale *17* 4450, 4468, 4473	0·30467	0·38287	0·31246	W
2108	Yale *21* 3282, 3290, 3302	0·45174	0·24140	0·30686	R
2109	Yale *14* 13837, 13850, 13873	0·36398	0·19384	0·44218	S
2110	Yale *14* 13524, 13547, 13550	0·19948	0·45515	0·34537	W
2111	Yale *11* 6346, 6356, 6374	0·54514	0·26182	0·19304	R
2112	Yale *12* I 6633, 6651, 6658	0·32101	0·41796	0·26104	R
2113	Yale *12* II 6518, 6539, 6551	0·29559	0·32302	0·38138	R
2114	Yale *12* II 6446, 6457, 6486	0·13678	0·53579	0·32743	W
2115	Yale *13* II 14296, 14306, 14328	0·38187	0·31746	0·30067	S
2116	Cape *17* 7803, 7804, 7826	0·27465	0·28286	0·44249	R
2117	Cape *17* 7688, 7689, 7742	0·27284	0·34997	0·37720	W
2118	Yale *13* II 9142, 9154, 9183	0·39418	0·49177	0·11405	W
2119	Yale *12* II 6959, 6984, *12* I 6098	0·24271	0·44599	0·31130	R
2120	Yale *12* II 6787, 6796, 6802	0·63495	0·12701	0·23804	W
2121	Cape *17* 8786, 8830, 8834	0·20557	0·53935	0·25508	R
2122	Cape *17* 8666, 8668, 8718	0·19614	0·46008	0·34378	W
2123	Yale *14* 439, 478, *13* I 246	0·37803	0·21908	0·40290	R
2124	Yale *14* 238, 259, 304	0·26059	0·40879	0·33061	R
2125	Yale *11* 5191, 5197, 5217	0·23695	0·40004	0·36301	R
2126	Yale *11* 5043, 5047, 5063	0·31642	0·32869	0·35489	R
2127	Cape Ft. 12165, 12184, 12267	0·28923	0·41616	0·29461	S
2128	Cape Ft. 11697, 11709, 11826	0·38762	0·39830	0·21408	R
2129	Yale *16* 5766, 5778, 5779	0·32925	0·24294	0·42782	R
2130	Yale *16* 5720, 5731, 5734	0·09853	0·32522	0·57625	W
2131	Yale *11* 6497, 6516, 6532	0·56358	0·07030	0·36613	R
2132	Yale *12* I 6905, 6909, 6936	0·19865	0·33977	0·46158	W
2133	Yale *12* II 7423, 7463, 7479	0·45398	0·11536	0·43066	W
2134	Yale *12* II 7246, 7261, 7263	0·45970	0·34593	0·19437	R
2135	Yale *12* II 4770, 4785, 4795	0·23166	0·47196	0·29637	W
2136	Yale *14* 11544, 11563, 11582	0·26092	0·40218	0·33691	R
2137	Yale *14* 11470, 11481, 11504	0·21658	0·39448	0·38895	W
2138	Yale *13* I 5652, 5655, 5671	0·54291	0·12289	0·33420	S
2139	Yale *12* II 5551, 5564, 5572	0·37940	0·50836	0·11224	S
2140	Yale *14* 10475, 10496, 10514	0·26916	0·42991	0·30092	S
2141	Yale *14* 10342, 10343, 10362	0·30305	0·33491	0·36205	R
2142	Yale *16* 263, 268, 280	0·31499	0·42990	0·25511	R
2143	Yale *16* 262, 263, 275	0·36684	0·39385	0·23931	R

TABLE II—*continued*

No.	Comparison Stars	Dependences			
2144	Cord D. 10227, 10283, 10359	0·51798	0·21384	0·26819	S
2145	Cape Z. 12466, 12511, 12540	0·31471	0·17339	0·51189	S
2146	Cape Z. 12412, 12466, 12481	0·43193	0·34575	0·22232	W
2147	Yale *12* II 6060, 6064, 6083	0·45099	0·23107	0·31794	R
2148	Yale *12* I 5286, 5294, 5304	0·20144	0·40600	0·39256	R
2149	Cape *17* 11461, 11473, 11503	0·37632	0·25872	0·36496	R
2150	Yale *12* II 6965, 6988, *12* I 6112	0·39124	0·52168	0·08707	S
2151	Yale *12* II 6922, 6934, 6943	0·15059	0·61217	0·23724	W
2152	Yale *11* 7348, 7358, 7372	0·34743	0·25071	0·40186	S
2153	Yale *11* 7275, 7303, 7319	0·18810	0·48625	0·32565	R
2154	Yale *13* II 14060, 14092, 14094	0·36257	0·39987	0·23756	R
2155	Yale *12* I 6550, 6562, 6597	0·48855	0·29625	0·21520	S
2156	Yale *12* I 6487, 6493, 6508	0·32788	0·34674	0·32538	W
2157	Yale *11* 6793, 6815, 6816	0·26783	0·24458	0·48759	R
2158	Yale *16* 8394, 8405, 8408	0·11478	0·48747	0·39775	R
2159	Cape *17* 9352, 9403, 9427	0·25745	0·38937	0·35318	W
2160	Cape *18* 8562, 8611, 8614	0·37385	0·38306	0·24309	R
2161	Yale *21* 295, 313, 321	0·42682	0·29705	0·27612	R
2162	Yale *14* 13996, 14014, 14027	0·52161	0·19127	0·28712	R
2163	Yale *13* I 8526, 8568, *14* 13874	0·37634	0·20236	0·42130	W
2164	Yale *13* II 12426, 12453, 12466	0·14652	0·21065	0·64283	W
2165	Yale *14* 12988, 12989, 13029	0·57603	0·24259	0·18138	W
2166	Yale *14* 9988, 10011, 10032	0·40995	0·38648	0·20357	R
2167	Yale *14* 9893, 9914, 9928	0·25388	0·44707	0·29905	W
2168	Yale *13* II 14701, 14715, 14733	0·19364	0·55639	0·24997	S
2169	Cape *17* 12162, 12189, 12194	0·21041	0·40239	0·38719	R
2170	Yale *13* II 14021, 14050, 14060	0·45203	0·20488	0·34309	R
2171	Yale *13* II 13942, 13967, 13983	0·25752	0·42491	0·31757	W
2172	Yale *14* 14880, 14911, *13* I 9279	0·42038	0·30292	0·27670	S
2173	Yale *12* I 5951, 5969, 5972	0·31280	0·32795	0·35925	S
2174	Yale *12* I 5835, 5836, 5854	0·32966	0·38060	0·28974	R
2175	Yale *13* I 9955, 9985, *12* II 9984	0·33361	0·18077	0·48562	S
2176	Yale *14* 12710, 12720, 12749	0·36308	0·23079	0·40613	R
2177	Yale *14* 12319, 12359, 12414	0·34900	0·36262	0·28838	R
2178	Yale *12* I 5095, 5106, 5112	0·28683	0·48788	0·22529	R
2179	Yale *11* 4725, 4748, *12* I 5025	0·19513	0·52254	0·28232	R
2180	Yale *14* 12738, 12741, 12762	0·26189	0·25609	0·48202	R
2181	Yale *14* 12701, 12723, 12738	0·23828	0·30932	0·45240	R
2182	Yale *14* 15126, 15161, *13* II 14431	0·40256	0·28956	0·30788	R
2183	Yale *14* 13487, 13507, 13530	0·37660	0·29972	0·32368	R
2184	Yale *14* 13417, 13447, 13452	0·29396	0·26589	0·44015	S
2185	Yale *12* I 7174, 7214, 7218	0·24975	0·22198	0·52827	R
2186	Yale *13* I 8670, 8673, 8698	0·31267	0·26435	0·42297	S
2187	Yale *12* II 8570, 8580, 8582	0·35406	0·28669	0·35925	R
2188	Yale *12* I 7311, 7341, *11* 6853	0·28388	0·43300	0·28312	S
2189	Cape Z. 19487, 19533, 19545	0·31854	0·40465	0·27681	S

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Occultations Observed at Sydney Observatory during 1966

K. P. Sims

The following observations of occultations were made at Sydney Observatory with the $11\frac{1}{2}$-inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. Since the observed times were in terms of coordinated time (UTC), a correction which was derived from *Mount Stromlo Observatory Bulletins A* was applied to convert to universal time (UT2). For 1966 a correction of +0·00972 hour (=35 seconds) was applied to the time in UT2 to convert it to ephemeris time with which *The Astronomical Ephemeris for 1966* was entered to obtain the position and parallax of the Moon. The apparent places of the stars of the 1966 occultations were provided by H.M. Nautical Almanac Office.

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims, 1966). The observers were W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox* 1950·0 (Robertson, 1940).

The star involved in occultation 485 was not in Z.C., it is Y 13471. The apparent place was R.A. 19h 19m 50^s·61, Dec. —26° 14′ 36″·7.

References

Robertson, A. J., 1940. Astronomical Papers of the American Ephemeris, Vol. X, Part II.

Sims, K. P., 1966. *J. Proc. Roy. Soc. N.S.W.*, **100**, 15; *Sydney Observatory Papers*, **54**.

Table I

Serial No.	Z.C. No.	Mag.	Date	U.T.2	UT2–UTC	Observer
477	0740	6·3	1966 Feb. 1	12 32 42·12	—0·05	W
478	0676	7·1	1966 Feb. 28	9 37 41·56	—0·04	S
479	1108	6·9	1966 Mar. 30	12 21 55·21	—0·03	S
480	1432	7·0	1966 May 26	8 38 34·99	—0·02	R
481	1996	6·9	1966 June 27	11 29 29·73	—0·02	R
482	2182	6·3	1966 Aug. 22	12 03 11·60	0·00	S
483	2319	6·9	1966 Aug. 23	12 36 20·60	0·00	R
484	2824	7·4	1966 Oct. 20	12 11 35·29	—0·01	S
485	—	8·5	1966 Oct. 20	12 14 01·39	—0·01	S
486	3089	5·3	1966 Oct. 22	12 40 49·45	—0·01	W
487	3446	7·2	1966 Oct. 25	9 04 20·04	—0·01	R
488	2579	7·3	1966 Nov. 15	10 28 02·38	—0·02	W
489	3164	4·7	1966 Nov. 19	9 25 55·09	—0·02	W
490	3409	7·0	1966 Nov. 21	12 27 23·23	—0·02	S
491	3116	6·7	1966 Dec. 16	10 11 34·63	—0·02	R
492	3356	5·9	1966 Dec. 18	9 57 22·90	—0·02	W

TABLE II

Serial No.	Luna-tion No.	p	q	p²	pq	q²	Δσ	pΔσ	qΔσ	Coefficient of Δα	Δδ
477	533	+98	—18	97	—18	3	+2·1	+2·1	—0·4	+13·6	+0·01
478	534	+100	— 3	100	— 3	0	+0·3	+0·3	0·0	+13·5	+0·21
479	535	+99	—16	97	—16	3	+0·8	+0·8	—0·1	+13·0	—0·24
480	537	+49	+87	24	+43	76	—0·5	—0·2	—0·4	+10·4	+0·67
481	538	+45	—89	20	—40	80	+2·6	+1·2	—2·3	+ 0·5	—1·00
482	540	+81	+58	66	+47	34	—1·3	—1·1	—0·8	+13·8	+0·27
483	540	+100	— 3	100	— 3	0	+1·1	+1·1	0·0	+13·3	—0·29
484	542	+70	+72	49	+50	51	0·0	0·0	0·0	+ 8·4	+0·78
485	542	+76	+65	58	+49	42	+0·4	+0·3	+0·3	+ 9·4	+0·72
486	542	+47	+88	22	+41	78	0·0	0·0	0·0	+ 2·7	+0·98
487	542	+91	+42	82	+38	18	+0·1	+0·1	0·0	+ 9·3	+0·78
488	543	+69	—73	47	—50	53	+1·9	+1·3	—1·4	+ 8·5	—0·77
489	543	+98	—21	96	—21	4	+0·2	+0·2	0·0	+14·0	+0·12
490	543	+77	—64	59	—49	41	+0·6	+0·5	—0·4	+14·3	—0·25
491	544	+75	+66	56	+50	44	+0·4	+0·3	+0·3	+ 7·3	+0·86
492	544	+98	—22	95	—22	5	+0·1	+0·1	0·0	+14·4	+0·21

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Royal Society of New South Wales

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NOTICE

The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity it was resuscitated in 1850 under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales". In 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, the Society assumed its present title, and was incorporated by Act of Parliament of New South Wales in 1881.

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