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THE STRATIGRAPHY OF THE WIANAMATTA GROUP TRIASSIC SYSTEM, SYDNEY BASIN

BY J. F. LOVERING, M.SC.

Assistant Curator of Minerals and Rocks, The Australian Museum, Sydney.

(Plate xii, ten text-figures; eight maps.)

SYNOPSIS.

The Wianamatta Group has been divided into two Sub-groups—The Liverpool Sub-group (lower, approximately 400 feet thick, predominantly shale lithology) and the Camden Sub-group (upper, approximately 350 feet thick, sandstone lithology prominent with shale). The Liverpool Sub-group includes three formations (Ashfield Shale, Minchinbury Sandstone, Bringelly Shale). The Camden Sub-group includes five formations (Potts Hill Sandstone, Annan Shale, Razorback Sandstone, Picton Formation, Prudhoe Shale).

The sedimentary petrology of the graywacke-type sandstones and the relation of the lithology to the sedimentary environment and tectonics is discussed. A new element, the *envirotope*, is defined to be used with the elements lithotope and tectotope (Krumbein and Sloss, 1951) to describe a lithologic sequence.

Post-depositional tectonics are briefly discussed and a new series of tectonic features described from the south-western suburbs of Sydney.

INTRODUCTION.

The sequence of rocks forming what has become known as the Wianamatta Group of the Triassic System in the Sydney Basin has long been neglected by local workers. Osborne (1948) pointed out the general lack of information on the local Triassic sequence and this first stimulated the writer to complete the present work.

In essence, the problem was to study the outcrop of the Wianamatta Group and determine if consistent and definite divisions could be made on lithologic grounds—divisions that had previously and commonly been regarded as unmappable. Fieldwork, together with interpretation of the available bore data, has shown that consistent and mappable divisions can be made.

It is hoped, and it already seems likely, that this work will be of some practical value to officers of the many Public Utilities who are directly concerned with the nature of the rock type of the Sydney Basin.

The completion of this work is directly due to the willing assistance of many people—too many to mention individually. Professor Marshall, the staff of the Department of Geology of the University of Sydney, and Dr. H. G. Raggatt figured in many helpful discussions; invaluable practical assistance was given by officers of the Joint Coal Board, Metropolitan Water, Sewerage and Drainage Board, Department of Main Roads, Geological Survey and others; Mr. K. Malcolm gave valuable information from his work on the Moss Vale sheet. The completion of the work would have been impossible without the co-operation of Dr. A. B. Walkom and Mr. R. O. Chalmers of the Australian Museum. A research grant awarded by A.N.Z.A.A.S. towards publication of the maps is gratefully acknowledged.

Review of Literature.

Hanlon, Joplin and Noakes (1952) have given a review of the literature but further search has shown amendments necessary and a fuller outline is given here.

The first reference to the rocks now defined as the Wianamatta Group was by Jukes (1847):—"From Parramatta by Liverpool to Campbell Town the country is low, gently undulating and composed almost entirely of black and brown shales, with a few thin inter-stratified beds of sandstone in their lower portion."

Jukes recognized the stratigraphical position as lying above the "Sydney Sandstone" (i.e., Hawkesbury Sandstone) and gave the thickness as at least 300 feet but probably more.

In the following year Clarke noted further information on these rocks and used, for the first time, the term "Wianamatta Rocks".

Clarke, in various publications between 1848 and 1870, referred in passing to the "Wianamatta beds" but in 1870 he further described the sequence and gave the thickness between 800 and 900 feet. His last description in 1878 was used by Hanlon *et al.* (1952) as the definition of the Wianamatta Group:—"The Hawkesbury Rocks are succeeded by another group or series of strata named by me from Wianamatta, or South Creek, which runs longitudinally through the basin which fills in the area between surrounding enclosure of the former series . . . The nearest beds of the latter to the underlying Hawkesbury Rocks, are shales which have occasionally filled in hollows previously existing, or contributed patches forming considerable masses as well as thin layers to the uppermost Hawkesbury Rocks . . . The Wianamatta Beds are, however, not all shale, for there are fine sandstones, more compact and heavier than the Hawkesbury, calcareous sandstones and ferruginous nodules, bearing fishes and small fresh-water molluscs . . . There are in the Wianamatta Beds in places columnar and pisolitic ironstone with an abundance of fossil wood, plant impressions and calcareous sandstones, which latter form the highest levels and summits of isolated hills that attain but moderate elevation (1100 to 1300 feet) in the centre or on the outskirts of the basin, which latter is chiefly confined to the heart of the County of Cumberland and part of which Bulbunmatta or Razorback Range and Menangle Sugar Loaf are outlying relics of a once wider extended plateau . . . very small patches of coal occur, but no seams nor any of value have been met with."

Tenison-Woods (1883) disputed this definition and considered ". . . the shales . . . do not lie on the top of the Hawkesbury Sandstone, but are intercalated with it . . . consequently there is no such formation as the Wianamatta". This criticism has never been substantiated and Clarke's definition is now generally accepted.

Nomenclature.—From the term "Wianamatta Beds" used by Clarke, the sequence has been referred to by a confusing array of terms. Various writers up to 1882 referred to "Wianamatta Beds, Formation and Shales" while in that year Wilkinson used "Wianamatta Series". Sussmilch (1911) mentioned the "Wianamatta Stage".

Willan (1923) divided the "Wianamatta formation" into upper, middle and lower stages. Unfortunately the criteria for the divisions were never fully described and although his map of the Sydney District (1925) showed the stages, the work has never been accepted because of some difficulty in reconciling the outcrop with the rather short descriptions:—

Lower Stage: approx. 200 feet of carbonaceous and clay shales with some sandy basal beds.

Middle Stage: approx. 200 feet of thin-bedded sometimes ripple-marked sandstones, lenticular, calcareous, tuffaceous sandstones and interbedded seams of inferior coal up to 3 feet thick.

Upper Stage: 200-300 feet thick. Composed of thick bedded and subdividing bands of medium to coarse sandstone with some tuffaceous material and plant remains, mud breccias and shales.

David (1950) gave a two-fold division of the "Wianamatta Series" based on lithologic grounds but no map was published and the descriptions of the stages are rather sketchy:

Lower Stage: shales . . . particularly near the base, are sometimes carbonaceous and ferruginous, but . . . are commonly grey and aluminous though occasionally sandy . . . a few impure coal seams up to 4½ feet thick and a little argillaceous limestone together with some lenticular beds of acid tuff material. 350 feet thick.

Upper Stage: . . . characterized by a large proportion of calcareous and fine siliceous sandstone in beds ranging from less than 1 foot up to 80 feet in thickness, the remainder of the sequence being made up of shale and shaly sandstone.

In the most recent work, Hanlon *et al.* (1952) have clearly established the Wianamatta as a Group as defined in the Australian Code of Stratigraphic Nomenclature (Raggatt, 1950) "consisting, as it does, mainly of shale and sandstone but neither can be considered the dominant rock type".

In this work it will be shown that a major lithologic division into two sub-groups is valid in the Group while these divisions are in turn capable of division into eight well-defined formations.

Age.—The Wianamatta Group rocks were originally included in the Palaeozoic by Beete Jukes (1847). Clarke, in his earlier writings, considered them as Carboniferous but later recognized their Mesozoic age. Wilkinson (1882) recorded the age as probably Triassic and it seems that this age then became confirmed in the literature.

Willan (1923, 1925) described his Lower and Middle Stages as Upper Triassic but considered the Upper Stage to be probably Jurassic, mainly on Chapman's (1909) determination of foraminifera and ostracoda. These generic and specific identifications are now considered generally to be doubtful (Lovering, 1953) and cannot be used with any certainty as an indication of Jurassic age.

David (1950) stated the fossil evidence shows that the "Wianamatta Series" are Upper Triassic.

It is suggested here that: because of (1) the scant nature of the recorded fossils, and (2) the observation (p. 187) that those described have been confined to a zone less than 100 feet above the Hawkesbury Sandstone, the Upper Triassic age, if substantiated, can only be applied with any degree of positiveness to a very small portion (about 100 feet) of the Group. The overlying sequence, of some 650 feet, may well be included with the Jurassic and so correlated with the sequence in the Clarence River Basin, Great Artesian Basin and other lesser basins in New South Wales—but this is speculation and must remain so until more palaeontological work settles the question. For the purpose of the present work, no finer age definition than Triassic is proposed for the Group.

METHODS OF MAPPING.

The various formations of the Wianamatta Group have major outcrops in some 10 sheets of the inch-to-mile military system (Sydney, Port Hacking, Broken Bay, Windsor, Liverpool, Camden, Mittagong, Wollongong, Moss Vale and Kiama). On present geographic extent, then, the Wianamatta Group is confined to the Cumberland Basin as described by Osborne (1948) from Willan's (1923) work.

The outcrop of isolated remnants of the basal formation (the Ashfield Shale) on the edges of four surrounding sheets (St. Albans, Wallerawang, Katoomba and Burragorang) suggests the extent was originally much greater and probably covered an area at least 90 miles from north to south and 40 miles from east to west, and so related to the sedimentation of the Permo-Triassic Sydney Basin of central eastern New South Wales.

The boundaries with the Hawkesbury Sandstone alone have been shown on the maps. Tertiary igneous intrusions have been shown only where they are in direct association with the Wianamatta Group. These boundaries have been taken from the Bureau of Mineral Resources 4 mile-to-inch geological series Wollongong and Sydney sheets with additional information from the present work.

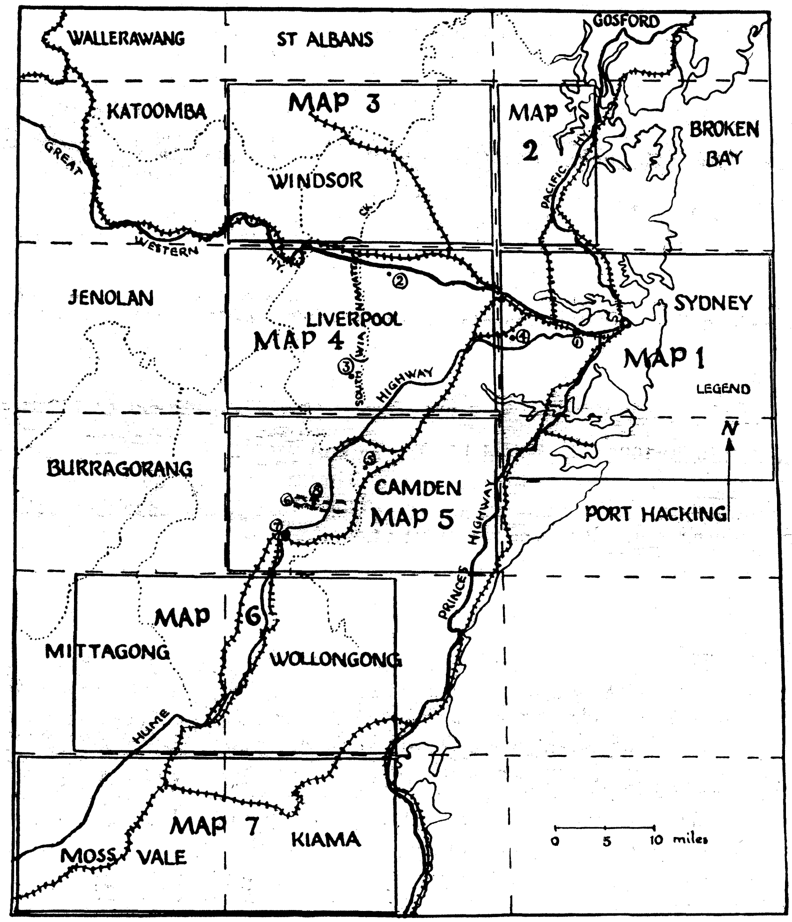

Fig. 1.—Relation of Maps to Military Sheet System. Boundary of inch to mile Military Sheet - - - - ; boundary of map, ————. Localities of Formational Geographic Names : 1, Ashfield; 2, Minchinbury Trig.; 3, Bringelly; 4, Potts Hill; 5, Mount Annan; 6, Razorback Range; 7, Picton; 8, Mount Prudhoe Trig.

Maps 1-7.

The base maps used in the mapping of the Group were, in general, the inch-to-mile military sheets. For convenience, some of the maps are a combination of two adjacent military sheets where the outcrop area on each is not sufficient to warrant two separate maps. Figure 1 gives the relation of the maps to the military sheet system as well as the localities of the geographic names of the formations. Extraneous information has been kept to a minimum on the maps as it was originally intended that they should be used as overlays on the appropriate military sheet. For this purpose the grid co-ordinates with intervals of 10 were marked on the maps. For publication, however, the maps have been drastically reduced* and the co-ordinates are now only useful as a guide to comparisons with the appropriate military sheet.

In some places (especially on the Moss Vale sheet), areas marked as Ashfield Shale may actually be part of the passage beds with the Hawkesbury Sandstone. Further work is necessary in these areas to determine the exact relations.

For completeness a list of the scattered outliers of shale from the Ashfield Shale is given:

St. Albans Sheet:

(*a*) Thin capping confined to ridge about ½ mile east and west of Bilpin (508605).†

(*b*) Thin capping on Blaxland Ridge (around 720605).

(*c*) Around Mitchell Trig. (813609).

(*d*) Under the basalt cap of Mount Tootie (494648) and extending to Little Tootie (497662).

(*e*) Possible thin capping along the Wheelbarrow Ridge and other high localities. Only the Ashfield Shale would be represented.

Wallerawang Sheet:

Ashfield Shale underlies the basalt of Mount Irvine (447624).

Katoomba Sheet:

(*a*) Thin capping along the line of the Bell road as far as the 420 north-south grid.

(*b*) Under the basalt on Mount Tomah (415549) and Mount King George (Mount Banks, 361497).

Burragorang Sheet:

This sheet has not yet been published. Outcrops are confined to a few scattered remnants along the ridges of the eastern margin of the sheet.

Mapping of the boundaries proved very difficult in most cases due to the considerable soil cover and poor outcrops. The Minchinbury Sandstone, a persistent sandstone formation sandwiched between 400 feet of shale, forms very poor outcrops and is only exposed in road cuttings and quarries. The continuity of extent

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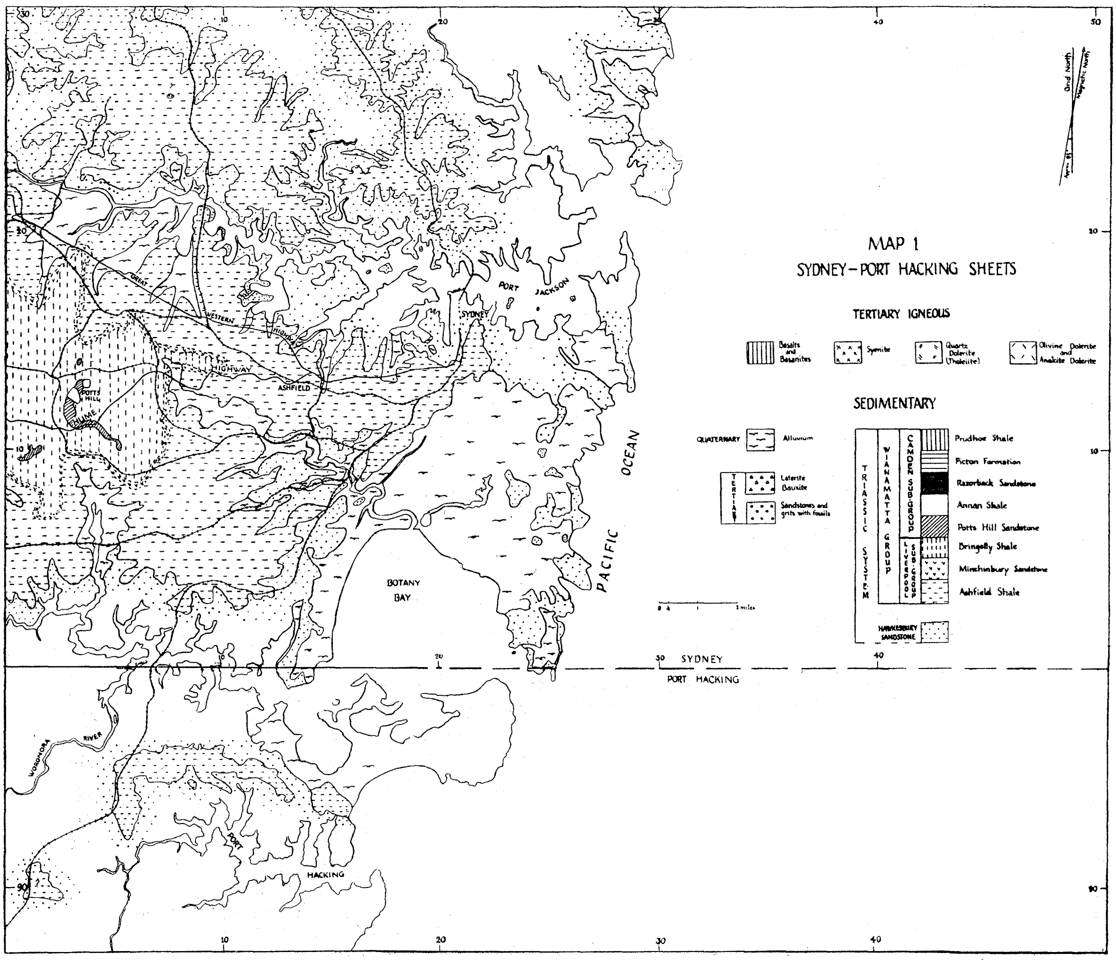
* The originals of these maps, on the scale of 1 mile to the inch, and of figures 8, 9, 10 are filed at the Australian Museum and are available for consultation.

† Numbers in brackets refer to military sheet grid reference.

and the stratigraphic position are quite definite. In general, the boundaries with the Ashfield Shale below and the Bringelly Shale above are shown by broken lines on the map. Unbroken lines are used where the information is more definite.

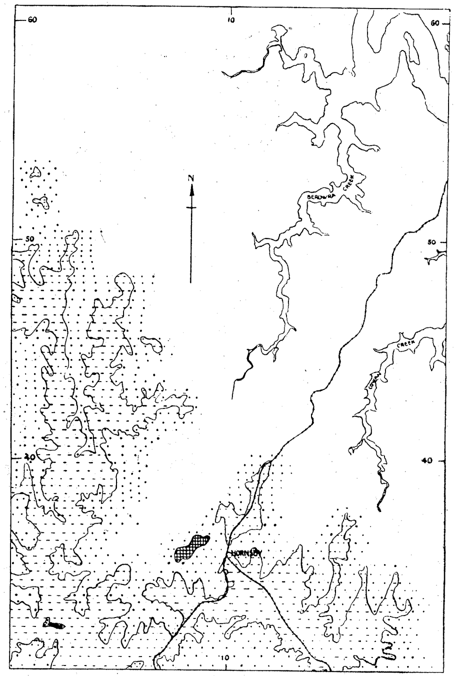
Map 8: Razorback Range.

This map is the type area for the Camden Sub-group. The heavily dissected Razorback Range with its land-slips, thick soil cover and complications due to local warping has previously defied mapping by usual methods, at least in a reasonable time. The outcrop of the various formations was recognized as forming a series of bench levels—the sandstone formations standing out amongst the shales. These levels were the basis for the mapping of the formations since they were readily and accurately plotted on the excellent series of air photos lent by the State Electricity Commission. It is from these photographs that this map is drawn, with frequent ground work for control.

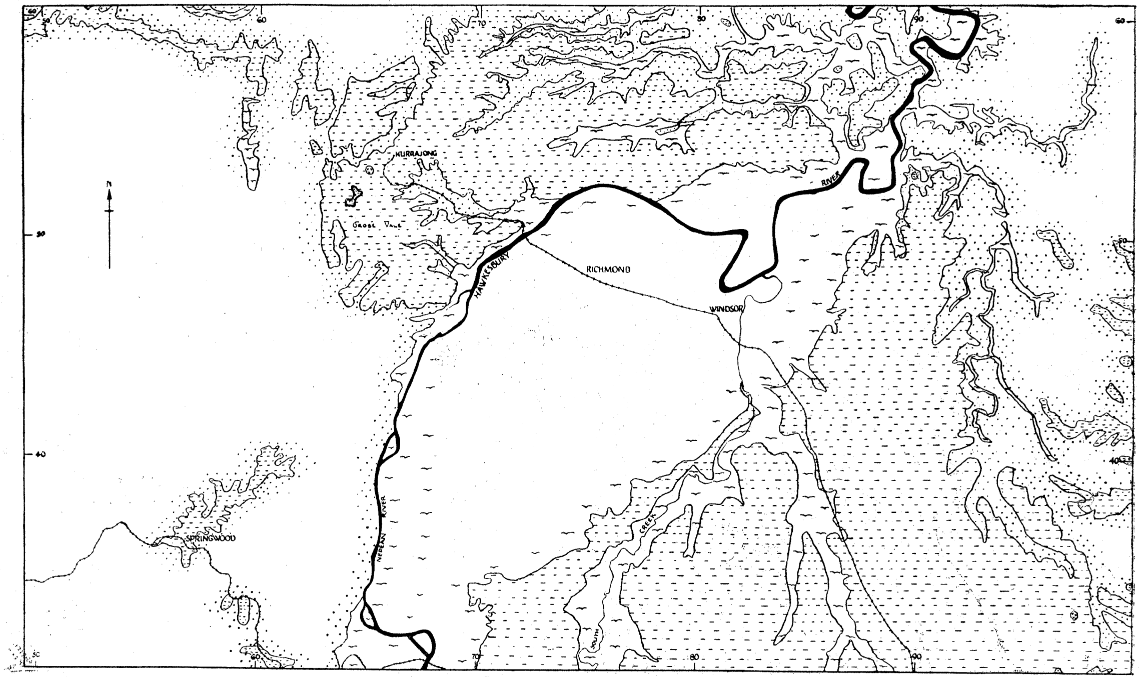


MAP 1

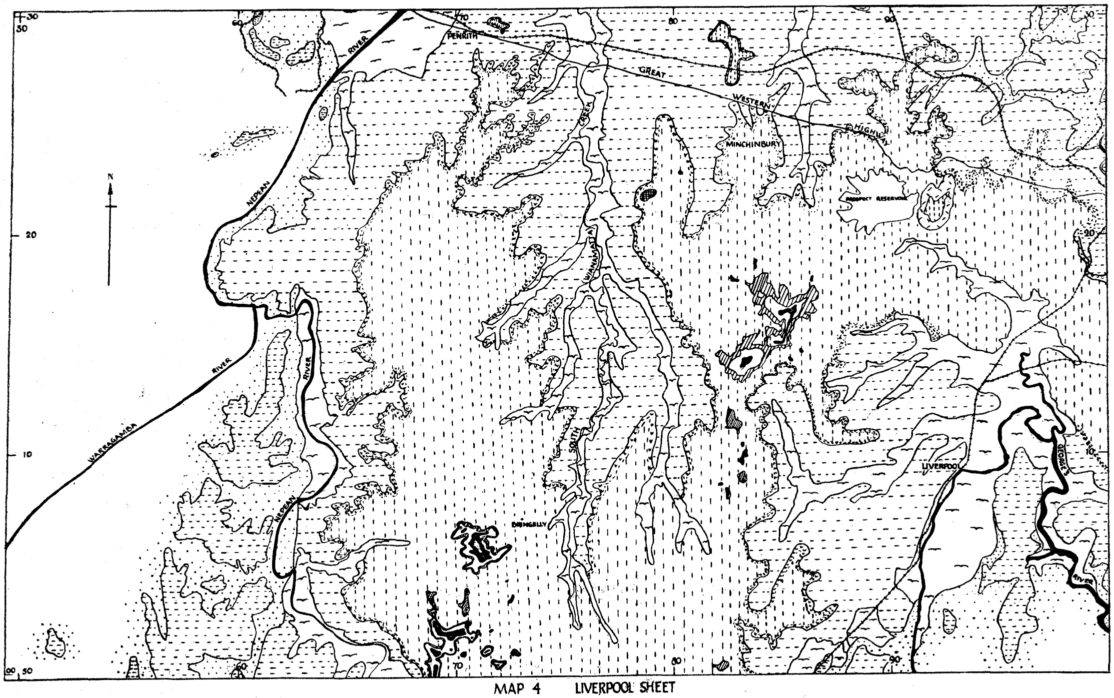
SYDNEY–PORT HACKING SHEETS



MAP 2
BROKEN BAY SHEET

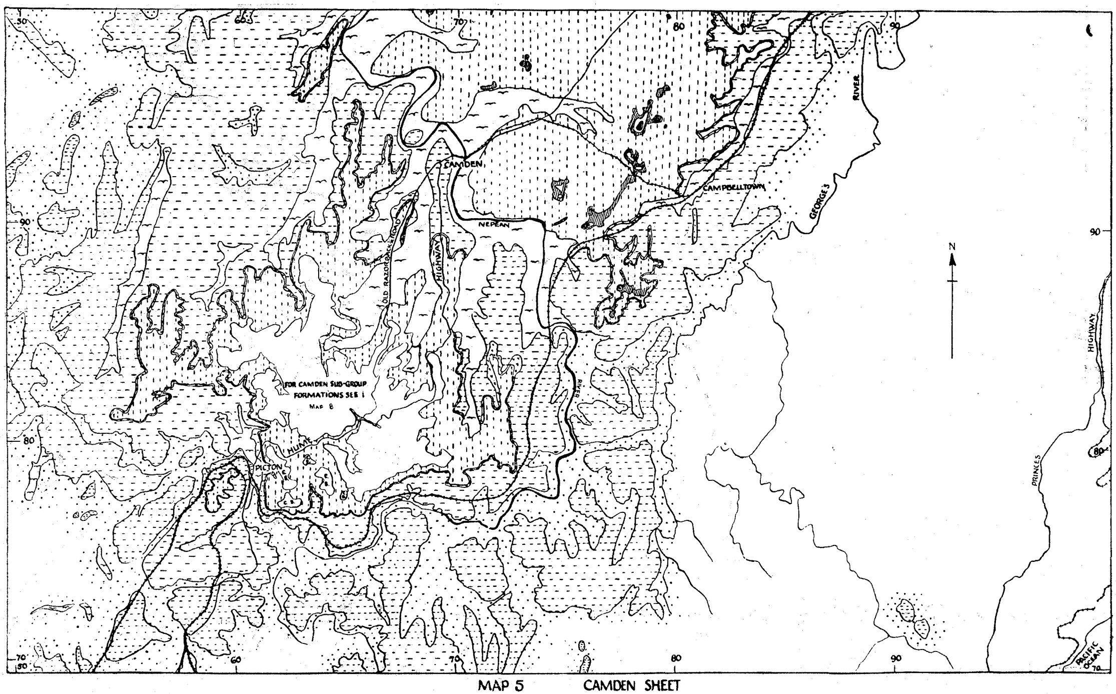


MAP 3 WINDSOR SHEET



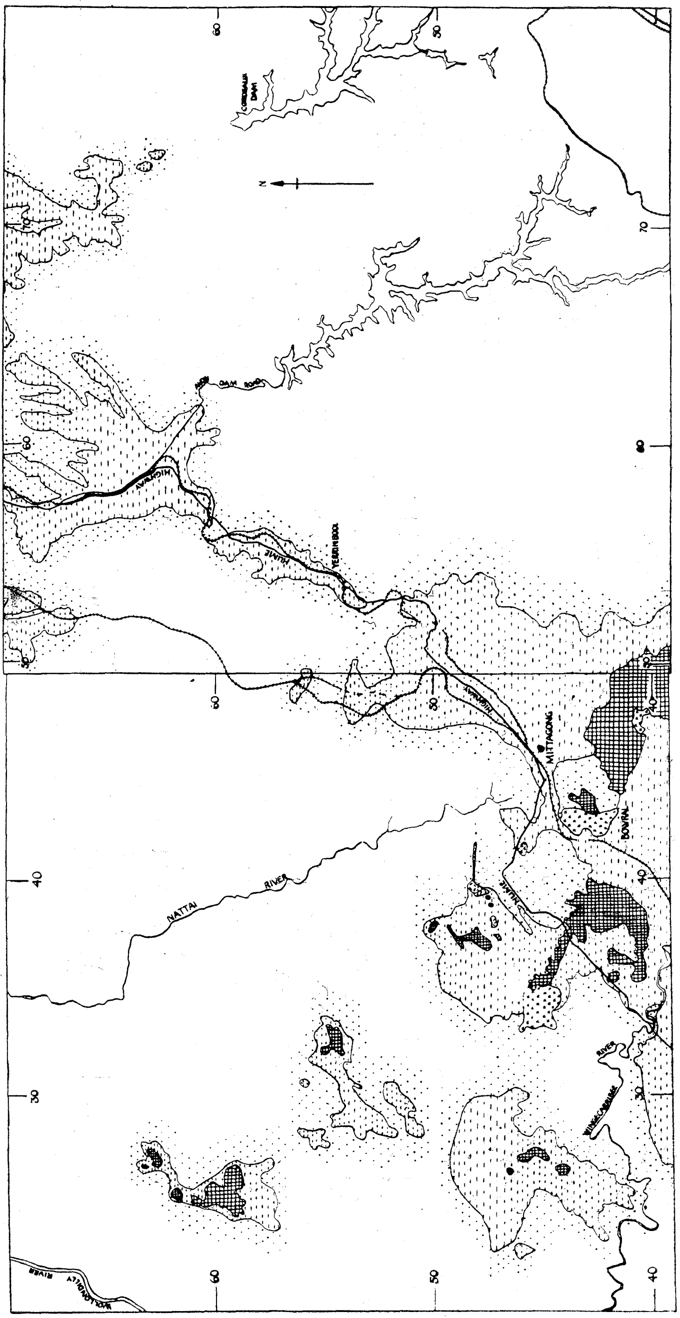
MAP 4 LIVERPOOL SHEET

0 ½ 1 2 miles.

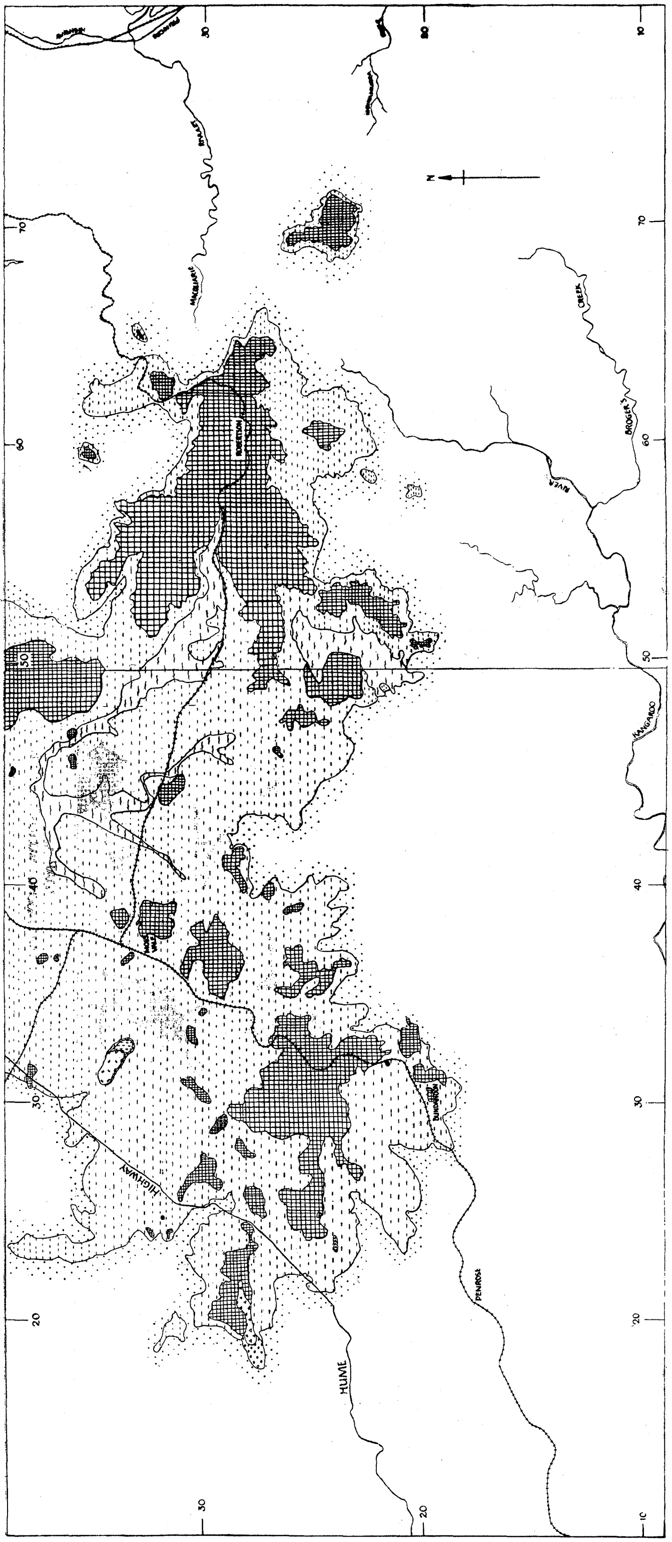


MAP 5 CAMDEN SHEET

0 ½ 1 2 miles.

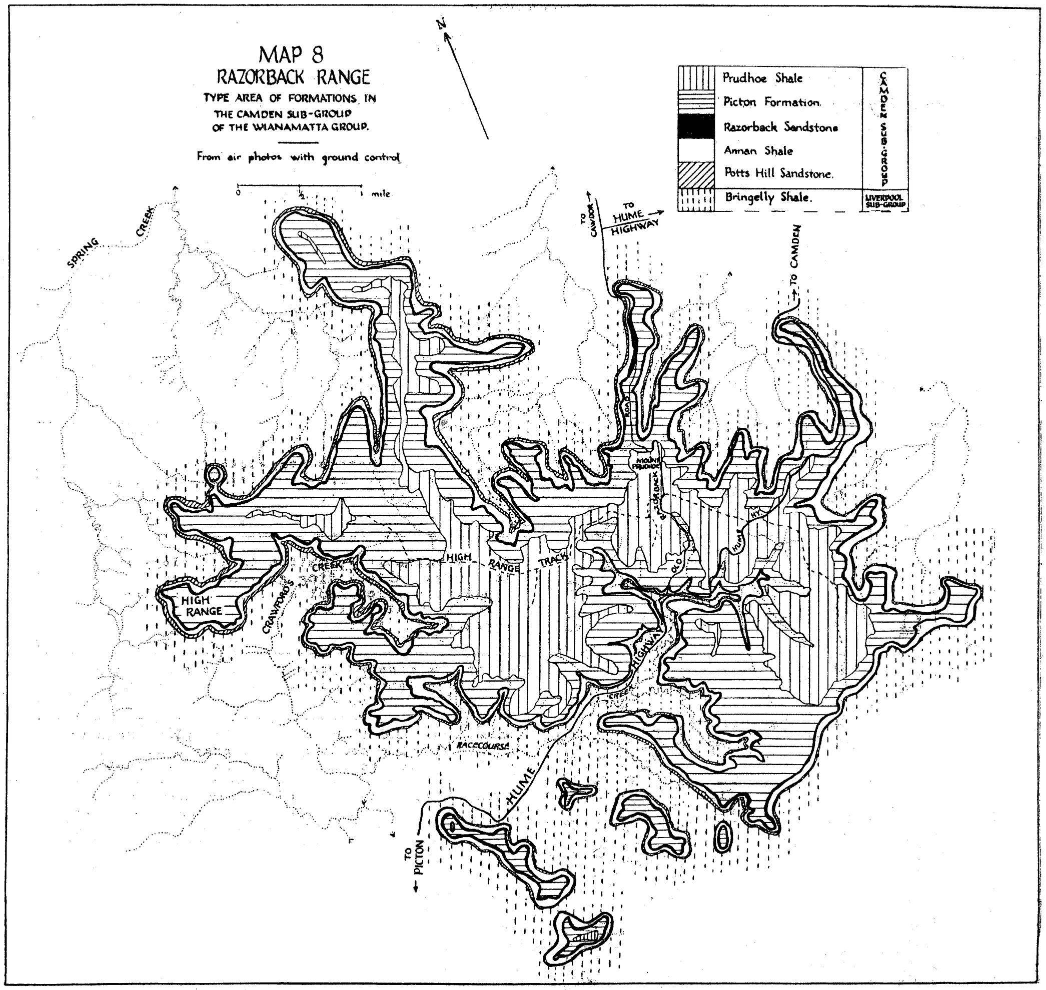


MAP 6.
MITTAGONG - WOLLONGONG SHEETS



MAP 7

MOSS VALE - KIAMA SHEETS


MAP 8
RAZORBACK RANGE
TYPE AREA OF FORMATIONS IN THE CAMDEN SUB-GROUP OF THE WIANAMATTA GROUP.
From air photos with ground control
0 ½ 1 mile
N
Prudhoe Shale
Picton Formation
Razorback Sandstone
Annan Shale
Potts Hill Sandstone
CAMDEN SUB-GROUP
Bringelly Shale
LIVERPOOL SUB-GROUP
SPRING CREEK
TO CAWDOR
TO HUME HIGHWAY
TO CAMDEN
MOUNT PRUDHOE
RAZORBACK
ROAD
OLD HUME HY.
HIGH RANGE TRACK
CRAWFORD'S CREEK
HIGH RANGE
HIGHWAY
CREEK
RACECOURSE
HUME
TO PICTON

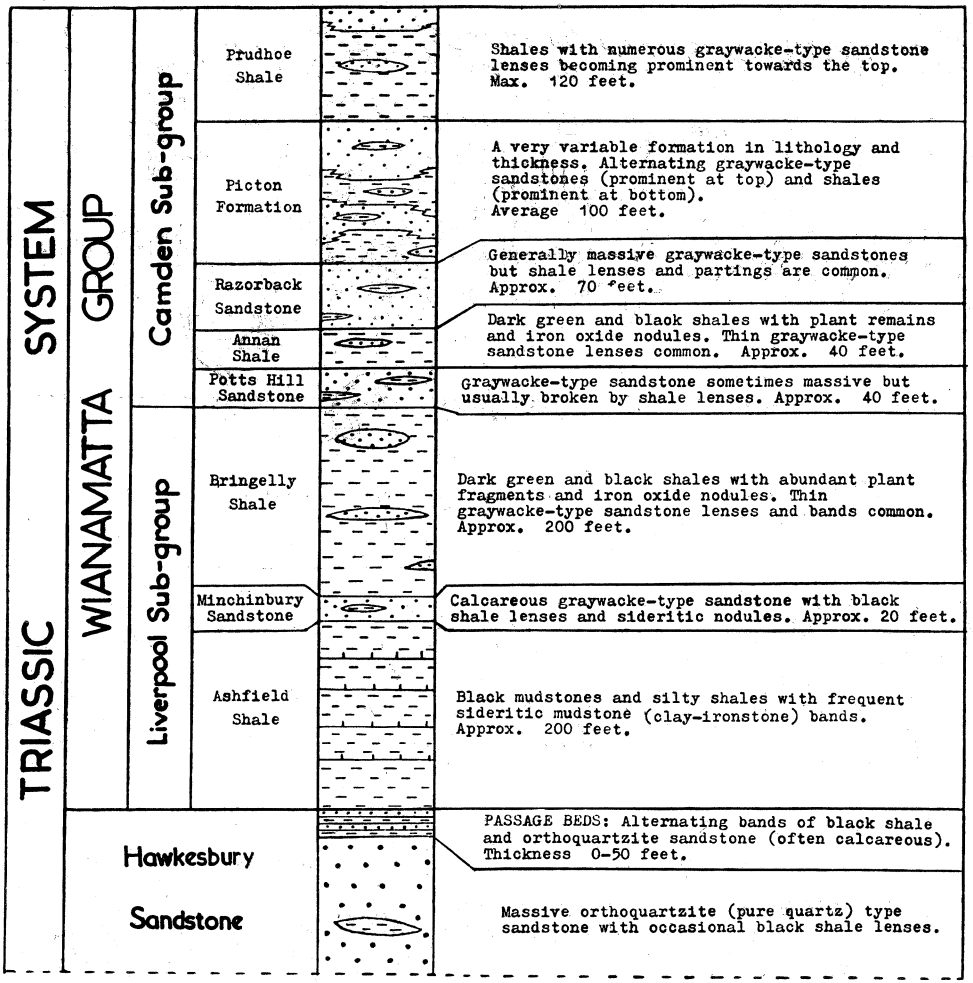
STRATIGRAPHY.

General Definition.

The Wianamatta Group has been defined previously as the upper unit in the Triassic System of the Sydney Basin. The sequence of the Triassic System has been given by Hanlon *et al.* (1952) as:

TRIASSIC SYSTEM	Wianamatta Group Hawkesbury Sandstone Narrabeen Group

David's (1950) conception that the Wianamatta Group may be divided into two divisions on lithologic grounds has been discussed above but up to the present time such a division has not been adequately defined and mapped. The first results of the present work indicated that a two-fold division was valid. The boundary is well defined and divides the Group into two distinct lithologic units—the lower, predominantly shale, and the upper, mostly sandstone with some associated shale.



Shales with numerous graywacke-type sandstone lenses becoming prominent towards the top. Max. 120 feet.

A very variable formation in lithology and thickness. Alternating graywacke-type sandstones (prominent at top) and shales (prominent at bottom). Average 100 feet.

Generally massive graywacke-type sandstones but shale lenses and partings are common. Approx. 70 feet.

Dark green and black shales with plant remains and iron oxide nodules. Thin graywacke-type sandstone lenses common. Approx. 40 feet.

Graywacke-type sandstone sometimes massive but usually broken by shale lenses. Approx. 40 feet.

Dark green and black shales with abundant plant fragments and iron oxide nodules. Thin graywacke-type sandstone lenses and bands common. Approx. 200 feet.

Calcareous graywacke-type sandstone with black shale lenses and sideritic nodules. Approx. 20 feet.

Black mudstones and silty shales with frequent sideritic mudstone (clay-ironstone) bands. Approx. 200 feet.

PASSAGE BEDS: Alternating bands of black shale and orthoquartzite sandstone (often calcareous). Thickness 0-50 feet.

Massive orthoquartzite (pure quartz) type sandstone with occasional black shale lenses.

Fig. 2 Stratigraphic Columnar Section of Wianamatta Group.

Vertical Scale 0 100 feet

This boundary was given to the Bureau of Mineral Resources for their 4 mile-to-inch geological series Wollongong sheet as the Lower and Upper Divisions.

Up till 1953, there was no provision in the Australian Code of Stratigraphic Nomenclature for a term to cover a major subdivision of a Group but in that year the term Sub-group was defined to meet such a need (Raggatt, 1953). At that time, the suggestion was made that the term should be used only if the division intended could not be expressed by using the other terms already provided for in the Code. In the present discussion the eight formations to be defined later are possibly capable of further division into members (although no such division was attempted in this work), so there was no alternative but to define the fundamental two-fold division of the Group with the rank of Sub-groups.

The Liverpool Sub-group.

Definition.—This unit lies immediately above the Hawkesbury Sandstone; the relation with this formation is discussed with the Ashfield Shale. The dominant lithologic type is shale, and two shale formations have been mapped. The thickness is fairly consistent at 400 feet. A centrally-placed sandstone formation some 20 feet thick has also been recognized but it is subsidiary to shale as the main lithologic type.

These shales limit the main agricultural areas of the County of Cumberland and, to some extent, Camden, as well as providing an extremely important raw material for the brick and ceramic industries.

Name.—The Sub-group takes its name from the town of Liverpool, the extreme south-western suburb of Sydney (Liverpool 925090). The name is appropriate by reason of the geographical position of the town—at once adjacent to outcrops of the three component formations.

Type area and section.—The formations of the Liverpool Sub-group cover almost the entire area of outcrop of the Group. Due to the lack of a complete natural section, no type area is given, but the type section is described in the logging of the Potts Hill bores shown in Figures 9 and 10.

The Camden Sub-group.

Definition.—Separated from the Liverpool Sub-group by a massive sandstone formation, this unit is composed of a series of alternating sandstone types and shales, with the sandstones rather more prominent. The thickness is rather variable but has a maximum of approximately 350 feet in the Razorback section.

Name.—The town of Camden (Camden 795932) is appropriate as the geographic name for the upper Sub-group being the town nearest the outcrop of the type section of the Razorback Range.

Type area and section.—Razorback Range is the type area. The type section is shown in Figure 3, a section along the Hume Highway on the south side of Razorback. The geographic extent of the Camden Sub-group is much less than the Liverpool Sub-group and is restricted to Maps 1, 4 and 5.

Map 1.—Sydney-Port Hacking Sheets: The basal formation of the Camden Sub-group has an outcrop confined to a small area around Potts Hill.

Map 4.—Liverpool Sheet: Isolated outcrops only in scattered localities, the more extensive being between Hoxton Park and Cecil Hills and also in the high country to the south-west of Bringelly.

Map 5.—Camden Sheet: Isolated outcrops are to be found in scattered localities —Badgelly Trig., Kenny Hill, Sugarloaf Trig. and others.

The geographic names of formations and Sub-groups have been approved by the New South Wales representatives of the A.N.Z.A.A.S. Standing Committee on Stratigraphic Nomenclature.

The Liverpool Sub-group.

(i) *Ashfield Shale.*

Name.—Ashfield, a suburb of Sydney and a station about 6 miles along the main western railway from Sydney (Sydney 127133), has been taken as the geographic name of this formation, being centrally situated with regard to its outcrop on the Sydney Sheet.

Type Area and Section.—There is no natural section in which the complete formation is exposed, although a number of excellent exposures, usually less than 50 feet, are available in the Sydney District brick quarries. On the other hand there are a number of sub-surface sections available from the bores logged in Figures 9 and 10 and these must serve as the type sections. It is unfortunate that the poor state of preservation of the cores does not allow a more complete lithologic logging to be made.

Lithology and Petrology.—The predominant lithology is shale with varieties such as mudstones and siltstones locally abundant. The sandy types appear to be more common at the top of the sequence especially towards the junction with the Minchinbury Sandstone. Micro-current bedding is very abundant.

The shales are typically black, only showing light colours if weathered. Associated with the black shales, and following a very common association pattern, are bands and lenses of sideritic mudstone (clay-ironstone) very irregular in vertical and horizontal extent but never exceeding 10 inches in thickness. The vertical spacing of the bands is also rather irregular but up to 10 bands occur in a 50-feet section. Siderite, in a rather oolitic form, and clay matter are the two main constituents. Partial analyses of four samples of the sideritic mudstone are given in Table 1. Associated with the sideritic mudstones is a suite of minerals (barite, pyrite, marcasite, etc.) partly of authigenic origin. This association of black shales and sideritic mudstone bands is characteristic of "coal measure" type sequences in both Carboniferous and Permian in all parts of the world. It is not surprising, then, that fragments of plants converted to vitrainous material are common in the shale and associated with thin, horizontally restricted lenses of impure coaly material.

TABLE 1.

Partial Analyses of Sideritic Mudstones from the Ashfield Shale.

(Per cent. of sample dried at 105° C.)

	A.	B.	C.	D.
Total ignition loss	25·3	22·9	26·5	25·8
CO_2	24·4	21·6	22·9	25·7
FeO	30·2	24·5	29·7	28·9
Fe_2O_3	4·1	1·1	6·4	2·9
CaO	1·4	n.d.*	2·9	n.d.
MgO	2·2	n.d.	1·5	n.d.
Mn	present	nil.	present	present
SiO_2	present	present	present	present
Ba	nil	nil	nil	nil
$FeCO_3$ (total Fe^{II})	48·7	39·5	47·9	46·6
Fe_2O_3	4·1	1·1	6·4	2·9
$CaCO_3$ (total Ca)	2·5	n.d.	5·2	n.d.
$MgCO_3$ (total Mg)	4·6	n.d.	3·2	n.d.
CO_2 (in excess of above)	2·4	6·6	0·7	8·0
Ignition loss (apart from CO_2)	0·9	1·3	3·6	0·1
	63·2	48·5	67·0	57·6

A, B.—Ashfield Brick Co. Pit, Milton Street, Ashfield.
C.—Punchbowl Brick and Pipe Co., Bond Street, Punchbowl.
D.—Spear's Brick Pit, Kingsgrove.
*.—Not determined.
Analyst.—Miss M. E. Neilson, C.S.I.R.O. Division of Building Research.

TABLE 2.

Analyses of Ashfield Shale.

<100 feet above Hawkesbury Sandstone.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2 ...	61·54	64·26	75·04	67·81	70·70	65·72	65·54	67·74	65·96	59·62	62·77	60·24	58·44	57·04	58·40	64·12
TiO_2 ...	0·48	0·60	0·48	0·56	...	1·10	0·95	0·75	0·64	0·70	2·51*a*	...	...	...	0·80	0·78
Al_2O_3 ...	18·60	22·09	16·82	20·24	19·95	19·26	20·21	19·26	19·10	21·44	20·97	18·96	19·02	16·85	21·10	19·59
Fe_2O_3 ...	6·00	0·50	0·50	0·60	0·35	1·40	1·20	1·40	3·30	4·70	} 2·30	7·30	6·02	6·26	5·50 {	1·99
FeO ...	...	0·90	0·37	0·45	0·45	...	...	...	0·18	0·86						0·54
MnO ...	0·26	nil	nil	Tr.	...	0·02	0·02	Tr.	Tr.	0·02	...	...	...	...	...	0·08
MgO ...	0·90	0·55	0·28	0·56	0·46	0·60	0·58	0·44	0·57	0·40	0·73	...	...	...	0·70	0.56
CaO ...	0·80	0·84	0·09	0·33	0·21	...	nil	nil	0·30	0·02	1·33	0·32	0·30	0·58	0·20	0·44
Na_2O ...	0·28	0·06	0·53	0·29	0·28	0·14	0·21	0·15	0·11	0·30	...	...	...	...	0·08	0.22
K_2O ...	2·20	1·90	1·59	1·87	1·98	2·69	2·50	2·06	2·31	2·30	...	...	...	...	2·06	2·13
$H_2O +$ ...	3·93	6·34	2·91	5·83	} 5·60 {	6·66	6·62	6·80	5·67	7·05	6·84	...	...	...	} 11·00 {	5·87
$H_2O -$ ...	1·17	1·94	1·02	1·67		1·07	0·88	1·42	0·97	3·24	1·55	...	...	...		1·49
P_2O_5 ...	0·10	0·11	0·14	0·15	...	0·07	0·12	0·07	0·23	0·17	...	...	...	...	...	0·13
CO_2 ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SO_3 ...	...	...	...	...	...	Tr.	Tr.	Tr.	...	...	...	...	...	...	Tr.	Tr.
Cl ...	...	...	...	...	...	Tr.	Tr.	Tr.	...	...	...	...	...	...	...	Tr.
BaO ...	...	...	...	...	...	<υ·01	< 01	<0·01	...	...	...	...	...	...	...	<
SrO ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
NaCl ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Organic ...	3·74	...	...	...	...	1·09	1·14	0·08	0·88	nil.	...	...	...	...	0·40	1·22
Misc. ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	Tr.*b*	Tr.
	100·00	100·09	99·77	100·36	99·98	99·82	99·97	100·17	100·22	100·31	100·00	...	...	...	100·26	100·08

a. With alkalies and undetermined. *b*. FeS_2.

1. " Shale ".—Waterloo Brickworks. *Ann. Rep. Mines Dept. N.S.W.*, 1912, p. 195. Analysis No. 2156.
2. " Shale ".—Waterloo Brickworks. *Ibid.*, 1912, p. 195. An. No. 2157.
3. " Shale ".—Waterloo Brickworks. *Ibid.*, 1912, p. 195. An. No. 2158.
4. " Shale ".—Waterloo Brickworks. *Ibid.*, 1912, p. 195. An. No. 2159.
5. " Shale ".—Industrial Quarry, Waterloo. *Ibid.*, 1912, p. 195. An. No. 852.
6. " Clay-shale ".—State Brickworks, Botany. *Ibid.*, 1915, p. 177. An. No. 1170.
7. " Shale ".—State Brickworks, Botany. *Ibid.*, 1917, p. 177. An. No. 1171.
8. " Shale ".—State Brickworks, Botany. *Ibid.*, 1917, p. 177. An. No. 1172.
9. " Clay-shale ".—Homebush State Brickworks. Mines Dept. N.S.W. An. No. 2/1912.
10. " Clay-shale " (weathered, from overburden).—Homebush State Brickworks. Mines Dept. N.S.W. An. No. 3/1912.
11. " Shale ".—Hurstville State Brick Co. Mines Dept. N.S.W. Analysis.
12. " Clay-shale ".—Central Brick Pit, St. Peters. Mines Dept. N.S.W. An. No. 877/1915.
13. " Clay-shale ".—Bakewells Brick Pit, St. Peters. Mines Dept. N.S.W. An. No. 878/1915.
14. " Clay-shale ".—Sydney Brick Co. Pit, St. Peters. Mines Dept. N.S.W. An. No. 879/1915.
15. " Shale ".—Berrima. *Ann. Rep. Mines Dept. N.S.W.*, 1924, p. 106. An. No. 3182. Analyst, W. A. Greig.
16. Average, 1–15.

TABLE 3.

Analyses of Ashfield Shale.

>100 feet above Hawkesbury Sandstone

	1	2	3	4	5	6	7	8	9	10	11	12	13
SiO_2	70·60	72·31	65·80*c*	62·79*d*	61·50*e*	61·74*f*	61·96*g*	69·92	73·10	66·10	65·73	58·10	51·03
TiO_2	...	0·65	0·90	0·75	0·70	0·64	0·60	0·84	...	...	0·74	0·65	...
Al_2O_3	13·45*a*	13·86	17·63	17·97	16·29	15·68	17·44	19·47	16·53	21·46	16·98	15·40	13·47
Fe_2O_3	5·75	2·30	2·15	3·50	7·50	7·60	5·60	1·60	0·20	0·33	4·04	4·02	8·06
FeO	0·31	0·36	0·31	0·45	0·36	0·35	0·36	0·87	0·63	0·87	0·49	2·45	...
MnO	0·02	0·04	Tr.	Tr.	Tr.	Tr.	Tr.	nil	Tr.	Tr.	0·02	...	...
MgO	0·54	0·69	0·59	0·78	0·50	0·74	0·73	0·94	0·25	0·47	0·64	2·44	1·15
CaO	0·50	0·12	0·15	0·40	0·09	0·70	0·54	0·46	0·60	0·60	0·40	3·11	0·78
Na_2O	0·79	0·59	0·89	0·58	0·48	0·38	0·43	0·15	0·38	·019	0·51	1·30	0·41
K_2O	1·14	0·97	1·28	2·11	0·52	1·38	1·21	2·91	1·49	3·11	1·48	3·24	3·16
H_2O+	6·60	5·61	5·80	6·30	7·06	6·56	6·33	5·61	5·47	6·09	6·33	5·00	0·81
H_2O-		2·44	4·22	3·78	3·84	4·30	4·79	2·60	1·70	1·15	3·36		
P_2O_5	0·08	0·04	0·08	0·03	0·06	0·05	0·02	0·04	...	...	0·05	0·17	0·31
CO_2	nil	...	...	...	...	...	...	...	...	...	...	2·63	...
SO_3	...	Tr.	Tr.	0·27	0·11	0·06	0·04	nil	...	...	0·11	0·64	...
S	...	...	...	...	...	...	...	...	...	...	...	...	7·29
BaO	...	Tr.	0·04	0·38	0·05	Tr.	Tr.	...	...	...	0·12	...	...
SrO	...	nil	Tr.	Tr.	Tr.	nil	nil	...	...	...	Tr.	...	...
NaCl	...	0·15	0·20	Tr.	0·26	0·18	0·20	...	...	...	0·21	...	...
Organic	0·22*b*	nil	0·35	nil	0·70	nil.	nil	1·47*h*	nil	0·13	0·5	0·80	13·11
Misc.	...	...	...	...	...	...	...	...	...	...	...	...	...
	100·00	100·13	100·36	100·10	100·02	100·30	100·25	100·00	100·35	100·50	100·21	99·95	102·90*i*

1. " Clay-shale ".—1¼ m. west of Auburn. *Ann. Rep. Mines Dept. N.S.W.*, 1914, p. 216. Analysis No. 4378.
2. " Clay-shale ".—Shannon's Pit, Duck Creek, Auburn. Mines Dept. N.S.W. An. No. 3936.
3. " Clay-shale ".—Trenholmes Pit, Mary Street, Auburn. Mines Dept. N.S.W. An. No. 3937.
4. " Clay-shale ".—Sherwood Brick and Tile Works, Auburn. Mines Dept. N.S.W. An. No. 3938.
5. " Clay-shale ".—Sherwood Brick and Tile Works, Auburn. Mines Dept. N.S.W. An. No. 3939.
6. " Clay-shale ".—Goodlet and Smith's Quarry, Granville. Mines Dept. N.S.W. An. No. 3940.
7. " Clay-shale ".—Goodlet and Smith's Quarry, Granville. Mines Dept. N.S.W. An. No. 3941.
8. " Clay-shale ".—Concord. *Ann. Rep. Mines Dept. N.S.W.*, 1912, p. 195. An. No. 2161.
9. " Micaceous shale (light coloured) ".—Rouse Hill, Parramatta. *Ibid.*, 1899, p. 204. An. No. 4534.
10. " Micaceous shale (light coloured) ".—Rouse Hill, Parramatta. *Ibid.*, 1899, p. 204. An. No. 4535.
11. Average, 1–10.
12. Average shale.—*U.S. Geol. Surv. Bull.* 770, 1924, p. 34.
13. Black shale.—Dry Gap, U.S.A. *U.S. Geol. Surv. Bull.*, 770, 1924, p. 552. Includes 3·32 hydrocarbons. Analyst, L. G. Eakins.

a Including any TiO_2 present.
b Organic plus undetermined.
c $\left.\begin{array}{ll}\text{Free } SiO_2 & = 33\cdot60 \\ \text{Combined } SiO_2 & = 32\cdot20\end{array}\right\}65\cdot80.$
d $\left.\begin{array}{ll}\text{Free } SiO_2 & = 31\cdot45 \\ \text{Combined } SiO_2 & = 31\cdot34\end{array}\right\}62\cdot79.$
e $\left.\begin{array}{ll}\text{Free } SiO_2 & = 34\cdot90 \\ \text{Combined } SiO_2 & = 26\cdot60\end{array}\right\}61\cdot50.$
f $\left.\begin{array}{ll}\text{Free } SiO_2 & = 33\cdot94 \\ \text{Combined } SiO_2 & = 27\cdot80\end{array}\right\}61\cdot74.$
g $\left.\begin{array}{ll}\text{Free } SiO_2 & = 33\cdot08 \\ \text{Combined } SiO_3 & = 28\cdot88\end{array}\right\}61\cdot96.$
h Organic plus undetermined.
i Less O = S; total becomes 100·17.

Analyses of shales from the Ashfield Shale have been recorded and for convenience have been divided into analyses of shale less than 100 feet above (Table 2) and more than 100 feet above (Table 3) the Hawkesbury Sandstone.

The average analysis for each table is very similar and appears to be a normal shale by comparison with the analysis (Table 3, No. 12) of the average shale of Clarke. Organic matter is almost always present but not to the extent of the analysis (Table 3, No. 13) of a black shale from Dry Gap, U.S.A. The black colour so typical of the Ashfield Shale is partly due to this organic matter but the rather high total iron content, together with some FeS_2, would account for the dark colour. The main point of difference from the average shale analysis is the almost universal preponderance of MgO over CaO—a state of affairs more in keeping with Pettijohn's (1949, p. 273) views for the normal shale. In general the CaO content is low and no analysis would fall under the category of a calcareous shale. A cone-in-cone calcareous shale does exist as well as calcite fillings of sub-vertical joints and cavities, so it appears that some horizons, at least, are more calcareous than the analyses would suggest.

Preliminary work has indicated that two horizons, characterized by a particularly unusual lithologic type, may be recognized. Future work could profitably be directed to a more detailed examination of their vertical and horizontal stratigraphic extent for possible use as marker horizons.

The Cone-in-cone Shale.—A band of calcareous cone-in-cone shale occurs in the floor of the Ashfield Brickworks Quarry, about 50 feet below the ground surface and approximately 100 feet above the top of the Hawkesbury Sandstone. The thickness is rather irregular but never exceeds 6 inches. The cones are of the usual type with the apices vertical to the bedding.

TABLE. 4

Analyses of Calcareous Members of the Ashfield Shale.

Type.	Locality.	Reference.	Soluble Residue.	Insoluble Residue.	
			Per cent.		Per cent.
Calcareous cone-in-cone shale.	Picton district	Sach (1892)	21·2	$CaCO_3$:	67·54
				Fe_2O_3 :	4·14
				$MgCO_3$:	0·70
				H_2O :	3·1
Calcareous clay-shale ...	5 miles from Picton towards The Oaks.	*Ann. Rep. Dept. Mines, N.S.W.*, 1906, p. 182.	78·18	$CaCO_3$:	5·46
				Fe_2O_3 + Al_2O_3 :	7·0
				MgO + Undetermined :	2·16
				H_2O :	7·20

A similar occurrence was described by Sach (1892) from the "upper course of the Picton Creek". The locality is not well defined but it is most probably comparable in stratigraphic position with the Ashfield locality. An insoluble residue test showed the residue to be mostly fine sand particles mixed with clay matter. Table 4 gives a partial analysis of the soluble portion.

The Mottled Sideritic Mudstone.—Between 0 and 50 feet above the base of the Ashfield Shale there is a zone formed by several bands of a hard, black sideritic mudstone with a peculiar light-coloured mottling. The cause of the mottling is not apparent, but it may be due to a concentration of clay matter about a number of centres. Several bands, from 3 to 6 inches thick, make up the zone and are interbedded with the normal black shale of the Ashfield Shale.

The zone has been recorded from a wide area; specimens have been collected from Mortdale Brick Quarry (Sydney 083027), road cutting on Mount Hunter-High

Range road (Camden 604888), railway cutting on Picton-Thirlmere loop (Camden 595790), shallow quarry on Douglas Park-Cordeaux Dam road (Camden approx. 723728), road cutting on Werombi road (Camden 612993) and from along the Burragorang Valley-The Oaks road.

It seems likely that the zone will prove very useful as a marker horizon for further detailed stratigraphic work on the Ashfield Shale.

Thickness.—The average thickness of the Ashfield Shale is 200 feet. A minimum of 150 feet and a maximum of 210 feet would cover all known measurements.

Palaeontology.—In common with black shale associations in world-wide occurrences, fossils are comparatively rare in the sequence. Only a few *Phyllotheca* fragments have been collected during this work but previous records have been made of other forms of plants and animals. Some of the old identifications and names may be viewed with some suspicion but, for completeness, are included in this list.

Flora.

Etheridge (1889): *Cycadopteris scolopendrina.*

Tillyard (1916): *Thinnfeldia, Sphenopteris, Cladophlebis, Macrotaeniopteris, Oleandridium, Taeniopteris, Podozamites, Baiera.*

Fauna.

Lamellibranchia: An assemblage of rather small freshwater lamellibranchs was described by Etheridge (1888) from the basal beds of the Ashfield Shale and the passage beds with the Hawkesbury Sandstone at Surry Hills, Waterloo, and the railway cutting at the north end of the Gibraltar Tunnel (Mittagong 417435). *Unio? wianamattensis, Unio dunstani* and *Unionella bowralensis* were described and named. After an inspection of the type material, Mr. D. F. McMichael of the Australian Museum has reported: "The fossil lamellibranchs were described as belonging to the genera *Unio* and *Unionella*, the latter having doubtful affinities with the family Unionidae. Present-day classification of the freshwater mussels of the world allows four distinct families with numerous sub-families. The genus *Unio* is confined to recent specimens from England and Europe. The true generic relations of the group are obscure but most of the species of *Unio* described by Etheridge seem to definitely belong to the freshwater mussels. The form *Unionella bowralensis* seems to be more closely related to *Unio wianamattensis* while the *Unio dunstani* has rather different affinities and probably represents a distinct genus."

Isopoda: Chilton (1917) described a freshwater form *Phreatoicus wianamattensis* from the basal beds of the Ashfield Shale at Newtown.

Insecta: Tillyard (1916) recorded an insect assemblage from the basal beds at St. Peters: *Notoblattites subcostalis, Mesotitan giganteus, Elaterites wianamattensis, Metrorhynchites sydneiensis, Etheridgea petricia, Mesorhynchophora dunstani.*

Amphibia: A well preserved specimen of *Cyclotosaurus* was found at St. Peters and is the only complete stereospondylous labyrinthodont known. *Bothriceps* and *Mastodonsaurus* have also been recorded.

Fish: Smith-Woodward (1908) described a fish fauna from the basal beds of the Ashfield Shale, less than 100 feet above the Hawkesbury Sandstone at St. Peters. Two distinct faunas occurring in two different host rock-types were described. A. "From dark indurated shale" (probably one of the sideritic mudstone bands): *Pleuracanthus parvidens, Sagenodus laticeps, Palaeoniscus crassus, Elonichthys armatus, Elonichthys semilineatus, Myriolepis pectinata, Elpisopholis dunstani, Platysomus* sp., *Acentrophorus* sp. B. "From soft grey shale or mudstone" (the normal black shale type): *Palaeoniscus antipodeus, Semionotus formosus, Cleithrolepis granulatus, Pholidophorus australis.*

Age.—It is an important observation that the fossils listed are confined to the basal 100 feet of the Ashfield Shale while the other seven formations of the approximately 800 feet thick Wianamatta Group have no recorded fossils. Attempts to fix the age of the Group on the recorded fossils are based on insufficient evidence and only the age of the fossiliferous basal beds of the Ashfield Shale can be derived. From this, David's (1950) statement "the fossil evidence shows that these (the Wianamatta Series) are Upper . . . Triassic" cannot be applied to the whole of the Wianamatta Group. The evidence would suggest, however, that at least the basal parts of the Ashfield Shale are probably Upper Triassic.

Relation to Underlying Formation.—The Ashfield Shale lies directly upon the Hawkesbury Sandstone, the junction usually being described as showing evidence of contemporaneous erosion. The general relation seems rather to be transitional with the typical massive orthoquartzites of the Hawkesbury Sandstone giving way, through a series of passage beds, to the black shales of the Ashfield Shale.

The passage beds, varying in thickness between 0 and 20 feet, with an extreme thickness of approximately 50 feet as in the Gib Tunnel cutting (Mittagong 417435), consists of alternating black shale and sandstone bands and lenses of varying thickness. The shales are black and are comparable with the normal type Ashfield Shale and also very similar to the bands and lenses of black shale occurring lower down in the Hawkesbury Sandstone sequence itself. The sandstones of the passage beds are generally reminiscent of the orthoquartzites of the Hawkesbury Sandstone although finer grained and almost always calcareous. A similar thickening of the passage beds is to be found in other areas of the Mittagong sheet.

The boundary between the Wianamatta Group and the Hawkesbury Sandstone, where passage beds occur, has been fixed at the top of the uppermost sandstone band in the transitional zone. The passage beds are considered with the Hawkesbury Sandstone. The boundary is not placed arbitrarily, but has a genetic significance in as much as: (1) the Ashfield Shale so defined is a lithologically homogeneous shale formation, and (2) the black shale of the passage beds does allow comparison with the shale lenses in the Hawkesbury Sandstone while no sandstones of that type are found in the true sequence of the Wianamatta Group.

Because of the lithologic similarity of the normal black Ashfield Shale and shale lenses in the Hawkesbury Sandstone, some of the isolated thin outcrops of shale referred to in the maps as Ashfield Shale may actually be shale lenses within the Hawkesbury Sandstone. Differential thermal analysis of the shales (Ferguson and Hosking, 1953) has indicated a means of separating Ashfield Shale and shale from the Hawkesbury Sandstone. Preliminary work suggests that shale outcrops around French's Forest and Heathcote (shown as Ashfield Shale?) are rather referable to the shale in the Hawkesbury Sandstone.

(ii) *Minchinbury Sandstone.*

Name.—The Minchinbury Sandstone derives its name from the district and trig. station Minchinbury (Liverpool 827244) about 4 miles east of St. Marys along the Great Western Highway. Minchinbury is also the name of a vineyard in the area owing its existence to the calcareous soil provided by the rock type of the formation.

Type Area and Section.—Willan (1923) recognized the formation and put it in his Middle Stage. David (1950) referred it to his Middle Stage and compared it incorrectly with the sandstones of the Razorback Range.

The type area, with the best natural outcrops, is in the Minchinbury district described above. The best sections are figured in the logging of the Water Board bores (Figures 9, 10). These are the type sections, the cores being quite well preserved at the Water Board's depot at Potts Hill.

Other Localities.—The outcrop of the Minchinbury Sandstone is generally very weak and is only apparent when excavations and bores have revealed it in section. This fact, together with the thick soil cover, makes accurate mapping of the outcrop very difficult between areas of known occurrence. The comparatively minor thickness has proved difficult to show on the inch-to-mile scale of the maps and the width of outcrop is, in general, rather arbitrary.

Sections are shown in road cuttings in several districts: Grose Vale-Kurrajong (Windsor 643516 and 649532); Kellyville (Windsor 974329); Rogans Hill (Broken Bay 017324); Epping (Sydney 074261); Bankstown Brick Quarry (Sydney 024086); Pendle Hill (Liverpool 943230); Bonnyrigg (Liverpool 867137); Menangle (Camden 714842); Brownlow Hill (Camden 644981); Gingenbullen (Moss Vale 309344); and other localities.

Lithology.—The sedimentary petrology of the sandstone formations is discussed in more detail below (p. 194). The discussion here is limited to a description of the main lithologic characteristics.

The Minchinbury Sandstone, in common with the other sandstones, is more closely allied to the graywacke types; however, the term "sandstone" is retained in the formational name as it best describes the field occurrence of the rock. In other outcrops it resembles a grey, compact calcareous marlstone, probably a transitional type to the associated shales. The sandstone is typically calcareous and secondary calcite veins often occur. The section is normally quite massive but some sections are split by dark shale lenses. Fragments of the shale (often calcareous), angular pieces of chert, ironstone and sideritic nodules are often seen in the sandstone. Current bedding, usually from a northerly direction, and ripple marks also occur.

The fresh sandstone is characteristically blue-grey but rapidly weathers to a buff colour. The exposed sections in road cuttings have a characteristic tendency to spheroidal weathering and it spalls easily.

Thickness.—The usual thickness of the massive section varies between 10 and 20 feet. A maximum thickness of 35 feet was measured in Bore 15N of the City Tunnel Series (Figure 9) in which the massive sandstone was very much broken by black shale bands.

Palaeontology.—Plant fragments, apparently of *Phyllotheca,* are abundant along bedding planes in the massive sandstone as well as the associated shale lenses. No specimens have been recorded from the formation.

An important microfossil assemblage of algae (*Globochaete alpina, Eothrix alpina*), foraminifera (cf. *Trochammina, Spiroplectammina, Fibrosphaerae*) and ostracoda has been recorded (Lovering, 1953).

Age.—Chapman (1909), on the evidence of an assemblage of ostracods and foraminifera described by him, considered that there was an indication of "a curious intermingling of Rhaetic and Lower Jurassic types, with others more properly referable to the Upper Palaeozoic of Europe". In view of the uncertainty of these identifications (Lovering, 1953), however, little reliance can be placed on these microfossils alone as an indication of a definite Jurassic age. The problem has other features which have been discussed above (p. 171).

Relation to Underlying Formation.—The Ashfield Shale is related to the Minchinbury Sandstone by means of a marked change in lithology. The boundary is quite definite and is defined at the appearance of the first sandstone in the sequence.

(iii) *Bringelly Shale.*

Name.—The outcrop of the shale formation defined as the Bringelly Shale has its greatest geographic extent in the area around Bringelly (Liverpool 730070). It is from this town that the geographic name is taken.

Type Area and Section.—The Bringelly Shale has its type area around the Bringelly district but even here the poor outcrop and low relief of the area preclude the occurrence of any complete natural section. The sequence logged in the Water Board's City Tunnel exploratory bores (Figures 9 and 10), although taken from poorly preserved cores, is used as the type section.

Other Localities.—This formation has extensive outcrops in the Sydney (around the western suburbs), Liverpool and Camden Sheets.

Small, isolated outcrops also occur capping Box Hill (Windsor 643516), Rogans Hill (Broken Bay 017324) and Gingenbullen (Moss Vale 309344).

Lithology and Petrology.—The predominant lithologic type is shale. When unweathered the shale is dark and resembles the black shale of the Ashfield Shale although it lacks the sideritic mudstone bands characteristic of that formation. Usually, and more particularly when weathered, the shale is a typical olive-green colour. Impure coal bands and lenses and iron oxide concretions have been recorded in the shales.

The Bringelly Shale differs from the Ashfield Shale in having a subsidiary sandstone lithology. The sequence has many sandstone bands and lenses varying from 1 inch to 5 feet in thickness, with a tendency for the thicker bands to be concentrated at the top. The horizontal extent of the bands is very limited and most thin out very rapidly. As a type, these sandstones are identical with those of the other more massive formations and related to the graywacke-types (see p. 188).

TABLE

Analyses of Bringelly Shale.

	1	2	3	4
SiO_2	74·30	65·97	70·13	77·8
TiO_2	0·44	0·70	0·57	0·6
Al_2O_3	13·65	20·59	17·12	9·5
Fe_2O_3	0·60	Tr.	0·60	0 9
FeO	1·34	1·08	1·21	2·6
MnO	0·10	...	0·10	0·2
MgO	0·64	0·55	0·59	1·6
CaO	0·46	0·11	0·28	1·2
Na_2O	1·00	0·88	0·94	2·0
K_2	1·48	2·13	1·80	1·5
H_2O+	3·68	5·13	4·40	1·6
H_2O-	1·32	1·60	1·46	0·1
P_2O_5	0·05	0·16	0·11	0·2
CO_2	...	...	...	0·5
S	...	...	...	0·1
Organic	0·94*a*	1·47	1·20	0·2
	100·00	100·37	100·18	100·4

a. Organic plus undetermined (trace of soluble chlorides detected).

1. "Clay-shale".—Lion Tile Quarry, Liverpool Road, Enfield. Mines Dept. N.S.W. Analysis No. 1679/1912.
2. "Clay-shale".—Liverpool Road, South Strathfield. *Ann. Rep. Mines Dept. N.S.W.*, 1912, p. 195. An. No 2064.
3. Average 1 and 2.
4. Average of three subgraywackes. Pettijohn (1949), p. 256.

Table 5 gives analyses of two samples of Bringelly Shale. A comparison with the analyses of Ashfield Shale (Tables 2 and 3) shows some similarity save in one important regard—the predominance of ferrous over ferric iron. In this respect it suggests comparison with the average analysis of three subgraywackes (Pettijohn, 1949) given in the same Table. Although the Bringelly Shale analyses do show a rather smaller Na_2O than K_2O content, the similarity is sufficient to suggest that the shales are of comparable composition with the subgraywackes with which they are associated and, following from this, are actually the shale equivalents of the graywacke-subgraywacke sandstones.

The shales are quarried in several western suburbs of Sydney for brick and general ceramic manufacture.

Thickness.—The formation has a rather constant thickness around 200 feet.

Palaeontology.—No fossils have yet been recorded from this formation. Plant remains, probably of *Phyllotheca,* are very abundant in the shales and are also found in the sandstone bands.

Relation to Underlying Formation.—The rather massive Minchinbury Sandsone passes quite abruptly into the shales of the Bringelly Shale. Some evidence of contemporaneous erosion can be found, though very much localized at the contact.

The Camden Sub-group.

(i) *Potts Hill Sandstone.*

Name.—The formation defined as the Potts Hill Sandstone takes its name from a low ridge of Potts Hill (Sydney 030115) about 1 mile north of Bankstown, a suburb to the west of Sydney. The ridge owes its existence to the resistant outcrop of the sandstones.

Type Area and Section.—The type area and section is that of the Water Board quarry at Potts Hill (Sydney 028121). The quarry face varies between 20 and 25 feet but is an excellent section to illustrate the characteristic lateral variation from at least 25 feet of massive sandstone to sandstone very much broken by silty dark shale bands and lenses.

Other Localities.—The outcrop of the Potts Hill Sandstone forms the lowest of the three bench levels which mark the outcrop of the three major sandstone formations of the Upper Division. It is well shown in cuttings along the Hume Highway and other roads over the Razorback Range.

There are a number of other outcrops in the Liverpool and Camden Sheets. Good sections are often available in small quarries opened up in the sandstone at a number of localities in these sheets: Hoxton Park (Liverpool 833091) and Cecil Hills; Bringelly district (Liverpool 723033); Western side of Badgelly Trig. (Camden 783946); near Kelly Hill (Camden 780927); western side of Mount Annan (Camden 760903); Sugarloaf Hill (Camden 775875).

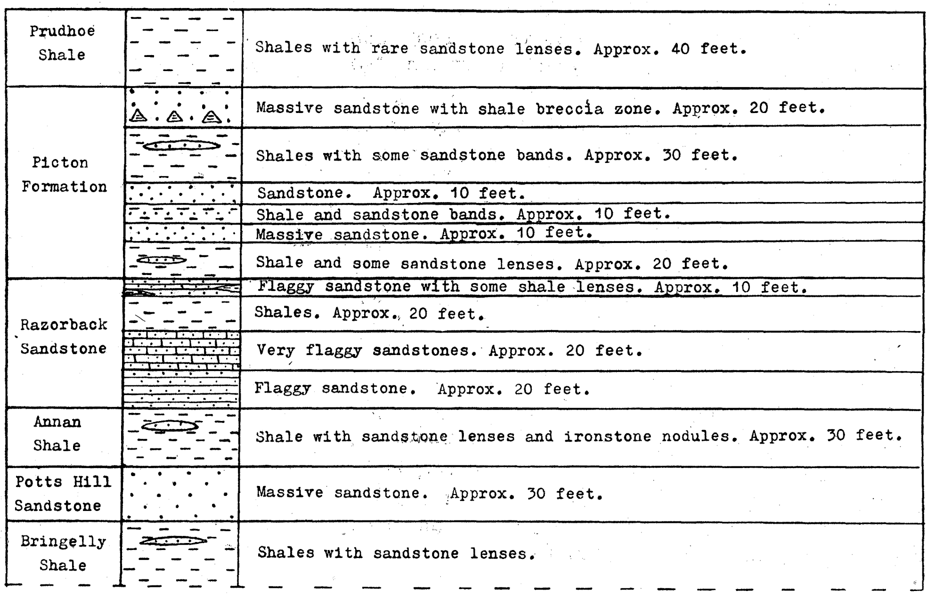
Lithology.—In the general case, the Potts Hill Sandstone is a massive formation of the graywacke-type sandstone characteristic of the Wianamatta Group. The type at Potts Hill is rather unusual in as much as it is considerably richer in quartz than the normal sandstone and is rather a feldspathic sandstone (see p. 196). All types are often calcareous and subvertical joints filled with secondary calcite are common.

Black and greenish shale lenses show in varying abundance throughout the section. Iron oxide and sideritic nodules, current-bedded layers (generally from a northerly direction) and spheroidal weathering (in the more massive outcrops) are commonly shown.

Thickness.—A maximum thickness of 40 feet has been observed on the Razorback Range section but 30 feet is an average measurement.

Palaeontology.—McCoy (1847) described a number of plants (*Gleichenites odontopteroides, Odontopteris microphylla, Pecopteris ? tenuifolia, Phyllotheca hookeri*) from "the fine sandstone at Clarkes Hill, near Cobbittee". The locality is rather doubtful and cannot be traced, but it seems likely that it refers to an outcrop of the Potts Hill Sandstone, probably one of the outcrops capping two hills to the east of Cobbitty and about 2 miles north of Narellan.

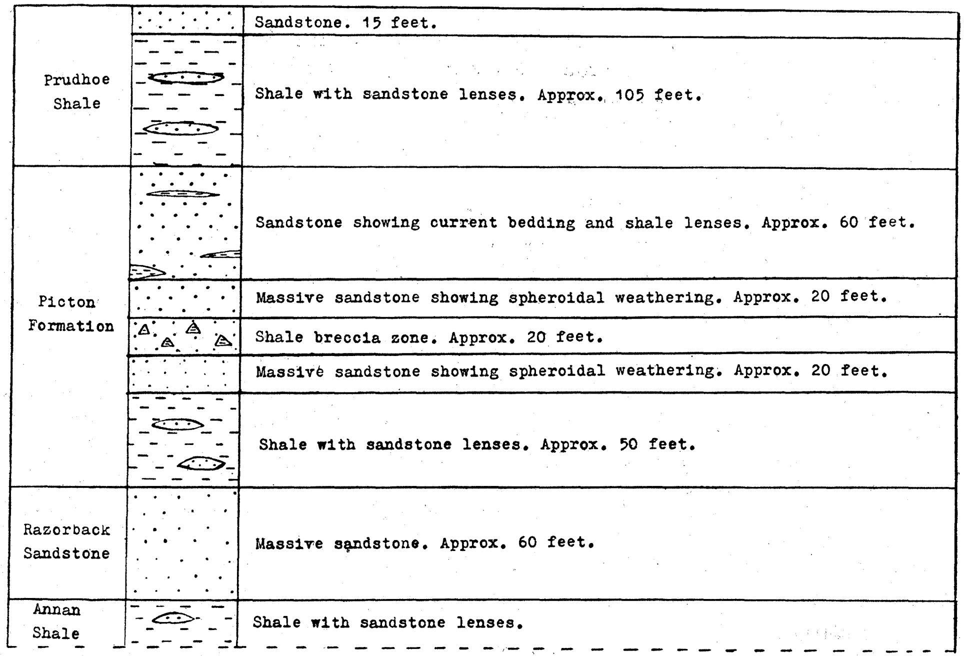
Relation to Underlying Formation.—The Bringelly Shale passes into the Potts Hill Sandstone through a small transitional zone of alternating sandstone and shale bands. The passage from the dominant shale formation to the massive sandstone is complete in less than 10 inches.



Prudhoe Shale	Shales with rare sandstone lenses. Approx. 40 feet.
Picton Formation	Massive sandstone with shale breccia zone. Approx. 20 feet.
	Shales with some sandstone bands. Approx. 30 feet.
	Sandstone. Approx. 10 feet.
	Shale and sandstone bands. Approx. 10 feet.
	Massive sandstone. Approx. 10 feet.
	Shale and some sandstone lenses. Approx. 20 feet.
Razorback Sandstone	Flaggy sandstone with some shale lenses. Approx. 10 feet.
	Shales. Approx. 20 feet.
	Very flaggy sandstones. Approx. 20 feet.
	Flaggy sandstone. Approx. 20 feet.
Annan Shale	Shale with sandstone lenses and ironstone nodules. Approx. 30 feet.
Potts Hill Sandstone	Massive sandstone. Approx. 30 feet.
Bringelly Shale	Shales with sandstone lenses.

Fig.3.Section along the Hume Highway on the South side of Razorback.

0 100 feet
Vertical Scale



Prudhoe Shale	Sandstone. 15 feet.
	Shale with sandstone lenses. Approx. 105 feet.
Picton Formation	Sandstone showing current bedding and shale lenses. Approx. 60 feet.
	Massive sandstone showing spheroidal weathering. Approx. 20 feet.
	Shale breccia zone. Approx. 20 feet.
	Massive sandstone showing spheroidal weathering. Approx. 20 feet.
	Shale with sandstone lenses. Approx. 50 feet.
Razorback Sandstone	Massive sandstone. Approx. 60 feet.
Annan Shale	Shale with sandstone lenses.

Fig.4 Section along the North side of the Old Razorback Road.

0 100 feet
Vertical Scale

(ii) *Annan Shale.*

Name.—The Annan Shale takes its geographical name from Mount Annan, parish Narellan, county Cumberland. (Camden 760903).

Type Area and Locality.—The type area is the Razorback Range and the type section is exposed along the Hume Highway on the south side of the Razorback Range. This section, of some 30 feet of dark and green shales with lenses and bands of graywacke-type sandstone, is shown in Figure 3.

Other Localities.—Other outcrops are to be found in the Liverpool Sheet, where the Annan Shale outcrops in the high country above the Cecil Hills Tunnel and again in the area to the south-west of Bringelly, and in the Camden Sheet where, besides the main outcrop in the Razorback Range, others less prominent occur as follows: north of Narellan (729975); Badgelly Trig. (783946); near Kenny Hill (780927); Mount Annan (760903); north-west of Mount Annan (745920); and Sugarloaf Hill (775875).

Lithology.—The normal section is of grey-green shales, rather dark when unweathered, and commonly with iron-oxide nodules and concretions.

Thickness.—The type section is 30 feet, but the formation shows a tendency to variable thickness. The northern side of the Hume Highway climb over Razorback shows another section in which the Annan Shale, still with the same lithology, reaches a maximum of about 120 feet though accurate measurements are impossible due to a cover of land-slip and scree material. This is a maximum measurement and an average thickness of 40 feet has been derived from a consideration of all sections.

Palaeontology.—No fossils have been recorded from this formation but *Phyllotheca*-like fragments are common. A zone in which plant fragments are extremely abundant occurs along the northern climb of the Hume Highway over Razorback.

Relation to Underlying Formation.—The Potts Hill Sandstone passes rather rapidly into the Annan Shale through a distinct lithologic break. Passage beds, less than 10 inches thick, of alternating shales and sandstone bands mark the junction—the shale bands becoming more prominent towards the Annan Shale.

(iii) *Razorback Sandstone.*

Name.—The Razorback Range (parish Picton, county Camden) is a prominent geographic feature crossed by the Hume Highway about 7 miles south of Camden. This formation takes its geographic name from this feature.

Type Area and Section.—The type area is the Razorback Range and the type section is shown in cuttings along the northern climb of the Hume Highway over the Razorback Range (Camden 691825) where 60 feet of massive graywacke-type sandstone is exposed.

Other Localities.—The outcrop of the Razorback Sandstone is generally marked by the presence of the distinct second physiographic bench-level. This level has been recognized in the type area at Razorback but also in the outcrops in both the Liverpool and Camden Sheets.

Liverpool Sheet: Isolated outcrops occur around Cecil Hills and Bringelly.

Camden Sheet: Scattered outcrops cap various geographic features in the area: north of Narellan (729975); Badgelly Trig. 783946); near Kenny Hill (780927); Mount Annan (760903); north of Mount Annan (745920); Sugarloaf Hill (775875).

Lithology.—In general the formation follows the lithologic pattern of the type section—60 feet of massive graywacke-type sandstone with some very thin (less than 12 inches) and horizontally restricted dark shale lenses. Current bedding (with a southerly dip), iron-oxide concretions and calcite veins are common.

Another section (Figure 3) exposed in the cuttings along the south side climb of the Hume Highway over Razorback shows the shale bands becoming much more prominent although still subsidiary to the essentially sandstone lithology.

Thickness.—The formation has a rather consistent thickness of between 60 and 70 feet.

Palaeontology.—Plant fragments are abundant in both the sandstone and associated shales but no recorded occurrences are available.

Relation to Underlying Formation.—The Annan Shale gives way to the Razorback Sandstone through a rather definite lithologic break. Generally there is a zone of several thin sandstone bands alternating with shale bands before the rather massive sandstone of the Razorback Sandstone becomes dominant.

(iv) *Picton Formation.*

Name.—The town of Picton, parish Picton, county Camden (Camden 608795), by reason of its close geographic association with the outcrop of the formation has been chosen as the geographic name.

Type Area and Section.—The type area is the Razorback Range and the type section is exposed along the Hume Highway on the south side of Razorback Range (approx. Camden 664812) and shown in Figure 3.

Other Localities.—The outcrop of the formation is characterized by the final (third) physiographic bench-level first recognized in the type area. The level may be traced to another outcrop in the Liverpool Sheet where the Picton Formation caps a hill to the south-west of Bringelly (Liverpool 694017).

Lithology.—This formation differs from the other formations defined in the Wianamatta Group in that its lithology cannot be conveniently described by a single lithologic term and, in accordance with the Australian Code of Stratigraphic Nomenclature (Raggatt, 1950), the designation "Picton Formation" is appropriate.

The variability in the sequence is apparent from Figures 3 and 4 in which two sections of the formation, including the type section, are figured. Shales and graywacke-type sandstones alternate and intercalate in a rather haphazard way although it already seems apparent that a further division into constituent members will be possible. The sequence does show sufficient regularity to enable the formation to be defined: (*a*) the lower part of the section is predominantly shale, differentiating the Picton Formation from the underlying massive Razorback Sandstone, and (*b*) the upper portion is invariably a massive sandstone between 20 and 60 feet thick. The resistant outcrop of this member is responsible for the characteristic third bench-level.

The section in the vicinity of Peach Tree Bend (Camden 663832) on the north climb of the Old Razorback Road (see Figure 4) is complicated by local warping and soil cover but an important shale breccia zone, about 15 feet thick, is evident. Dark shale fragments, usually sub-angular, are very closely packed in a matrix of the normal greenish graywacke-type sandstone. This shale breccia zone is rather similar to others described from the Hawkesbury Sandstone (Osborne, 1948) and may, on more intensive mapping, become an important marker horizon. Preliminary work suggests that this may be the case.

The massive sandstone sections commonly show local current-bedding layers with dips generally to the south, while any section that has been exposed for some time exhibits a type of spheroidal weathering. In other zones the sandstones become rather flaggy and shale lenses creep in the section.

The shale zones, themselves associated with minor sandstone lenses, are dark when fresh but rapidly change to green-grey on exposure.

Thickness.—The type section is about 100 feet thick but this measurement does vary considerably in other sections. The Peach Tree Bend section, though difficult to record accurately, is around 160 feet while other sections have thicknesses less than 100 feet.

Palaeontology.—Poorly preserved plant fragments are common through the sequence.

Relation to Underlying Formation.—In the definition of the Picton Formation it was pointed out that the basal beds were invariably shale types. These shales lie with a rather sharp lithologic break on the massive sandstone of the Razorback Sandstone; little in the nature of a transitional zone is apparent.

(v) *Prudhoe Shale.*

Name.—Mount Prudhoe is the name of the highest point of the Razorback Range, being the hill marked by the trig. station 1071 feet in portion 110, parish Picton, county Camden (Camden 663829). Prudhoe is taken as the geographical name for the Prudhoe Shale, the last existing formation of the Wianamatta Group.

Type Area and Section.—The type area is the Razorback Range but the type section is difficult to define. The thickest section (under Mt. Prudhoe) has only the lower beds exposed in the Old Razorback Road cuttings while the upper part is covered by soil. A composite section has been drawn from the observations made and is shown in Figure 4.

Other Localities.—The Prudhoe Shale is almost confined to the higher parts of the Razorback Range and even in this area the greater portion of the outcrop is restricted to thin shale beds capping the upper bench-level marking the top of the Picton Formation. One very isolated occurrence, too small to be apparent on the Liverpool Sheet, forms a thin capping of the Picton Formation to the south-west of Bringelly (Liverpool 694017).

Lithology.—The exposed beds of the section are predominantly of the usual green-grey shale with some associated graywacke-type sandstone bands and lenses. Mt. Prudhoe itself appears to be capped by a rather massive sandstone band, probably 20 feet thick.

Thickness.—With no upper limit to the formation, only a measurement of the thickest section (120 feet under Mt. Prudhoe) can be given.

Palaeontology.—*Phyllotheca*-like plant fragments are common in the section.

Relation to Underlying Formation.—The shales of the Prudhoe Shale lie conformably on the upper massive sandstones of the Picton Formation.

SEDIMENTARY PETROLOGY AND PETROGRAPHY OF THE SANDSTONE FORMATIONS.

The earliest writers on the Wianamatta Group realized the essential difference between the sandstones of the Group and those of the Hawkesbury Sandstone. The Hawkesbury types were always referred to as white, coarse-grained and porous with an abundance of glistening quartz grains. On the other hand the rather unusual Wianamatta types are green to buff coloured, fine-grained and compact with a dull lustre; they were usually described as calcareous or tuffaceous sandstones.

It was an important step to realize this inherent distinction, the genetic significance of which has only just become apparent.

The typical rock-type of the Hawkesbury Sandstone is a medium to coarse grained quartz-rich sandstone—the characteristic "orthoquartzite" of Pettijohn (1949) and the "pure quartz sandstone" of Krumbein and Sloss (1951). Some physical characteristics shown by the Hawkesbury Sandstone, and typical of the orthoquartzites are: (*a*) abundance of well sorted and rounded quartz grains with rare feldspar set in a matrix of clay, iron oxide and/or calcareous material; (*b*) stable types (tourmaline, zircon, rutile, ilmenite, etc.) predominant in the heavy mineral assemblages (Whitworth 1931); (*c*) consistency of the lithologic type; (*d*) abundance of current bedding; (*e*) rarity of fossils.

TABLE 6.

Analyses of Hawkesbury Sandstone.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2 ...	78·75*a*	82·05*d*	88·85*e*	86·75*f*	84·75*g*	91·44	90·52	81·98	85·19	74·28	87·50	79·28	79·12	79·66	83·58	92·3
TiO_2 ...	0·51	0·35	0·66	0·69	0·36	0·52	0·30	0·05	0·68	0·55	0·22	0·52	0·75	0·45	0·47	0·0
Al_2O_3 ...	10·93	9·20	6·01	6·12	8·16	4·41	4·95	9·90	6·16	11·59	7·41	7·96	8·44	9·43	7·9	1·4
Fe_2O_3 ...	0·10	0·50	0·10	0·30	0·41	0·50	0·35	0·30	0·50	0·40	0·60	1·40	0·70	0·10	0·45	0·2
FeO ...	2·48	1·92	1·37	1·92	1·56	0·18	0·18	2·07	1·71	2·79	0·09	2·88	3·42	3·00	1·83	0·3
MnO ...	0·08	0·05	0·04	0·06	0·04	nil	<0·01	...	Tr.	Tr.	Tr.	0·02	0·06	...	0·05	...
MgO ...	0·52	0·39	0·25	0·36	0·36	0·18	0·17	0·11	0·36	0·81	0·10	0·41	0·59	0·56	0·37	0·1
CaO ...	0·16	0·22	0·08	0·20	0·18	0·34	nil	0·15	0·40	1·14	nil.	0·32	0·14	0·64	0·28	3·0
Na_2O ...	0·21	0·16	0·01	0·15	0·06	0·04	0·19	0·18	0·15	0·36	0·31	0·62	0·66	0·23	0·24	0·1
K_2O ...	1·58	1·50	0·81	1·14	1·50	0·60	1·11	1·45	1·09	1·75	0·36	2·39	2·22	2·16	1·4	0·1
H_2O+ ...	2·50	1·80	1·05	0·98	1·41	1·57	2·10	8·56	1·64	2·94	2·96	2·46	1·74	1·52	1·86	0·2
H_2O- ...	0·94	0·68	0·33	0·40	0·49	0·25	0·24		0·36	0·80	0·24			0·60	0·48	
P_2O_5 ...	*b*	*b*	*b*	*b*	*b*	0·01	0·08	...	Tr.	...	0·05	Tr.	Tr.	...	0·05	...
CO_2 ...	1·61	1·34	0·84	1·29	1·16	...	...	1·14	1·07	3·03	0·04*h*	1·97	2·34	1·94	1·48	2·30
SO_3 ...	Tr.	Tr.	Tr.	Tr	Tr.	nil	nil.	nil	Tr.	0·06	0·03	...	...	...	0·05	...
Cl ...	Tr.	Tr.	Tr.	Tr.	Tr.	nil	Tr.	Tr.	Tr.	Tr.	0·02	Tr.	Tr.	...	0·02	...
Organic ...	Tr.	Tr.	Tr.	Tr.	Tr.	...	Tr.	...	...	...	...	...	...	...	Tr.	...
Misc. ...	*c*	*c*	*c*	*c*	*c*	...	...	...	...	...	...	...	...	...	...	...
	100·37	100·16	100·40	100·36	100·44	100·04	100·19	99·89	100·31	100·50	99·93	100·23	100·18	100·29	100·23	100·0

1. Sandstone.—Green's Quarry, Annandale. *Ann. Rep. Mines Dept. N.S.W.*, 1902.
2. Sandstone.—Saunders' Quarry, Pyrmont. *Ibid.*, 1902, p. 122.
3. Sandstone.—Purgatory Quarry, Pyrmont. *Ibid.*, 1902, p. 122.
4. Sandstone.—Ryan's Quarry, Waverley. *Ibid.*, 1902, p. 122.
5. Sandstone.—Phippard's Quarry, Waverley. *Ibid.*, 1902, p. 122.
6. Iron-stained sandstone.—Botany Brickworks. *Ibid.*, 1915, p. 197. An. No. 2138.
7. Kaolinized sandstone.—Botany Brickworks. *Ibid.*, 1915, p. 197. An. No. 2139.
8. " Sydney sandstone ".—Undercliffe Quarry, Tempe. *Ibid.*, 1905, p. 165. Analyst, H. P. White. An. No. 4607.
9. Sandstone.—Guile Quarry, Botany. *Ibid.*, 1906, p. 182. Analyst, W. A. Greig. An. No. 1225.
10. Sandstone.—Cataract River. *Ibid.*, 1906, p. 182. Analyst, W. A. Greig. An. No. 2753.
11. Sandstone.—7 miles east of Mt. Werong. *Ibid.*, 1914, p. 217. Analyst, H. P. White. An. No. 3739.
12. Sandstone.—Core from Diamond Drill Bore, North Bondi Quarry. *Ibid.*, 1922, p. 103. An. No. 96.
13. Sandstone.—Core from Diamond Drill Bore, North Bondi Quarry. *Ibid.*, 1922, p. 103. An. No. 97.
14. Sandstone.—Gosford Freestone Quarry. *Ibid.*, 1926, p. 104. Analyst, W. A. Greig. An. No. 3380.
15. Average, 1–16.
16. Average of 7 " orthoquartzite type " sandstones. Pettijohn, 1949, p. 241.

a $\left.\begin{array}{l}\text{Free SiO}_2 = 66{\cdot}35\\ \text{Combined SiO}_2 = 12{\cdot}40\end{array}\right\}78{\cdot}75.$

b Included in Al_2O_3.

c Analyses 1–5 contained a fair quantity of $FeCO_3$.

d $\left.\begin{array}{l}\text{Free SiO}_2 = 72.70\\ \text{Combined SiO}_2 = 9{\cdot}35\end{array}\right\}82{\cdot}05.$

e $\left.\begin{array}{l}\text{Free SiO}_2 = 83{\cdot}55\\ \text{Combined SiO}_2 = 5{\cdot}30\end{array}\right\}88{\cdot}85.$

f $\left.\begin{array}{l}\text{Free SiO}_2 = 80{\cdot}50\\ \text{Combined SiO}_2 = 6{\cdot}25\end{array}\right\}86{\cdot}75.$

g $\left.\begin{array}{l}\text{Free SiO}_2 = 77{\cdot}20\\ \text{Combined SiO}_2 = 7{\cdot}55\end{array}\right\}84{\cdot}75.$

h + Organic matter.

Further similarity is shown in Table 6 in which the average of fourteen Hawkesbury Sandstone analyses is compared with Pettijohn's average of seven typical orthoquartzite analyses. The general agreement is marked, though the Hawkesbury Sandstone average does seem to have rather more clay cement which would account for the rather lower silica, higher alumina and higher MgO:CaO ratio. It is evident that as a lithologic type it is best described as an orthoquartzite.

The sandstones of the Wianamatta Group are also, with rare exceptions, lithologically consistent but the essential difference from the orthoquartzites of the Hawkesbury Sandstone is apparent even in hand-specimen, with colours varying from greenish to buff. The mineral grains show poor to medium sorting with grain-size variable between 0.1 and 0.2 mm. with occasional grains 0.3 mm. Most of the grains and fragments are angular with little or no orientation. The composition of the detrital mineral fraction is rather consistent. The minerals commonly present, together with percentage compositions determined with the Leitz integrating stage are:

Quartz: Angular and badly sorted grains vary in abundance between 10% and 20% with 15% as an average figure. One exceptional type from the Potts Hill Sandstone type locality had 50%. This quartz-rich type is confined to this one occurrence. Secondary (authigenic?) micro-mosaics of quartz occur in the matrix.

Feldspar: Both plagioclase and potash feldspars occur, although the plagioclase types are dominant. Sections are often quite fresh and were determined as soda-rich types, almost exclusively within the oligoclase range, in sections from all formations. The potash feldspars are always kaolinized but comparatively fresh microcline grains have been recognized in the Minchinbury Sandstone. The feldspar composition varies between 15% and 30% with about 20% as an average figure. Some of the exceptionally calcareous types have little or no feldspar. It seems very likely that the calcite has replaced and/or incorporated any feldspar originally present.

Siderite: Siderite grains and oolite-shaped aggregations are abundant in all the formations but are particularly abundant in the Minchinbury Sandstone. (Plate xii, figure 1.)

Glauconite: Scattered pellets of glauconite are found in all formations. All are length-slow and show olive-green → yellow-green pleochroism, medium relief and interference colours masked by the natural colour. Most sections show the glauconite replacing organic remains, often of ostracods.

Chlorite and *sericite* flakes are also found.

Rock fragments: Rock fragments, mostly sub-angular fragments of shaly material, vary between 5% and 20% of total constituents.

Iron-Oxide: Iron-oxide grains, mostly hematite varieties, are quite common. An exceptional type from the Minchinbury Sandstone near Menangle had 10% of hematite grains.

The matrix and cement comprises a considerable bulk of most sections varying between 25% and 60% of total constituents. The matrix may be of several types, any combination of which may comprise the total matrix of the rock.

Clay: A clay matrix is almost always present, varying between 10% and 50% of the rock.

Calcite: Calcite is always present, to a greater or less degree, in all sections. It can form anything up to 25% on an average, with many types from 25% to 60%. It is always interstitial and apparently of authigenic origin. Thin cracks and joints are often filled with calcite crystal aggregates.

Chlorite: Besides being of allogenic origin, some chlorite occurs as an authigenic mineral in the base commonly rimming, and apparently replacing, quartz grains (Plate xii, figure 3).

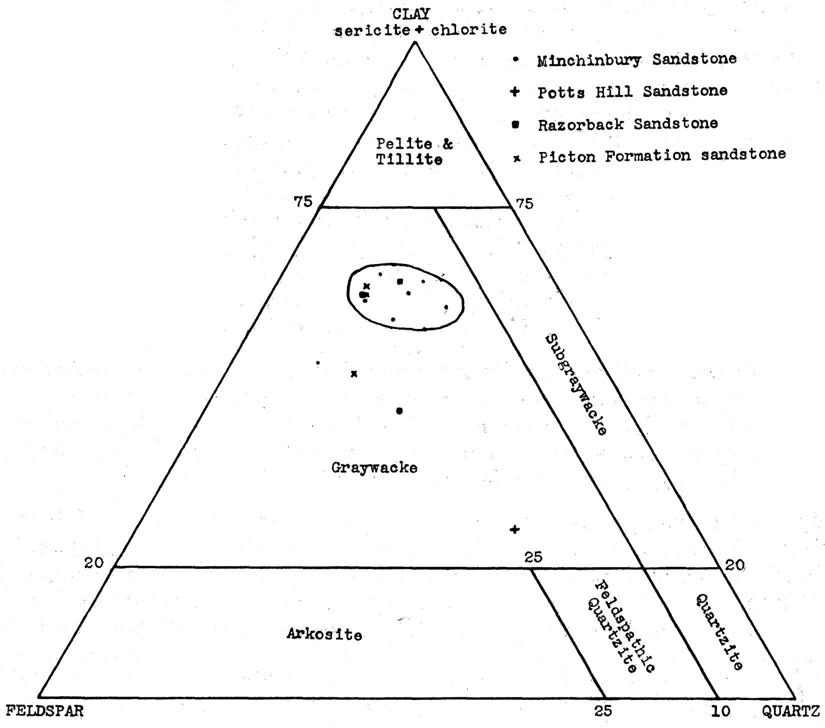


Fig. 5. Mineral composition of Wianamatta Group sandstone types plotted on Pettijohn's scheme.

A Classification of the Wianamatta Group Sandstones.

Plotting the detrital mineral composition on Pettijohn's tri-ordinate scheme (Figure 5) gives a field in which the greater majority of the analyses fall. The field lies in the top right-hand corner of the graywacke area and rather tending towards the subgraywacke area. Taking into consideration the general characteristics and lithologic association, it is intended in this discussion to use the term "graywacke-type sandstone" for the sandstones of the Group. The term is admittedly cumbersome but the fact that the rock type is not a typically high-rank graywacke, though it falls in the graywacke area, but shows tendencies towards the subgraywackes, is implied or at least suggested in the name.

For field description and the formational name, "sandstone" is still used, after careful consideration, as the all-embracing group name.

Some of the exceptional analyses outside the field are closer to the true graywackes. On the other hand a section of a Potts Hill Sandstone shows distinct relation to the fieldspathic quartzite area.

At this point, keeping in mind the problems met with in the identification of the Wianamatta Group sandstones, it is appropriate to consider:

The Graywacke Problem.

The group of sedimentary rocks known as the sandstones (or arenites, after Pettijohn) occupy an important position amongst the more common sedimentary lithologic types. In the literature, such terms as orthoquartzite, pure quartz sandstone, feldspathic sandstone, arkose, graywacke and subgraywacke have been applied to various members of the group. Of all these terms, graywacke has probably suffered most at the hands of careless workers and a confusing array of literature has arisen on the "correct" use of the term. Pettijohn (1949, p. 243-245) has given an excellent summary of this literature and concluded: ". . . graywacke is a petrographically distinct type of sandstone that is marked by its induration and dark colour. It is composed of large very angular detrital grains mainly quartz, feldspar, and rock fragments (mainly chert, phyllite, and slate). These grains are set in a prominent-to-predominant "clay" matrix which was, on low grade metamorphism, converted to a mixture of chlorite and sericite and partially replaced by carbonate."

A more rigid classification by Pettijohn, based on the mineralogical composition of the detrital fraction, gives the relation of the various members of the sandstone group (Figure 5). Such a scheme is extremely useful in the accurate classification of sandstone but it suffers to the extent that it presupposes an accurate determination of the clay, quartz and feldspar content of the rock.

Another problem to be overcome is the need for the further subdivision, on something more than arbitrary premises, of the comparatively large graywacke area. It is already becoming apparent that graywackes are not nearly as uncommon in the sedimentary record as was once thought. Indeed, as has been brought to light in this discussion, probably a large bulk of unusual types formerly described as tuffaceous sandstones are, in fact, graywacke types. From Figure 5 it is apparent that the usual type of Wianamatta Group sandstone lies within the graywacke field, but with definite affiliations with the subgraywacke field.

As it stands, then, the graywacke area by comparison with the other areas of the diagram is far too large for accurate definition of a lithologic type. However, any division at the present would lack precision and could only be attempted after a complete and exhaustive study of graywacke types from various occurrences. At the present time, without this information, it can only be suggested that there exists a basis for subdivision of the area into three parts. It seems a possible scheme that the fields be defined on the basis of the mineralogical composition of the three graywacke types characteristic of the tectotopes with which they are associated—geosynclinal, unstable intracratonic basin and unstable shelf. Future work may be profitably directed along these lines.

Chemical Discussion.

A number of analyses of Wianamatta Group sandstones have been collected and assigned to their appropriate formations.

Minchinbury Sandstone.—Six analyses of specimens from the Minchinbury Sandstone are listed in Table 7. The average analysis (7) has a very low silica percentage (38.48) and high CaO (18.92) and CO_2 (21.79) content. From the key to Table 7 it seems that this is due to the analysed specimens belonging to the marly constituent of the formation, a suggestion further substantiated by the great similarity in all constituents with the analysis of a marine marlstone (8) from the Ordovician of Ohio, U.S.A.

TABLE 7.

Analyses of Minchinbury Sandstone.

	1	2	3	4	5	6	7	8
SiO_2	51·00	34·65	41·15	38·46	34·93*d*	30·60	38·46	48·12
TiO_2	1·44	...	...	...	...	...	1·44	0·78
Al_2O_3	15·03	8·13*a*	10·45	8·00	2·71	13·75	11·08	12·80
Fe_2O_3	4·10	1·60	3·25	3·75	4·47		2·85	1·60
FeO	4·50	4·32					4·41	3·25
MnO	0·14	0·31	...	...	...	...	0·22	0·09
MgO	4·68	1·04	1·36	...	0·70	1·39	1·83	2·55
CaO	6·00	23·75	5·43	20·08	30·02	28·23	18·92	10·77
Na_2O	2·34	0·85	...	...	...	...	1·59	0·60
K_2O	1·89	1·07	...	...	...	...	1·48	3·60
H_2O+ ...	5·48	3·15	1·23		2·71	...	5·48	3.25
H_2O-... ...	...			...		0·92	0·92	1·70
P_2O_5	...	0·38	Tr.	...	Tr.	nil	0·38	0·65
CO_2	3·36	20·50	37·31*c*	20·08	24·78	24·72	21·79	9·19
S	...	...	...	...	...	...	...	0·88*f*
SO_3	...	...	nil	...	nil	nil	...	0·24
BaO	...	...	...	...	...	...	...	0·01
SrO	...	...	...	...	Tr.	...	Tr.	nil
Organic ...	...	0·25*b*	...	...	Tr.	0·39*e*	0·32	0·24
	100·36	100·00	100·18	...	99·78	100·00	100·06	100·36

a. Including any TiO_2 present.
b. Organic plus undetermined.
c. $CaCO_3$.
d. Insoluble matter—almost entirely coarse sand with a small quantity of clay.
e. Organic plus undetermined.
f. FeS_2.

1. " Calcareous clay-shale ".—Minchinbury, Rooty Hill. *Ann. Rep. Mines Dept. N.S.W.*, 1907, p. 117. An. No. 7710.
2. " Argillaceous limestone ".—1¼ miles west of Auburn. *Ibid.*, 1914, p. 216. An. No. 4379.
3. " Calcareous sandstone ".—Near Granville. *Ibid.*, 1891, p. 59.
4. " Calcareous Wianamatta (Ostracodal) ".—Grose Vale Road, Kurrajong to Richmond. Mines Dept. N.S.W. An. No. 3210/1802. Analyst, J. C. H. Mingaye.
5. " Limestone ".—Near Sydney Water Supply Canal, Co. Cumberland. *Ann. Rep. Mines Dept. N.S.W.*, 1890, p. 50.
6. " Argillaceous limestone ".—Prospect Dam, Prospect. *Ibid.*, 1889, p. 46. *See* Table 2.
7. Average, 1–6.
8. Marine marlstone (calcareous shale).—Shale components of Maysville, Ordovician Butler Co., Ohio. *Ohio Geol. Surv. Bull.* 42, p. 114. Analyst, D. Schaaf.

TABLE 8.

*Partial Analysis of Minchinbury Sandstone.**

$CaCO_3$	:	39·67
Clay	:	39·42
Fe_2O_3	:	2·69
$FeCO_3$	:	13·48
$MnCO_3$	:	0·43
$MgCO_3$	:	1·63
Alkalies (as chlorides)	:	0·68
H_2O	:	2·26
		100·24

* Minchinbury Sandstone (" limestone "). Duck Creek, Auburn. Smith, H. G., 1892.

A partial analysis of another marl type from Duck Creek is given in Table 8. A point of interest is the considerable percentage of siderite (13.48) in the analysis. Thin sections of the marly types show abundant, oolite-like siderite grains often aggregated together to form prominent blebs in the rock.

TABLE 9.

Analysis of Potts Hill Sandstone.

	1	2		1	2
SiO_2	68·64	69·69	K_2O	1·24	71
TiO_2	0·32	0·40	H_2O+	5·64	2·08
Al_2O_3	16·31	13·53	H_2O-		0·26
Fe_2O_3	3·90	0·74	P_2O_5	0·22	0·10
FeO	0·81	3·10	CO_2	...	0·23
MnO	0·04	0·01	O_3	Tr.	...
MgO	0·92	2·00	Organic	Tr.	...
CaO	0·68	1·95			
Na_2O	1·08	4·21		99·80	100·01

1. " Sandstone ".—Por. 15. Ph. Picton, Co. Camden. *Ann. Rep. Mines Dept. N.S.W.*, 1924, p. 105. Analyst H. P. White. An. No. 3400.
2. Average of 3 Franciscan (Jurassic) graywackes—after Taliaferro. *Am. Assoc. Pet. Geol., Bull.*, vol. 27, 1943, p. 136. (Pettijohn, 1949, p. 250.)

Potts Hill Sandstone.—Table 9 lists an analysis of a sandstone from the south-east flanks of the Razorback Range (between Douglas Park and Maldon) which, in all probability, is referable to the Potts Hill Sandstone. The analysis was very similar to an average analysis of three Fransciscan (Jurassic) graywackes quoted by Pettijohn (1949, p. 250) and included in Table 9. The agreement of the major constituents (silica and alumina) is very marked. The higher Fe_2O_3:FeO ratio of the Potts Hill Sandstone is probably explained by the specimen being weathered. This observation is lent further weight from the fact that the combined Fe_2O_3 and FeO content of both analyses (4.71 for 1; 3.84 for 2) is very similar. One point of difference is the rather high soda content of 2 which is not found in the Potts Hill Sandstone. The difference may be accentuated by the removal of some soda during the weathering process.

TABLE 10.

Analysis of Razorback Sandstone.

	A*a*.	B*b*.	C*c*.		A*a*.	B*b*.	C*c*.
SiO_2	73·72	77·8	64·2	H_2O+	4·28	1·6	2·1
TiO_2	0·22	0·6	0·5	H_3O-		0·1	0·1
Al_2O_3	11·74	9·5	14·1	P_2O_5	0·08	0·2	0·1
Fe_2O_3	4·60	0·9	1·0	CO_2	..	0·5	1·6
FeO	0·81	2·6	4·2	SO_3	Tr.	...	...
MnO	0·02	0·2	0·1	S		0·1	...
MgO	1·08	1·6	2·9	Organic ...	Tr.	0·2	...
CaO	0·44	1·2	3·5				
Na_2O	1·64	1·5	2·0				
K_2O	1·14	1·5	2·0		99·77	100·4	100·0

A*a*. Razorback Sandstone (" Upper Sandstone "). Por. 15. Ph. Picton Co. Camden. *Ann. Rep. Mines Dept. N.S.W.*, 1924, p. 105. Analyst, H. P. White. An. No. 3399.

B*b*. Average of 3 subgraywackes. Pettijohn (1949), p. 256.

C*c*. Average of 5 graywackes. Pettijohn (1949), p. 250.

Razorback Sandstone.—An analysis of a sandstone (A) from the same locality as the analysed Potts Hill Sandstone, and most likely representative of the Razorback Sandstone, is listed in Table 10. This analysis has been chosen as a typical analysis of the Wianamatta Group sandstone type and in the table is compared with an average analysis of three subgraywackes (B) and five graywackes (C) quoted by Pettijohn (1949). The main point brought out in the comparison is that the analysis is midway between that of the subgraywacke, on one hand, the graywacke on the other. Comparing the key constituents, silica and alumina, it is immediately apparent that the Razorback Sandstone has a composition somewhere between them—in actual fact the analysis is almost exactly half-way between the two extremes, with a very slight tendency toward the subgraywacke.

This result is what would be expected when we recall the determination already made during the discussion of the mineral composition—the Wianamatta Group sandstones are somewhere between the true graywackes and subgraywackes in their constitution.

Preliminary Insoluble Residue and Heavy Mineral Data from the Minchinbury Sandstone.

Insoluble Residue Studies.—The calcareous nature of the Wianamatta Group sandstones lends itself to the techniques of insoluble residue studies and preliminary work has suggested that this technique may prove a useful tool in further stratigraphic work on the Group. The Minchinbury Sandstone, because of its wide geographic extent, may well be used for variation studies with insoluble residues.

TABLE 11

Analysis of Soluble and Insoluble Residue Minchinbury Sandstone.[a]

	Insoluble Residue.	Soluble Residue.	Combined.		Insoluble Residue.	Soluble Residue.	Combined.
SiO_2	29·38	1·22	30·60	P_2O_5	...	nil	nil
Al_2O_3	7.59	1·20	13·75	CO_2	...	24·72	24·72
Fe_2O_3		2·75		SO_3	...	nil	nil
FeO		2·21		Organic ...	...	0·39*b*	0·39
MgO	...	1·39	1·39				
CaO	0·40	27·83	28·23				
H_2O	...	0·92	0·92		37·37	62·63	100·00

a. "Argillaceous limestone".—Prospect Dam, N.S.W. *Ann. Rep. Mines Dept. N.S.W.*, 1889, p. [illegible].
b. Organic and undetermined.

Table 11 gives an analysis of the soluble and insoluble portions of the Minchinbury Sandstone near Prospect.

Heavy Mineral Analysis.—A preliminary heavy mineral separation on a sample of the Minchinbury Sandstone from Kurrajong (Windsor 643517) showed that a definite mineral suite was available for study. It appears, from a preliminary examination by C. T. McElroy of the N.S.W. Geological Survey, that both stable (tourmaline, euhedral zircon) and unstable (garnet, monazite?, ferromagnesians) types are represented—a typical graywacke association.

Again, due to its wide areal extent, the Minchinbury Sandstone would probably provide an excellent basis for work on the lateral variation of the heavy mineral assemblage with the possibility that some extra light may be thrown on the source area of the sediments of the Group. It is hoped that future work may be directed towards this end.

THE SEDIMENTARY ENVIRONMENT AND SEDIMENTARY TECTONICS.

Krumbein and Sloss (1951, p. 381) stressed the fundamental concept that any area of deposition may be classified according to the degree of tectonism prevailing during sedimentation. They defined two elements, one lithologic (Lithotope) and the other tectonic (Tectotope) to describe a lithologic sequence.

Lithotope: defined as an area of uniform sedimentation. This unit would be represented in the vertical co-ordinate of the columnar geologic section by a section of homogeneous lithology.

Tectotope: the tectonic subdivision representing a particular tectonic environment. This unit is represented in the geologic section by a section deposited during a consistent tectonic condition.

The two elements defined were used by Krumbein and Sloss to illustrate the depositional tectonic history of a section of Desmoinesian cyclothems in western Illinois.

The authors completed their concept by integrating the tectonic elements, lithologic association and geographic environment in their Tectono-environmental classification. On this basis it is a logical extension of the Lithotope-Tectotope concept to define a third element, the Envirotope, to complete the description of an area of uniform sedimentation.

Envirotope: is defined as the environmental subdivision representing a particular depositional geographic environment. The units of the envirotope are those used by Krumbein and Sloss (p. 387) in their Tectono-environmental classification.

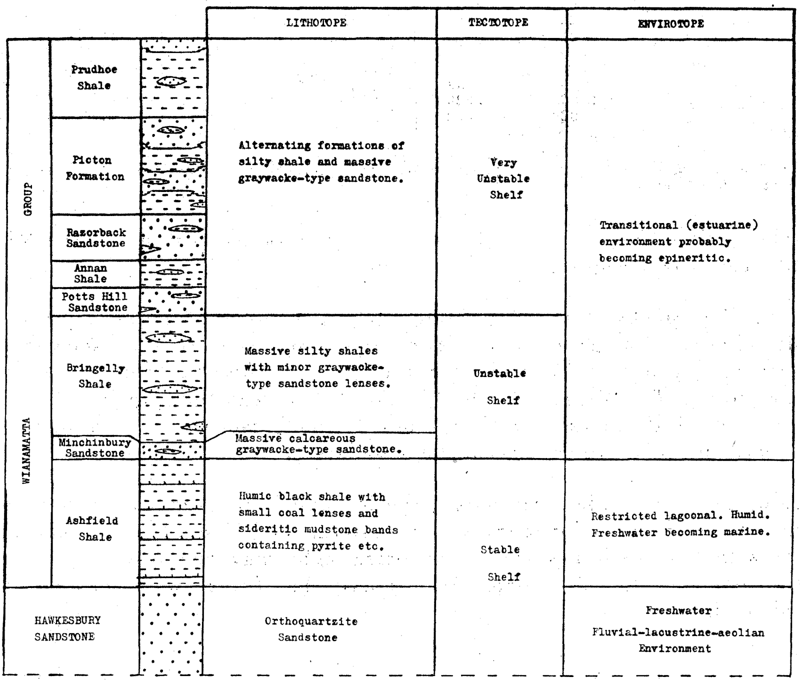


Fig. 6. Hawkesbury Sandstone-Wianamatta Group Sequence showing relation of observed lithotopes, inferred tectotopes and inferred envirotopes.

0 100 feet
Vertical Scale

With the three elements we may determine the sedimentary environment of a lithologic sequence. Figure 6 indicates the relation of the observed lithotopes to the inferred tectotopes and envirotopes for the Hawkesbury Sandstone-Wianamatta Group sequence.

The underlying Hawkesbury Sandstone is a widespread, lithologically consistent, massive orthoquartzite—the characteristic sandstone type of the stable shelf tectonic area. Furthermore, taking into consideration (*a*) the wide geographic extent, (*b*) orthoquartzite lithologic type, (*c*) freshwater indication of the described fauna and evidence of fresh sub-surface waters, and (*d*) abundance of current bedding, it appears that the environment is essentially continental with fluvial-lacustrine-aeolian conditions all represented at some stage. Such an environment is essentially in agreement with the views of Osborne (1948). Actually it appears that considerable sediment was transported from the south-west, west and north-west (Osborne, 1948, p. xxx) and deposited in an immense delta area. The crustal stability, with little sinking, provided an area in which fluvial, now lacustrine, then aeolian conditions predominated. The result of all three environments is the Hawkesbury Sandstone with its abundance of rounded, well sorted quartz grains and stable-type heavy minerals. Occasional slumps of the contemporaneously deposited shales formed the ubiquitous shale breccias, while old stream courses are probably represented by the coarser and pebbly bands found in the normal sandstone.

The change to Wianamatta deposition was through passage beds of alternating Hawkesbury-type Sandstone and Ashfield-type shale, probably representing an extension of the environment responsible for the dark shales in the Hawkesbury Sandstone. These passage beds do occur in all sheets but particularly in the Camden Sheet and other sheets to the south. Elsewhere the change is more pronounced and the Ashfield Shale appears to lie on contemporaneously eroded surfaces in the Hawkesbury Sandstone. The tectonic condition did not change noticeably in the passage—the shelf area was still stable with little sinking. On the other hand, the geographical environment did undergo considerable change. The conditions for the formation of the humic black shales with characteristic sideritic mudstone bands would suggest widespread lagoonal humid conditions with essentially restricted circulation. The abundant carbonaceous matter owes its preservation to rapid deposition of the associated fine sediment, a condition that implies increasing instability in the source area.

The environment suggests a fluctuating freshwater-marine area with definite tendencies to stabilize as marine. The evidence for a marine environment is discussed later, but here it is suggested by the observation that the described fauna of the Ashfield Shale, a freshwater fauna, is confined to a zone less than 100 feet above the Hawkesbury Sandstone. The general occurrence is of a great abundance of forms (molluscs, fish, etc.) tightly packed in vertically restricted zones indicating a catastrophic annihilation of the fauna—a condition most likely brought about, under the circumstances, by an influx of salt water. Other points which have led to this concept of fluctuating freshwater-marine conditions are: (*a*) The excellent state of preservation of the *Unio* shells suggests deposition in an environment of pH > 7. (i.e., the alkaline marine environment). In general, the slightly acid freshwater environment gives poorly preserved shells; (*b*) both pyrite and marcasite occur as authigenic minerals in the sideritic mudstone bands. Edwards and Baker (1951) have shown that authigenic pyrite is formed under alkaline conditions while authigenic marcasite needs acid conditions. This evidence indicates the delicate balance between the two environments.

The tendency appears to have been that marine conditions became increasingly regular and finally predominant after the Ashfield Shale deposition ceased.

The Minchinbury Sandstone and Bringelly Shale are discussed as a single lithotope—predominantly shale with subsidiary calcareous graywacke-type sandstone bands and lenses. A partly marine environment is proposed after consideration of the following facts:

(1) *The microflora and microfauna of the Minchinbury Sandstone.*—The evidence of the microfossil assemblage described previously (Lovering, 1953), consisting of marine-type arenaceous foraminifera, thin shelled ostracoda and algae, is indicative of definite marine conditions.

(2) *The lithologic types.*—The association of silty shale and graywacke-type sandstone is a typically marine lithology.

(3) *Salt content of the sub-surface waters.*—Old (1942) described a series of analyses of sub-surface waters from the Wianamatta Group rocks. The results

of the analyses indicate a consistently excessive salinity which, in some cases, is more saline than sea-water. Furthermore the salinity is not related or confined to any particular one of the formations.

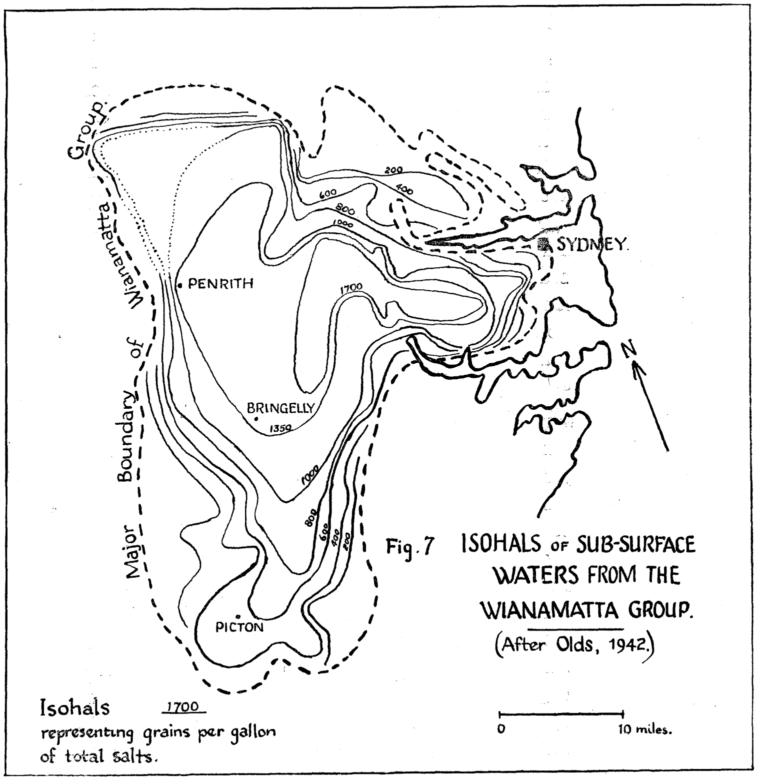


Fig. 7 ISOHALS OF SUB-SURFACE WATERS FROM THE WIANAMATTA GROUP. (After Olds, 1942.)

The most informative way of studying the lateral distribution of the salt is by drawing (after Old) a series of *isohals* which represent the maximum expectancy of salt content in various localities (Figure 7). It is apparent from the isohals that the salt content increases towards the central axis of the major structural basin where the maximum Wianamatta Group thickness is found and also where the group extends farthest below sea-level. It is an important feature that the 400 isohal bulges to include the great thickness represented by the Razorback Range.

This salt must represent connate salt, that is, salt derived from the marine waters of the depositional area included and retained by the shales because of a particular set of conditions: (*a*) Impervious nature of the shales: assisted retention; (*b*) low relief, little natural drainage of the basin: served to concentrate the salt.

The presence of considerable magnesium as well as sodium salts, together with the alkaline pH, both characteristics of present-day sea-water, strengthens the connate origin. On the other hand, the acid, non-saline waters from the Hawkesbury Sandstone are in turn in accord with the freshwater origin of that formation.

The lithologic association and microfossil assemblage suggest that transitional (fluvial-lagoonal-littoral) environment of Krumbein and Sloss (1951) with estuarine or even shallow wave and current-agitated marine water (epineritic) conditions predominating.

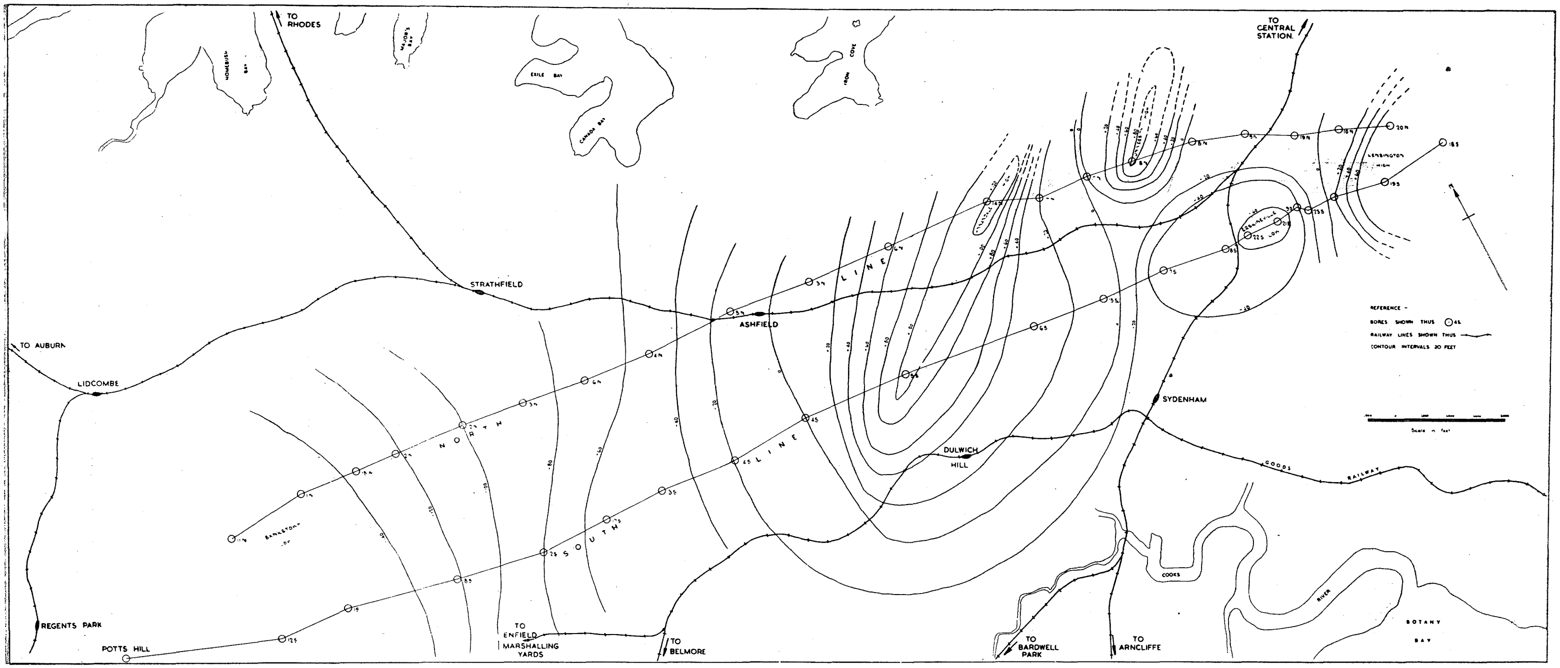


Fig. 8.—Structure contours on the base of the **Wianamatta Group. Data from north and south lines of bores for M.W.S.D.B. City Tunnel exploration.**

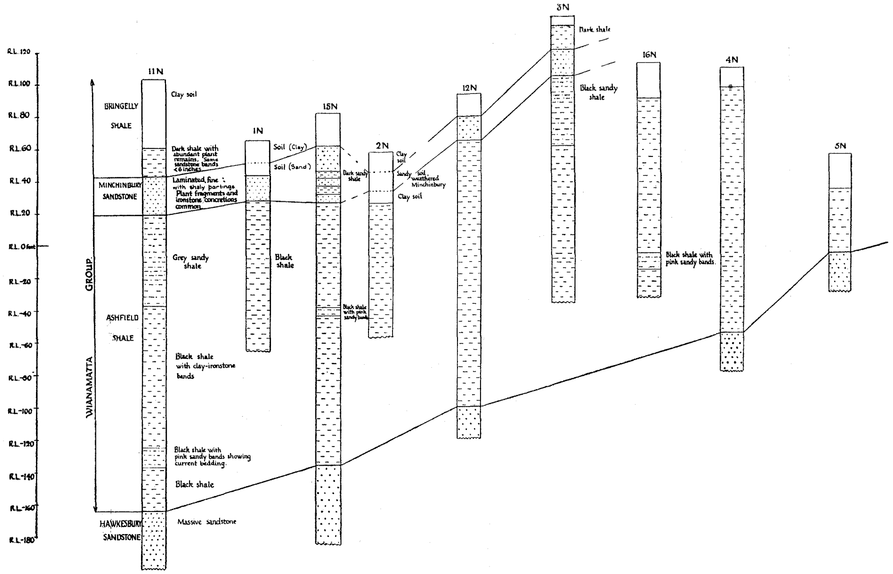


Fig. 9.—Sub-surface data from north line of M.W.S.D.B. City Tunnel exploratory bores. (Plan of bores shown on Fig. 8.)

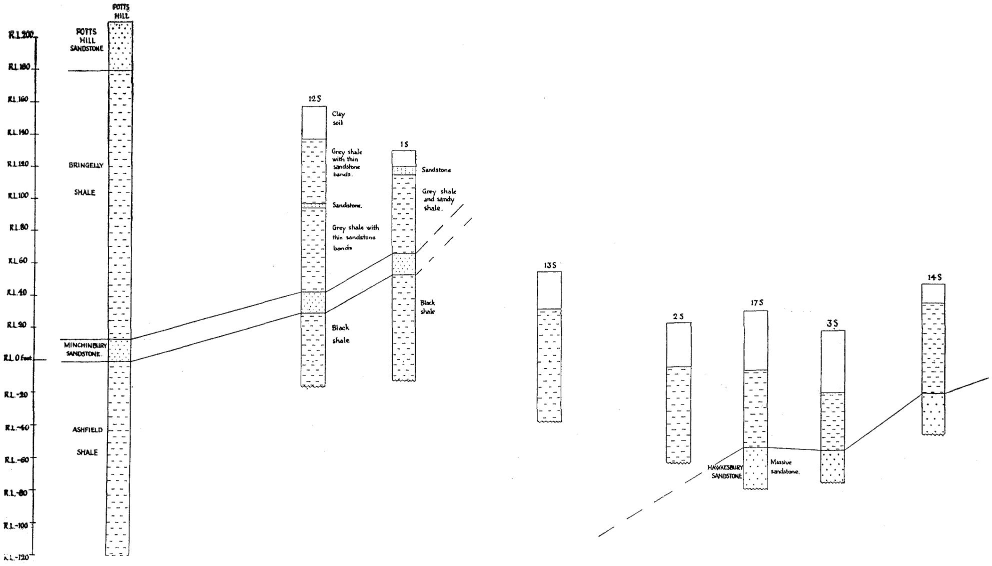


Fig. 10.—Sub-surface data from south line of M.W.S.D.B. City Tunnel exploratory bores (This line follows the actual tunnel. Plan shown on Fig. 8.)

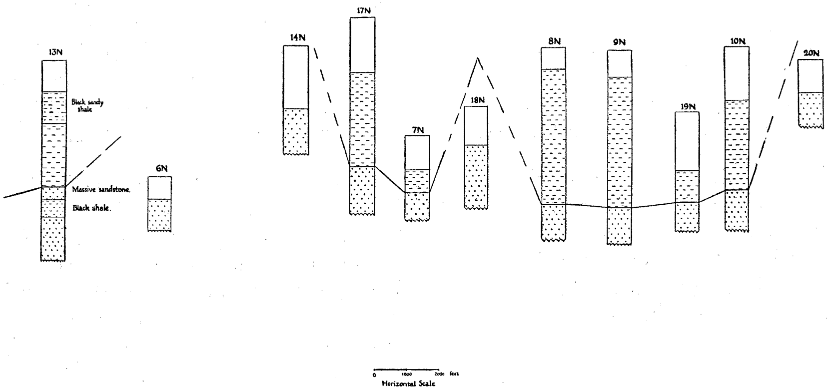


Fig. 9 (*contd.*)

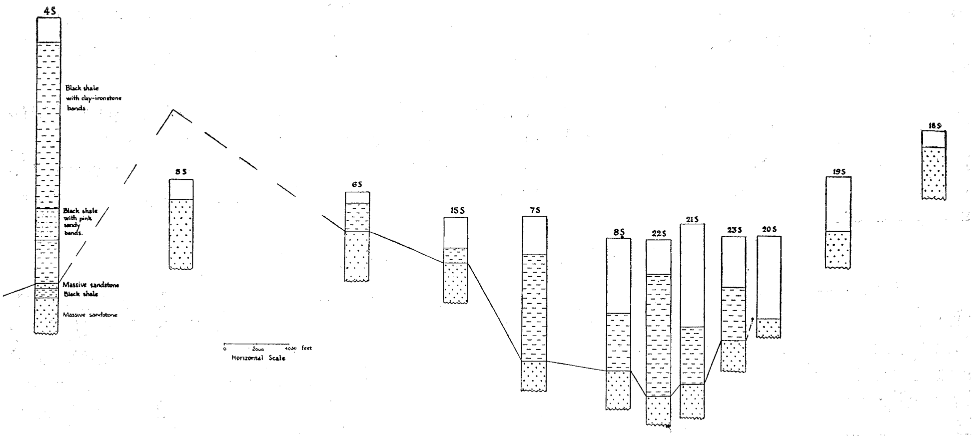


Fig. 10 (*contd.*)

The appearance of graywacke-type sandstones in the section gives the first indication of a changing tectonic condition—instability of the shelf area. The occasional quartz-rich sandstones found in localized areas suggest an area, such as a channel or shore line, in which conditions are relatively turbulent with a tendency to "clean-up" the original graywacke sediment. The abundance of calcite in some sandstones which, in some cases, causes the rock to become rather an argillaceous limestone, is characteristic of such a depositional area of tectonic instability and estuarine environment which allows free mixing of clastics and non-clastics.

The conditions acting during the deposition of the formations of the Camden Sub-group are an extension and consolidation of those operating during the Minchinbury Sandstone-Bringelly Shale deposition. The environment is still estuarine (transitional) with a tendency towards the shallow, open-circulation marine (epineritic) condition. The shelf area has consolidated as very unstable and the oscillatory movements, causing fluctuations of the strand line, have formed the rather complex association of massive graywacke-type sandstone and shale formations.

The illustration of the sequence shown in Figure 6 is, in broad outline, almost identical with the "mixed sections" of Pettijohn (1949, p. 461) in which the sequence is composed of formations belonging to several contrasting facies but with a particular arrangement. The sequence of the Huronian of Michigan is a typical example:

(1) Lower Huronian: orthoquartzite-limestone facies. cf. Hawkesbury Sandstone.

(2) Middle Huronian: an anerobic facies—thin basal orthoquartzite with overlying sideritic black shale and cherty iron carbonate. cf. Ashfield Shale.

(3) Upper Huronian: basal conglomerate followed by a very thick series of Flysch-like slates and graywackes. cf. Minchinbury Sandstone, Bringelly Shale and Upper Division formations.

The Palaeozoic of the Ouachita and Arbuckle Mountains is similar to the Huronian section, even to minor details of lithology.

It then appears that this sequence is not uncommon in the sedimentary record of the world and does represent a particular set of recurrent conditions reminiscent of the ideal cyclothem, but on a much larger scale. The Hawkesbury Sandstone-Wianamatta Group sequence forms a connecting link with the Huronian large scale section and the cyclothem small scale section.

The tectonic environment is essentially a shelf area originally stable but rapidly becoming increasingly unstable and reaching the peak of its rhythm in the upper part of the sequence. Such a condition probably represents a stage in the orogenic cycle possibly related to the initial stages of the development of a geosyncline from a shelf area.

POST-DEPOSITIONAL TECTONICS.

The post-depositional tectonic history of the Wianamatta Group is bound up with the tectonic vicissitudes of the whole Sydney Basin. Willan (1925) in his Sydney District map shows contours with 100-feet interval on the base of the Wianamatta and again on the top of the Upper Coal Measures. The two structure contour maps are basically very similar and a series of domes and basins are shown and named, e.g., Botany Basin, Fairfield Basin, Penrith Basin and Mulgoa Dome.

Countless minor faults and warps are found in the Ashfield Shale and other formations, but occasional major displacements with crushed zones up to 20 feet have been exposed in the driving of the Metropolitan Water, Sewerage and Drainage

Board's City Tunnel. The major structural feature affecting the Wianamatta Group is the Glenbrook Monocline and associated tectonic features apparent in the western edge of the Cumberland Basin. The problem of this feature and its associated physiographic effect is fully considered by Osborne (1948, p. xxxiii) and is not repeated here.

Some detailed work on the basin has been carried out in the western suburbs of Sydney with information provided by a series of exploratory bores sunk by the M.W.S.D.B. The location of the bores is given in Figure 8, together with structure contours (contour interval 20 feet) on the base of the Ashfield Shale. The logging of the two lines of bores is shown in Figures 9 (North Line) and 10 (South Line) together with the lithology of the represented formations. The profile of the basin is also shown and its irregular outline is at once apparent. The structure contour plan does give a picture rather different from that of Willan's map, mainly by reason of more data and smaller contour interval. The structure is much "tighter" in the central area than has previously been recognized, with a series of highs and lows in a relatively short horizontal distance.

The western boundary is the rather shallow basin-like structure of the Bankstown Low. Moving to the east the structure becomes gradually "tighter" with a pronounced high at Annandale (the Annandale High) and another centring on Sydney University (the University High) with a shallow basin to the south-west (the Erskineville Low). The eastern margin of the drawing is formed by another dome structure, the Kensington High.

The information gained in this rather restricted area indicates a complexity of tectonic structure which has not so far been recognized. In a plan for future work in the northern suburbs of Sydney it is intended to extend the contour plan on the Wianamatta Group-Hawkesbury Sandstone boundary.

The joint pattern imposed on the rocks by tectonic conditions is of interest. Two major sub-vertical (80-90°) systems N.30° W. and N.55° E. have been recognized. This pattern must have originated before the Tertiary igneous activity—the basic dykes strike along these directions and have been intruded into them.

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EXPLANATION OF PLATE XII.

1. Siderite aggregates in the Minchinbury sandstone. (A.M. 5700.) X 20.

2.—The typical graywacke-type sandstone of the Minchinbury sandstone. Angular quartz, altered feldspar and rock fragments in a matrix of calcite and clay. (A.M. 5699.) X 20.

3.—A graywacke-type sandstone from the Picton formation. Angular quartz (with chlorite rims), altered and fresh oligoclase, rock fragments in a clay and calcite matrix. (A.M. 5730.) X 20.

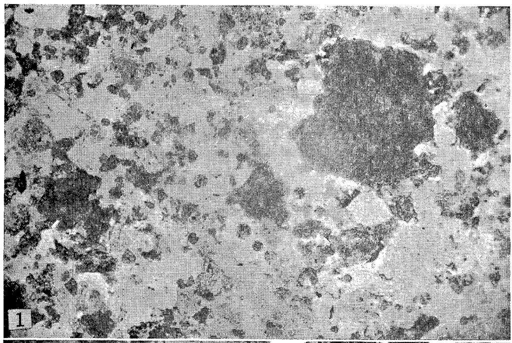
4.—A graywacke-type sandstone from the Picton formation (cf. Fig. 3). (A.M. 5731.) X 20.

5.—Junction of Hawkesbury sandstone and Ashfield shale, Liverpool Golf Course.

6.—Minchinbury sandstone overlain by Bringelly shale. Bonnyrigg (Liverpool 867137).

7.—Potts Hill sandstone. Potts Hill Quarry.

8.—Sugarloaf Hill (Camden 775875) showing capping of Razorback sandstone (1), with Annan shale (2), Potts Hill sandstone (3) and Bringelly shale (4).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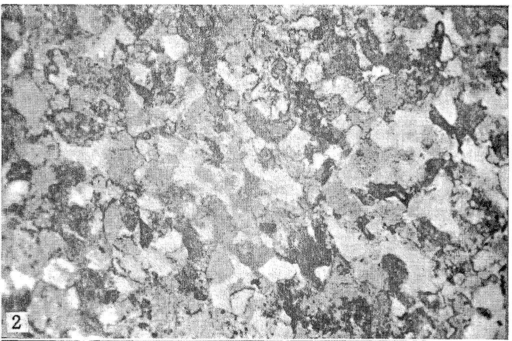
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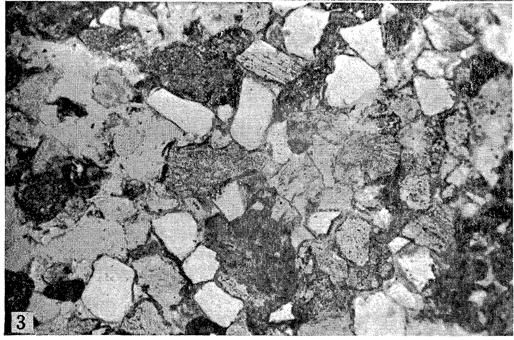
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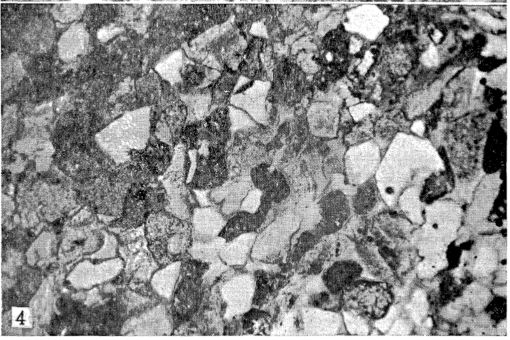
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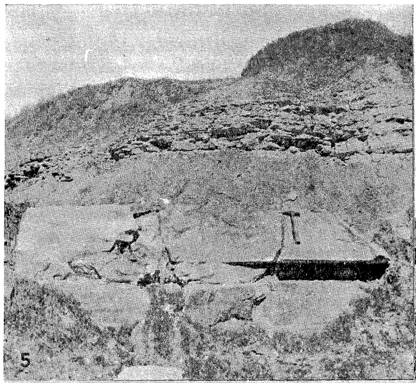
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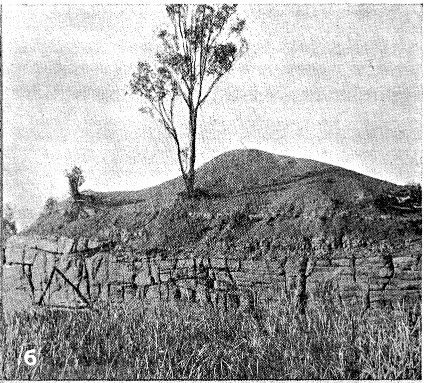
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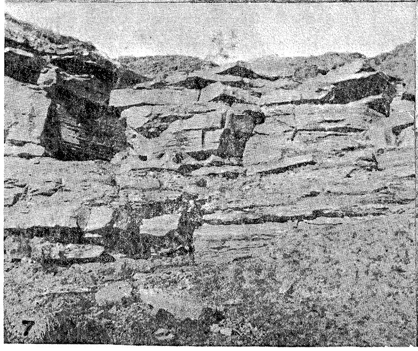
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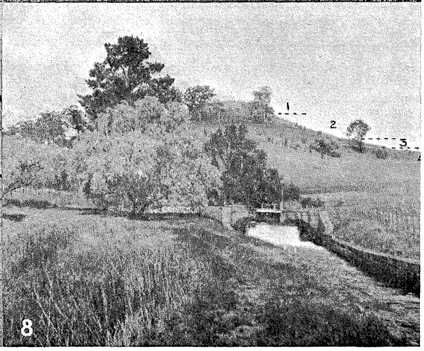
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