COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Report No. 53

GEOLOGY OF THE HOWICK AREA, SINGLETON-MUSWELLBROOK DISTRICT, NEW SOUTH WALES

BY

J. J. VEEVERS

Issued under the Authority of Senator the Hon. W. H. Spooner,
Minister for National Development
1960

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Minister : SENATOR THE HON. W. H. SPOONER, M.M.
Secretary : H. G. RAGGATT, C.B.E.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director : J. M. RAYNER

This Report was prepared in the Geological Section

Chief Geologist : N. H. FISHER

CORRIGENDA

p.12 - table: for '400' 00" ' read '440' 00"'

p.15: The missing caption to Fig. 5 is: 'Isopach maps of (A) Unit No. 4, and (B) Saltwater Creek Sandstone Member.'

p.18 and 19: Figure 11 should be Figure 12 and vice versa.

p.20: The error figures in para.1 should read: ± 3 gamma, 2 gamma, ± 5 gamma, and -3 gamma respectively.

In the last paragraph, line 2: for fig. 1 read fig. 10.
line 4: for 19 read 10.
line 6: for 8 read 17.

CONTENTS.

SUMMARY.

Bores in the Howick area of fifteen square miles penetrated 1,580 feet of Permian rocks, comprising 430 feet of Mulbring Beds (including 280 feet of Pond's Creek Formation) and 1,150 feet of Tomago Coal Measures. The Bayswater Formation is redefined, because of synonymy is renamed the Pond's Creek Formation, and is included in the Mulbring Beds. Three major cycles of sedimentation are identified in the Tomago Coal Measures. The lowermost comprises three minor cycles each about 100 feet thick and each consisting of greywacke sandstone, siltstone, shale, and coal; the coal seams are all 8 - 10 feet thick, and are widely distributed. The second cycle comprises seventeen seams of variable thickness, and associated sandstone members. A third cycle, which probably includes the thick Bayswater Seam, indicates a return to the regular type of deposition characteristic of the first cycle.

The axis of the Muswellbrook Anticline crosses the area and, except for local reversals, plunges $4\frac{1}{2}^{\circ}$ south-south-eastward. A broad anticline, whose axis coincides with that of the Muswellbrook Anticline, developed during the deposition of the Pond's Creek Formation, and continued to rise until the lowermost coal seam was laid down. Minor structures on the western flank of the Muswellbrook Anticline were probably caused by igneous intrusion.

The three groups of intrusive igneous rocks found in the area, the Carrington Sill, the Howick Sill, and the igneous rocks penetrated by bores, are probably parts of one intrusion. A magnetometer survey shows that the Carrington and Howick Sills are normally polarized; over poorly outcropping rock, the magnetometer helped in locating the boundary between sedimentary and igneous rock. The magnetic intensity of the sediments increases with their thickness.

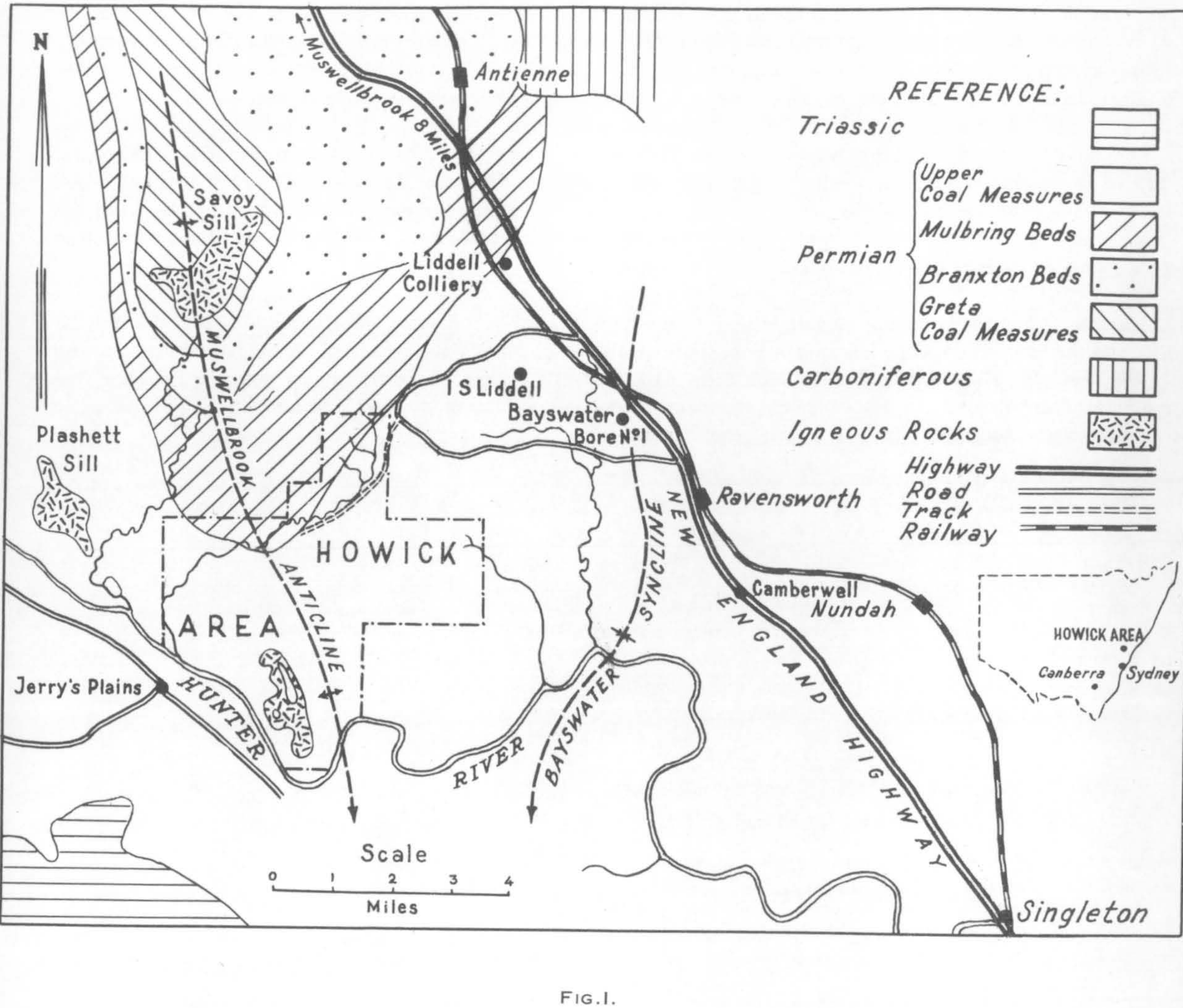

N
REFERENCE:
Triassic
Permian
Upper Coal Measures
Mulbring Beds
Branxton Beds
Greta Coal Measures
Carboniferous
Igneous Rocks
Highway
Road
Track
Railway
Antienne
Muswellbrook 8 Miles
Savoy Sill
Liddell Colliery
I S Liddell
Bayswater Bore No 1
Plashett Sill
MUSWELLBROOK
HOWICK AREA
ANTICLINE
Ravensworth
NEW ENGLAND HIGHWAY
Camberwell
Nundah
BAYSWATER SYNCLINE
Jerry's Plains
HUNTER RIVER
Scale
0 1 2 3 4
Miles
Singleton
HOWICK AREA
Canberra
Sydney

FIG. I.

INTRODUCTION.

The Howick area (fig. 1) lies within the Singleton-Muswellbrook Coalfield of New South Wales, 11 miles south-south-east of Muswellbrook and 12 miles west-north-west of Singleton; the hamlet of Jerry's Plains lies immediately to the south-west. Its 15 square miles embraces the axial part of the Muswellbrook Anticline that lies between the Hunter River in the south and the inferred outcrop of the base of the Pond's Creek Formation in the north.

The area contains two principal stratigraphical units, the uppermost part of the Mulbring Beds (including the Pond's Creek Formation) and the Tomago Coal Measures, and many related sills of igneous rock, of which the Carrington Sill is the largest.

The Bureau prospected the area for open-cut coal from March 1952 to June 1953. Bore statistics are :

Number of bores	117
Total footage drilled	27,380
Footage cored	22,753

Previous work.

Only the Carrington Sill (Morrison & Raggatt, 1928, p.111; Raggatt & Whitworth, 1930, pp. 78-79; 1932, pp. 194-195; Raggatt, 1938, p.106, fig. 12) was noted before 1952. Bursill & Veevers (1952) and Veevers (1953) described the economic geology of the area, and Booker (1953) used these results in part of his regional study of the Singleton-Muswellbrook Coalfield. The present report, based on an M.Sc. thesis submitted to Sydney University in 1954, contains the geological results of work in the Howick area.

STRATIGRAPHY.

A composite stratigraphical section estimated to be 1,580 feet thick was penetrated by bores in the Howick area (fig. 2). This section is made up of 1,150 feet of Tomago Coal Measures, and 430 feet of Mulbring Beds ('Upper Marine'), including 280 feet of Pond's Creek Formation. 2SR Pond's Creek penetrated 1,077 feet of strata dipping at 20°, and identified as :

Bore Depth	Stratigraphical Thickness (Bore thickness x 0.94)	Unit
0' - 1036'3" (includes 21 feet of intrusive igneous rock)	974 feet	Tomago Coal Measures
1036'3" - 1077'	38 feet 4 inches	Mulbring Beds (Pond's Creek Formation)

1S Jerry's Plains penetrated the youngest rocks (at the surface, an estimated 1,150 feet above the base of the Tomago Coal Measures); and 6S Pond's Creek the oldest (at the bottom, estimated by Reynolds (1956, fig.1) to be 430 feet below the base of the Tomago Coal Measures). The most complete stratigraphical and structural information was provided by 6S and 17S Parnell's Creek, 1S and 6S Farrell's Creek, 2SR and 4S Pond's Creek, and 1S Jerry's Plains.

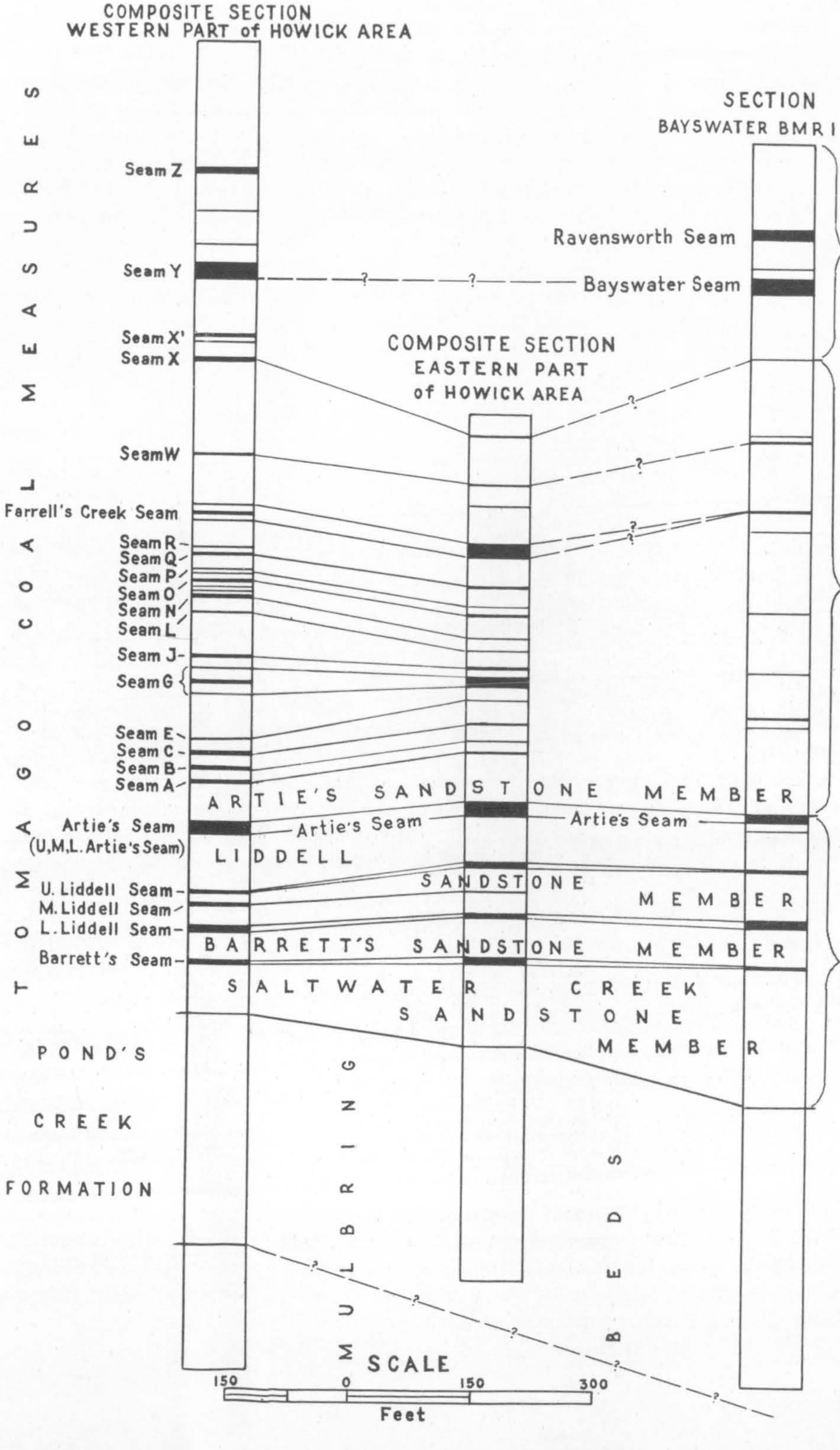

COMPOSITE SECTION
WESTERN PART of HOWICK AREA
COMPOSITE SECTION
EASTERN PART
of HOWICK AREA
SECTION
BAYSWATER BMR I
TOMAGO COAL MEASURES
Seam Z
Seam Y
Seam X'
Seam X
Seam W
Farrell's Creek Seam
Seam R
Seam Q
Seam P
Seam O
Seam N
Seam L
Seam J
Seam G
Seam E
Seam C
Seam B
Seam A
Artie's Seam
(U,M,L. Artie's Seam)
U. Liddell Seam
M. Liddell Seam
L. Liddell Seam
Barrett's Seam
Ravensworth Seam
Bayswater Seam
ARTIE'S SANDSTONE MEMBER
LIDDELL SANDSTONE MEMBER
BARRETT'S SANDSTONE MEMBER
SALTWATER CREEK SANDSTONE MEMBER
POND'S CREEK FORMATION
MULBRING BEDS
CYCLE 3
CYCLE 2
CYCLE 1
SCALE
150
0
150
300
Feet

FIG. 2.

Mulbring Beds.

The term Mulbring Beds was first used in the sense of the Australian Code of Stratigraphical Nomenclature by Booker, Bursill, & McElroy (1954, p.139). Booker & Hanlon (in Hill, 1955, fig.5) refer to the Mulbring Subgroup, but because the constituent formations are not named, this term is invalid.

The Bayswater Formation (Booker et al., 1954) is here renamed the Pond's Creek Formation because the term Bayswater Seam has priority (Foskett, 1953). It is here redefined as the sequence of claystone and siltstone with minor quartz greywacke conformably overlying fine quartz greywacke of the Tomago Coal Measures. It is the uppermost part of the Mulbring Beds, and is the first formation of these beds to be distinguished.

Several lithological units (Units 5 to 9 of Reynolds, 1956) within the upper part of the Mulbring Beds were penetrated by bores in the Howick area, and by the Bayswater No. 1 Bore. The unit above them (No. 4) is known to extend over a wide area, and Booker et al. (1954) called it the Bayswater Formation. Few details were published by Booker et al., and most of the published information is due to Reynolds. Still further detail, including bore logs, is found in the unpublished report by Veevers (1953). Reynolds' Figure 1 shows the distribution of Units 5 to 9. No. 4, the 'Bayswater Siltstone', is considered by Reynolds (p.20) to be "a transition zone with the final stage of marine deposition represented in the lower portion"; No. 3 is the lowermost unit of the Tomago Coal Measures. Reynolds' units can be regrouped into three parts (in descending order) :

(c) siltstone with a minor amount of fine-grained quartz greywacke, and claystone. Comprises Reynolds' units 4, 5, and 6, together with 31 feet of siltstone in the Bayswater No. 1 Bore, hitherto included in the Tomago Coal Measures;

(b) fine-grained quartz greywacke with some siltstone; units 7 and 8;

(a) siltstone and very fine-grained quartz greywacke, with minor amounts of claystone and shale; unit 9.

The separation of the Bayswater Formation (No. 4) from the underlying unit (No. 5), as they are defined by Booker et al. (1954) and by Reynolds (1956), is unsatisfactory. First, according to Booker et al. (p.139), the 'Bayswater Formation ... can only be separated from the underlying marine shales (Mulbring Beds) on palaeontological evidence'. Thus defined, the "Bayswater Formation" appears to be a biostratigraphical unit and not a rock unit, as its name purports. Secondly, according to Reynolds (pp. 5-6), who showed that he did not accept the Bayswater siltstone as a formation by putting the name in quotes, 'the boundary between the "Bayswater Siltstone" and this unit (No. 5) is not always evident, but certain features aid in the differentiation. The unit (No. 5) is generally finer in grain size, darker in colour, and contains less carbonaceous matter. The occurrence of abundant Ammodiscus multicinctus in the upper portion of this unit, however, is a most important diagnostic feature'. Reynolds (p.16 and Figure 1) indicates that this criterion is not everywhere valid, because A. multicinctus occurs abundantly in the "Bayswater Siltstone" in two bores, 16T Pond's Creek and 6S Parnell's Creek. The uncertain position of the boundary between the Bayswater Formation and the underlying unit suggests that a broader grouping of units would be more satisfactory. In this synthesis, the Bayswater Formation, renamed the Pond's Creek Formation, is amended to include Reynolds' units 5 and 6, and 31 feet of siltstone included by Booker et al. (op cit, text-fig. 2) in the Tomago Coal Measures. According to this arrangement, in the Bayswater No. 1 Bore and the Howick bores, the boundary between the Mulbring Beds and the overlying Tomago Coal Measures is a clear one, and is based solely on lithology; below the boundary, for some 200 feet of section, the rocks are claystone and siltstone, with a few thin beds of quartz greywacke; above the boundary, the rocks are quartz greywacke with thin beds of siltstone, claystone, and conglomerate, and coal seams.

The Pond's Creek Formation is almost certainly marine, as indicated by the occurrence in this unit of the foraminiferan Ammodiscus multicinctus (16T Pond's Creek and 6S Parnell's Creek, and nodules of pyrite (Reynolds, 1956, p.8). The plant remains in the Pond's Creek Formation almost certainly do not indicate freshwater deposition; the plants are fragmentary, and were probably transported some distance from their point of origin; in the Bayswater No. 1 Bore, plant remains occur at a depth of 1414 feet, 85 feet below the occurrence of A. multicinctus, in an interval of uniform marine shale and claystone. The significant thing in this section is not the first appearance of plants, which were continually shed into the 'Upper Marine' sea, but the lithological similarity of the uppermost units of the Mulbring Beds up to the base of the Tomago Coal Measures. Accordingly, the Pond's Creek Formation is referred to as the uppermost units of the Mulbring Beds. This conforms with Reynolds' view (1956, p.8) 'that there was little change of environment between the deposition of the uppermost marine beds and that of the "Bayswater Siltstone".' In their text, Booker et al. included the Bayswater Formation in the Tomago Coal Measures, but their graphic log of the Bayswater No. 1 Bore (op. cit., text-fig. 2) shows the Bayswater Formation below the base of the Tomago Coal Measures.

The Pond's Creek Formation has a maximum thickness exceeding 352 feet 3 inches in the Bayswater No. 1 Bore (1147'9" to 1500'). This bore terminated in unit 5. In the Howick area, the composite section, comprising units 4, 5, and 6, provided by 54T and 76T Parnell's Creek is estimated by Reynolds (op. cit., fig 1) to be about 280 feet thick. The type section of the Pond's Creek Formation is the Bayswater No. 1 Bore. As yet, Reynolds' Units 7-9 are known from the Howick area only, and are consequently not named.

The foraminifera in the Pond's Creek Formation are described by Crespin (1958).

Tomago Coal Measures.

Booker et al. subdivided the Tomago Coal Measures into the Bayswater Formation and the Rix's Creek Formation. The transfer of the Bayswater Formation to the Mulbring Beds makes the Rix's Creek Formation a synonym of the Tomago Coal Measures.

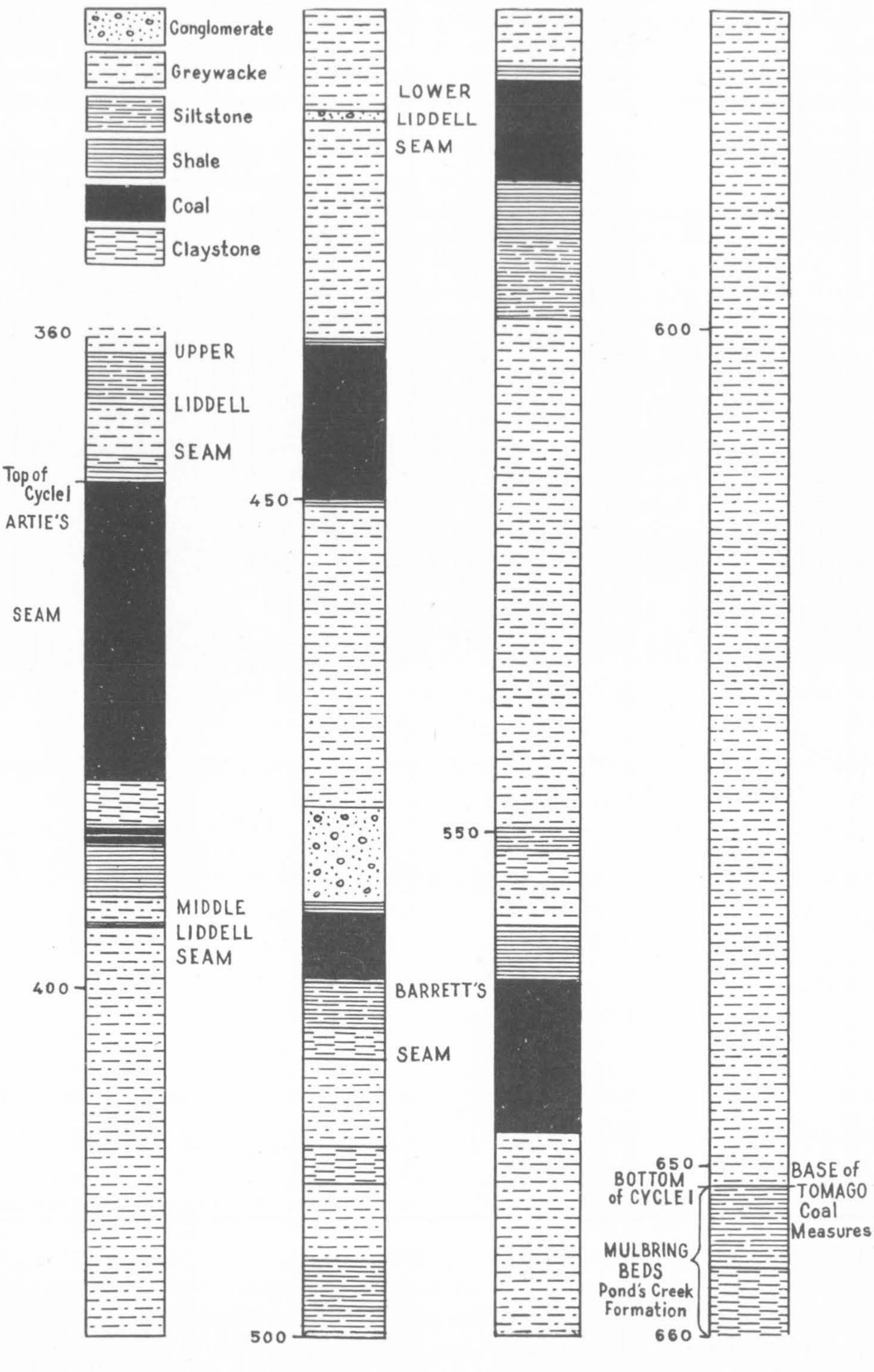
In the Singleton-Muswellbrook Coalfield the two thickest sections through the Tomago Coal Measures penetrated by bores, 2SR Pond's Creek (974 feet thick, including 21 feet of intrusive igneous rock) and the Bayswater No. 1 Bore (1,170 feet thick) consist of :

Rock	linear %				feet			
	2SR		Bayswater Bore	2SR*		Bayswater Bore
Greywacke sandstone	56.2		51	547		594
Conglomerate	5.7		6	55		72
Shale, siltstone and claystone - siltstone	22.3)	26.6	35	218)	260	404
- shale	4.3)			42)		
Coal	9.4		8	91		100
Igneous	2.1		-	21		-

* Calculated for a thickness of 974 feet.

These bores were not logged by the same person, so that, even were the sections identical, slight subjective differences would be expected. The differences between the corresponding values above are probably therefore not significant. Booker et al. (pp.139-140) indicate that the Tomago Coal Measures change gradually from a dominantly conglomeratic unit in the area between the Hunter Overthrust, Nundah, and Antienne, to a dominantly greywacke sandstone unit in the vicinity of Liddell, Ravensworth, and Rix's Creek. They

FIG. 3.


Conglomerate
Greywacke
Siltstone
Shale
Coal
Claystone
360
UPPER LIDDELL SEAM
Top of Cycle I
ARTIE'S SEAM
MIDDLE LIDDELL SEAM
400
LOWER LIDDELL SEAM
450
BARRETT'S SEAM
500
550
600
650
BOTTOM of CYCLE I
MULBRING BEDS
Pond's Creek Formation
660
BASE of TOMAGO Coal Measures

indicate further that this change in dominant rock type probably expresses the different distances of the two areas from outcropping Carboniferous rocks to the north and east, from which most of the conglomerate pebbles were probably derived. Raggatt (1938) found a comparable and parallel change in the Muree rocks of the Upper Marine' in this area. The unchanging lithology of the Tomago Coal Measures between the Bayswater and Howick areas, in particular the almost equal amount of conglomerate in both areas, indicates that the change in lithology described by Booker et al. does not extend into the Bayswater-Howick area.

Twenty-five coal seams were penetrated by bores in the Howick area. The thicker, persistent seams in the Howick area were identified with those penetrated by Bayswater No. 1 Bore. The others are probably local; if not, close boring between the Bayswater and Howick areas would be required to identify them. Booker et al. (p.147) claim that in the Bayswater No. 1 Bore "four major cycles of sedimentation can be identified in a depth of 1,250 feet, and on these are superimposed many minor cycles", but they did not actually identify the cycles. In this paper, three major cycles are identified (fig. 2).

Cycle 1 extends from the base of the Tomago Coal Measures to the top of Artie's Seam. In the Bayswater No. 1 Bore, it is 357 feet thick (800' to 1157') and in 2SR Pond's Creek 246 feet thick. Cycle 1 comprises three minor cycles, which are (in descending order):

Artie's Seam (Booker & McKenzie, 1956, p.17)
Liddell Sandstone Member (Booker & Adamson, 1955, p.71)

Liddell Seam (Booker & McKenzie, 1956, pp.17-18)
Barrett's Sandstone Member (Booker & Adamson, 1955, p.71)

Barrett's Seam (Booker & McKenzie, 1956, pp.18-19)
Saltwater Creek Sandstone Member (Booker & McKenzie, 1956, p.16)

This cycle is illustrated by the graphic log of part of 6S Parnell's Creek (fig. 3) (compiled from the log by M.C. Konecki and M.A. Reynolds, in Veevers, 1953). In this, as in most bores of the Howick area, cycle 1 is complicated by the three-fold splitting of the Liddell Seam, and hence there are actually five minor cycles. In ascending order, each minor cycle comprises a 20 to 80-foot bed of greywacke, a thin bed of siltstone, not everywhere present, a 1/4-inch to 10-foot bed of shale or claystone, a coal seam 3 to 17 feet thick, and a thin bed of shale or claystone. Conglomerate is rare, and occurs mostly at the base of the minor cycle. The roof and floor of the seam are almost everywhere argillaceous, though the shale may be no more than 1/4-inch thick. An extract from the log of 6S Parnell's Creek (M.C. Konecki and M.A. Reynolds, loc. cit) illustrates this point. At first glance the seam appears to be enclosed by thick beds of greywacke, but closer inspection of the log shows that both roof and floor of the seam are argillaceous.

Estimated depth	Estimated thickness	Strata
396'2")	43'10"	Greywacke sandstone with thin pebble bands, and thin claystone lenses.
400'0")		
)		
)		
440'5$\frac{1}{2}$")	5$\frac{1}{2}$"	Shale, grey.
))		
)	9'7$\frac{1}{2}$"	Coal, very thin rock bands, and very thin band of clay at bottom.
450'1")		
))		
)	18'5"	Greywacke, sandstone, coarse-medium -grained.
468'6")		
)		

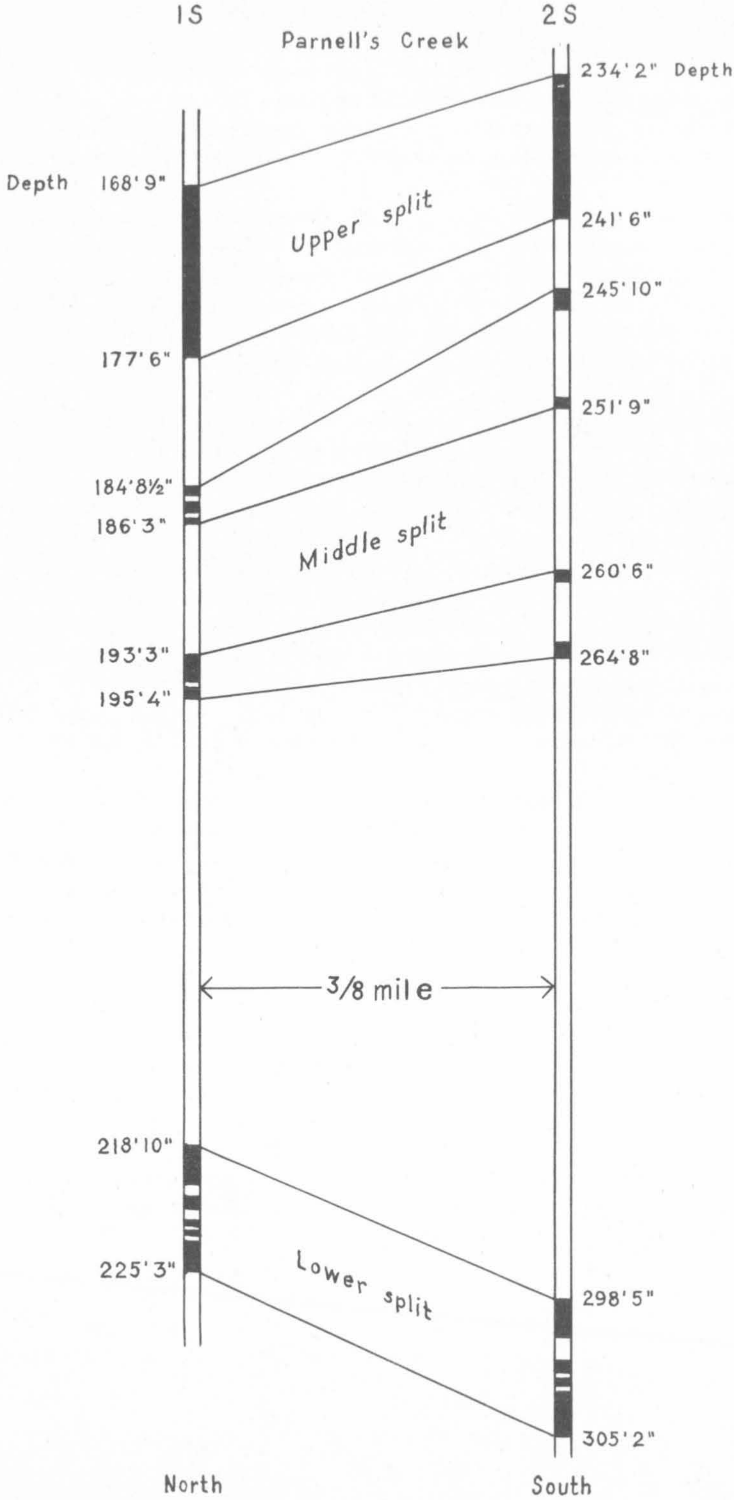


FIG. 4. SPLITS IN LIDDELL SEAM.

The fact that almost every seam is floored by a bed of clay probably indicates that at least the lower parts of the seams were formed in place.

The greywacke between the seams is cemented by clay, or locally by calcite or siderite. Carbonaceous detritus is profuse, and helps to pick out the characteristic scour-and-fill and cross-bedding structures. Siltstone and claystone lenses, diastems, and minor slumping are other typical features.

Text-figure 4 illustrates the splitting in the Liddell Seam. In 1S Parnell's Creek, the Liddell Seam has an aggregate thickness of 16 feet 3 inches over an interval of 56 feet 6 inches. In 2S Parnell's Creek, 3/8-mile south of 1S, the splits are more widely separated, and the Liddell Seam has an aggregate thickness of 13 feet 10 inches over an interval of 71 feet. North of the area, the individual splits have been traced back to the unsplit Liddell Seam. The only indications of washouts in the whole area come from 32T and 7S Parnell's Creek, in which the upper split of the Liddell Seam is missing.

Cycle 2 comprises seventeen coal seams, designated A, B, C, E, G, J, L, N, O, P, Q, R, Farrell's Creek Seam, V, W, X, X', and their associated sandstone members. This cycle has a maximum thickness of 580 feet in the western part of the Howick area. The seams, except the Farrell's Creek Seam, are thin, though locally two or more seams unite into a thick seam. Several seams cut out laterally. The quality of coal is low, and the ash-content high. Farrell's Creek Seam is exceptional in maintaining a mean thickness of 7 feet; its maximum thickness is 15.8 feet in 6S Parnell's Creek. Farrell's Creek Seam does not split in the Howick area, and its chemical composition is uniform: ash content 12-19%, volatiles 25-30%. In the Bayswater No. 1 Bore, the tentative indentification of a thin seam as the Farrell's Creek Seam indicates that this seam is probably best developed in the Howick area. In ascending order, each minor cycle, as in cycle 1, comprises a bed of greywacke sandstone from 10 to 100 feet thick (in some bores conglomeratic), a thinner bed of siltstone, a thin bed of shale or claystone, and a coal seam. The minor cycle of cycle 2 differs from that of cycle 1 in being less regular in the thickness and succession of beds.

Cycle 3 comprises seams Y (? Bayswater Seam) and Z, and enclosing clastic strata. A return to the more regular cycle of cycle 1 is indicated by the thick seams. Seam Y is recorded from 2SR Pond's Creek and 1S Jerry's Plains. It is split by thin bands of sandstone. The high stratigraphical position of seam Y (950 feet above the base of the Tomago Coal Measures) and its aggregate thickness of 18 feet probably indicate its continuity with the Bayswater Seam of the Bayswater-Ravensworth area (Foskett, 1953).

STRUCTURE.

The axis of the Muswellbrook Anticline crosses the area from north-west to south-east. The anticline is asymmetrical; it dips $4\frac{1}{2}^{\circ}$ south-eastward, and 21° south-westward. Dips on the western side therefore are the only ones for which allowance has to be made in computing stratigraphical thickness from bore data. The anticline plunges gently to the south-south-east. A minor reversal in plunge direction, shown in the axial section BB1 (Plate 2), takes place near 24S Parnell's Creek; north of 24S, the anticline plunges $4\frac{1}{2}^{\circ}$ to the south-south-east; south of 24S, 2° in the opposite direction. This change in plunge direction explains the nearly parallel outcrop traces of seams on either side of the anticlinal axis in the south-eastern part of the area.

Section CC1 (Plate 2) shows the simple structure typical of the greater part of the area. The structural contours of Barrett's, Artie's, and Farrell's Creek Seams are evenly spaced, parallel, and straight over short distances. The few irregularities in the structural contours are attributable to different thicknesses of stratigraphical units.

No evidence of faulting was seen.

The minor structures imposed on the Muswellbrook Anticline by the intrusion of the Howick Sill are described below (p. 17).

The main movements controlling cyclic deposition in the Tomago Coal Measures of the Howick area were epeirogenic, but, at the same time, there was broad folding along the axis of the Muswellbrook Anticline. According to Osborne (1950, p.72), the first movement of the Hunter-Bowen Orogeny followed the deposition of the "Muree" rocks, and the second the Mulbring Beds. It is the second episode that is reflected in the rocks of the Howick area. Although the top of the Pond's Creek Formation was locally scoured by the currents responsible for depositing the basal sandstone member of the coal measures, the isopachs of Reynolds' Unit 4 (fig. 5) probably indicate the approximate range of thickness before erosion. Unit 4 is

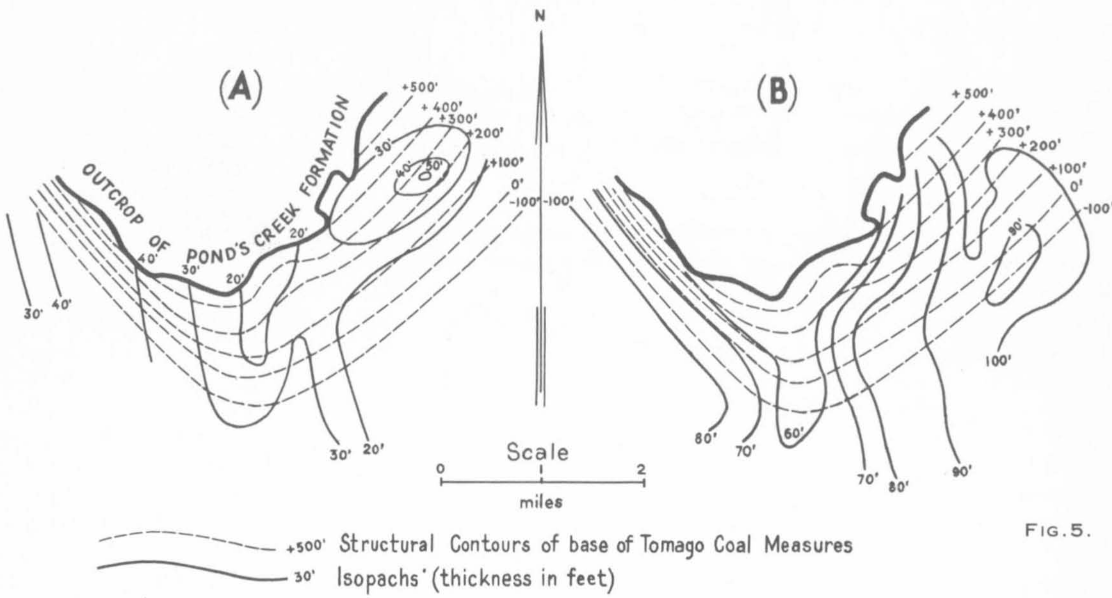


FIG. 5.

chosen instead of the entire Pond's Creek Formation because, whereas few bores penetrated the entire section of the Formation, several penetrated its uppermost part (Unit 4). A patch of anomalously thick Unit 4 (up to 51 feet thick) lies in the northern part of the area. The thickness of the rest of Unit 4 is probably related to the broad folding along the axis of the Muswellbrook Anticline: the crest of the anticline is an area of thin Unit 4, and the south-south-eastern plunge of the anticline is complemented by the thickening of Unit 4 in the same direction. East of the Howick area, in the Bayswater Syncline, unit 4 is 57'2" thick in B.M.R. 1S Liddell State Coal Reserve, and 79'3" thick in the Bayswater Bore.

A similar but clearer picture emerges from an examination of thicknesses of the Saltwater Creek Sandstone Member. The isopachs of this member in the Howick area complement the structural contours of the base of the member, although only the slightest movement could have taken place at the time. Thus in the western part of the area, over a structural contour interval of 400 feet (from 300' to -100' above sea-level), the Saltwater Creek Sandstone Member thickens 20 feet (from 60' to 80'). These contemporaneous movements are also reflected in the different thicknesses in the Howick area and Bayswater Syncline. From a maximum thickness of 116'10" in the Howick area - along the eastern margin at 1, 6S Farnell's Creek - the Saltwater Creek Sandstone Member thickens in the Bayswater Syncline to 160'5" in B.M.R. 1S Liddell, and to 155 feet in the Bayswater Bore. These weak movements are equivalent to the strong movements which 40 miles to the south-east, in the southern part of the Lochinvar Anticline, led to the overlap of the Mulbring Beds (David, 1950, Vol. 1, p.425). Appreciable movement along the Muswellbrook Anticline ceased before the deposition of Barrett's Sandstone Member, for the thickness of this and succeeding members is fairly constant. (See Fig. 2, showing generalized stratigraphical sections).

IGNEOUS ROCKS.

The main igneous intrusion of the area, the Carrington Sill, was first mentioned by Morrison & Raggatt (1928, p.111), who noted that the sill is 2 miles long and 75 feet thick, and that the rock 'approximates dolerite, with some acid phases resembling syenite.' Raggatt & Whitworth (1930) noted the Carrington Sill in a brief review of the igneous rocks of the Singleton-Muswellbrook District, and described the largest of these, the Savoy Sill. A sketch map of the Carrington Sill appeared in Raggatt's unpublished thesis (1938), but no detailed work was done.

Morrison & Raggatt (1928, p.111) point out that in addition to the Plashett and Carrington sills there are many small sills and dykes intruding the coal measures. Owing to this fact areas in which coal may be mined in the future will require to be carefully selected.' The survey of the igneous rocks of the Howick area was carried out with this fact in mind.

This account is restricted to a brief description of the field relations, shape, and magnetic properties of the intrusions. Rock samples and selected cores were given to Sydney University in 1953, and the late Dr. H. Rutledge undertook to study their petrology. This study was terminated by Dr. Rutledge's fatal accident in 1954.

Three groups of igneous rocks were found in the area: the outcropping Carrington Sill; the outcropping Howick Sill; and subsurface igneous rocks, penetrated in 2S-2SR, 4S, 15TR, and 16T Pond's Creek, and in 1S Jerry's Plains.

Carrington Sill.

In outcrop, the Carrington Sill (Plate 3) is 2 miles long and 1/3 to 3/4 mile wide; it is 50 to 200 feet thick, and dips south-west at 7^{o} to 10^{o}. The Carrington Sill forms the 'backbone' of the southern half of Howick ridge, which is a cuesta; the scarp of the southern half of the ridge (fig. 6) corresponds with the eastern, erosional, boundary of the Carrington Sill, and the western, dip slope (fig. 7), follows the slope of the sill. In plan the scarp is fairly straight; the dip slope is indented by watercourses. The six rafts of sedimentary rock that rest on the Carrington Sill have shielded it from erosion, and form the highest ground. Outcrops of igneous rocks are poor over flat ground, but are almost continuous, though deeply weathered, in watercourses. Tors up to 7 feet across abound over the southern part of the sill. At a few places (locs. 7, 8, 11, 29), the boundary between igneous and sedimentary rock is sharp, but in most places outcrop is poor, and magnetic data helped in locating the boundary.

The Carrington Sill consists of a dark medium-grained to coarse-grained holocrystalline rock, called diorite in the field, which is traversed by numerous veins, up to a foot across, of light-coloured, coarse-grained pegmatitic rock, called syenite. In the hand specimen, these veins, like certain of the acid phases of the Savoy rocks noted by Raggatt & Whitworth (1930, p.79), bear a remarkable similarity to the veins of pegmatitic syenite of the Mt. Gilbraltar intrusion, near Bowral, New South Wales.

The exposed part of the Carrington Sill is a simple sill with a flat upper surface. All visible contacts with intruded rock are concordant. Dip sections DD_1 (Plate 2) and MM_1 (Plate 4) show the flat roof and constant dip. The floor is exposed along the scarp of Howick ridge, so that the shape of the floor can be inferred from magnetic data only.

Howick Sill.

The outcrop of the Howick Sill (Plate 3), not hitherto named and described, is 1 mile long and 1/8 to 1/4 mile wide; its maximum thickness is 25 feet, and it dips generally to the west and south-west of

Fig. 6.
Looking south from Loc. 30 at scarp face of Howick Ridge, flat top of ridge formed by baked sedimentary rocks intruded beneath by Carrington Sill.

Fig. 7.
Looking south over dip slope of Howick Ridge, Hunter River and heights of Triassic rocks on right.

Fig. 8.
Loc. 40-42. Howick Sill, 1' thick, dip 10° at 300°, intruding shale and sandstone of the Tomago Coal Measures.

Fig. 9.
Panoramic view of Howick Ridge from Jerry's Plains.

6^{0} to 10^{0}. Though much thinner than the Carrington Sill, the Howick Sill nevertheless has probably played an equal part in shaping Howick ridge into a cuesta, and moreover has probably been instrumental in forming the highest ground on the ridge. The Howick Sill forms a broken line of outcrop around the northern flanks of Howick ridge and probably also on the top of the ridge at loc.43. Discontinuity of outcrop is probably due to concealment of outcrop and to thinning out of the sill. Like the Carrington Sill, the Howick Sill is concordant with intruded rock.

Two rock-types were found:

(a) Most outcrops consist of a uniform pink fine-grained rock, with porphyritic feldspar, called trachyte in the field. Weathering is deep, and even the cores of large blocks are weathered. The trachyte is possibly a fine-grained phase of the pegmatitic syenite of Carrington Sill. The trachyte is up to 25 feet thick and is similar in appearance to the indurated sedimentary rock concordantly enclosing it - massive, tough, light-coloured, and with a similar form of weathering. This similarity makes it difficult to trace the outcrop, especially where the sill thins to as little as one foot (fig. 8). Raggatt (1938) mapped only the two large outcrops of Howick Sill (Plate 3, locs. 47-50, and Plate 1, detail 2).

(b) Dolerite was found at two places only (Plate 3, locs. 37-39 and 60-62): at locs. 37-39, the dolerite occurs as loose boulders; at locs. 60-62, it occurs in a gully, is hard and dense, and onion weathered.

The field relations between the trachyte and dolerite are not known. They occur at the same stratigraphical level, so that if they form two separate sills, they possibly touch at the edge.

At most of its outcrops, Howick Sill lies immediately beneath Seam W. This seam was identified on the eastern side of Howick ridge by projecting the outcrop of the coal seam (Plate 1, detail 1) into the section recorded from 3S Pond's Creek, and on the western side by projecting the outcrop (Plate 1, detail 3) into 4S Pond's Creek.

Plate 1, detail 1 is a map of Seam W exposed on a spur, with the sill exposed on the spur and in a nearby gully. The structural contours indicate a dip of $8\frac{1}{2}^{0}$ to the north-west on the western side, and a dome on the eastern side. The structural dome is copied topographically by the north-running spur which comes off at right angles to Howick ridge from a point 1000 feet south-east of Howick Trig. Station. The correspondence of topography and geological structure is possibly maintained to the very top of Howick ridge, where, at Loc. 43, trachyte crops out near a coal seam. This interpretation, shown in fig. 10, is supported by the magnetometric evidence (see p. 20). Another local anticline, with a north-easterly-striking axis, is postulated at 4S Pond's Creek (Plate 2, Section EE.).

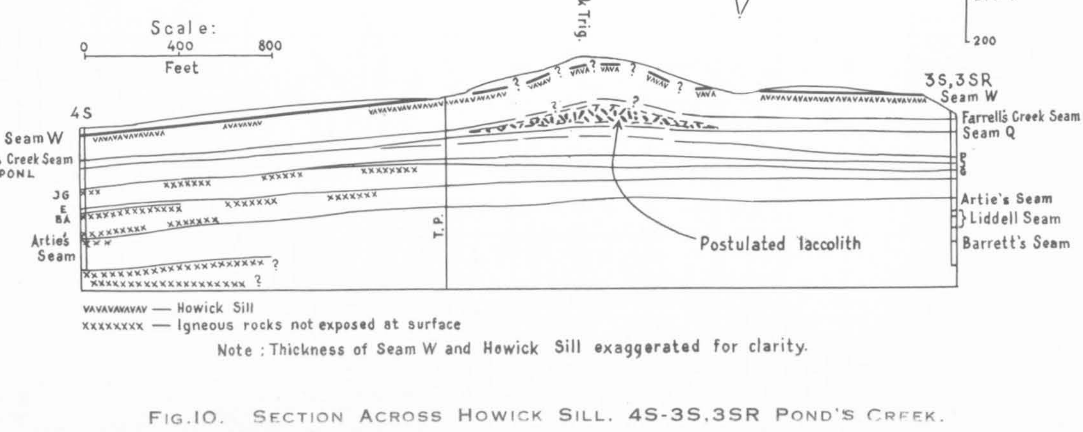


FIG.10. SECTION ACROSS HOWICK SILL. 4S-3S,3SR POND'S CREEK.

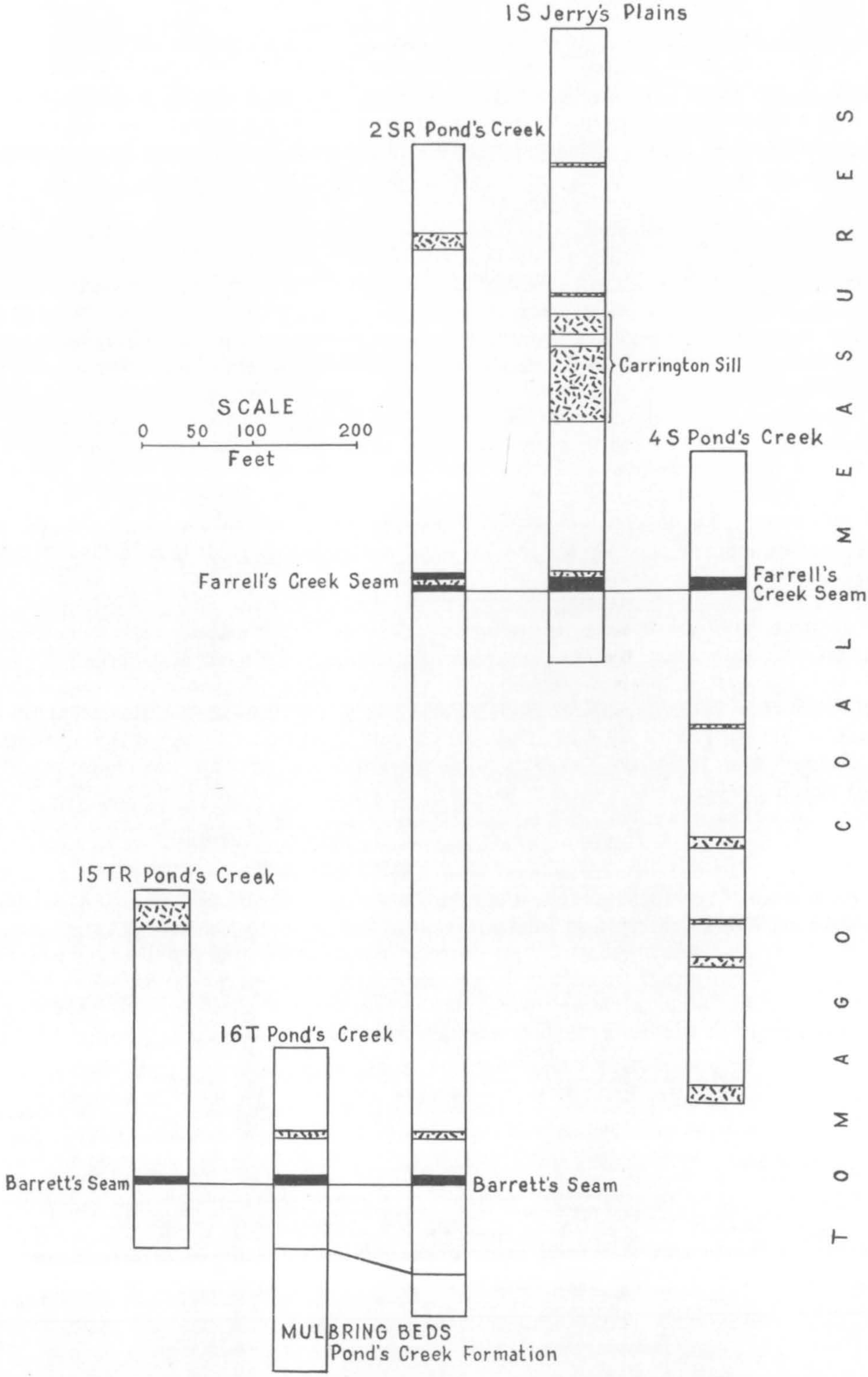


FIG. II. HOWICK AREA IGNEOUS ROCK IN BORES.
NOTE. BARRETT'S AND FARRELL'S CREEK SEAMS ARE SHOWN FOR THE PURPOSE OF CORRELATION.

The minor structures described above are superimposed on the western flank of the Muswellbrook Anticline, and were possibly caused by the updoming of sediments over a laccolithic intrusion.

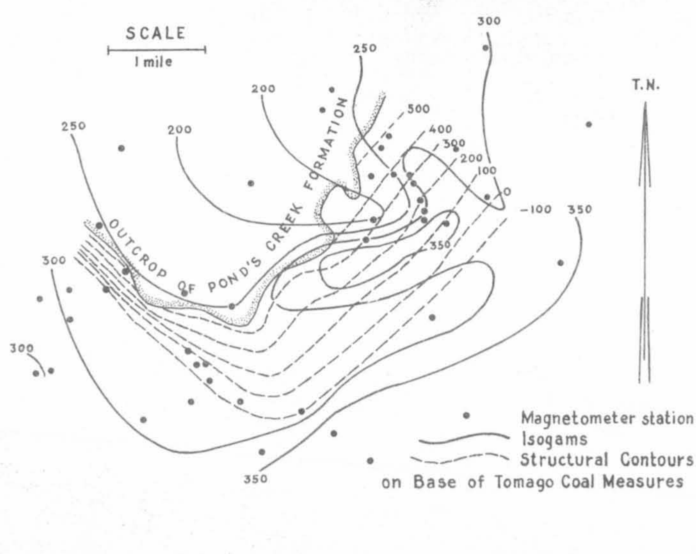
Igneous rocks penetrated by bores.

The Carrington and Howick Sills are but two of the highest igneous intrusions in the area: bores (fig.12) reveal igneous rocks sporadically distributed throughout the entire section of 1,200 feet of coal measures. The northern limit of igneous intrusion (taken also as the northern limit of cindering of coal seams - see Plate 1) lies parallel to the structural contours of the base of the Tomago Coal Measures except in the north-western part of the area, between 8S and 15T Pond's Creek. The distribution of igneous rocks in the coal measures is therefore controlled not by stratigraphy but by structure. This relationship implies that intrusion post-dated folding. The southern limit of igneous intrusion is unknown.

Of the igneous rocks penetrated by bores, only one is probably identifiable with outcropping igneous rocks. This is the igneous body penetrated in 1S Jerry's Plains between the depths of 261'5" and 365'5". In thickness and the stratigraphical level at which it is intruded, it corresponds with the Carrington Sill. This correspondence is shown by section EE_1 (Plate 2).

The Savoy Sill, 5 miles to the north, occupies the crest of the Muswellbrook Anticline, and the Plashett Sill, 3 miles to the north-west, has intruded the trough of a small syncline. In other words, both these intrusions, which are related to the Carrington Sill, are intruded into the axial parts of folds. Possibly, in the Howick area, igneous rocks were also intruded into the crest of the Muswellbrook Anticline, but at higher levels in the crest than in the flank, and have been subsequently stripped off by erosion; the absence of igneous rocks, representing feeding channels, in bores on the crest of the Muswellbrook Anticline does not rule out this possibility because such channels, if they did exist, would probably be thin and vertical, and only by an extreme chance would be penetrated by bores. No obvious sign of a large igneous body at the crest of the Muswellbrook Anticline appears in the isogam map (fig. 11), but the elogated east-west anomaly

FIG.12.



on the eastern flank possibly indicates an intrusion into rocks older than the Tomago Coal Measures (see p. 21) on the eastern flank.

Metamorphism.

The igneous rocks have baked the intruded sediments. The absence of vein infillings near the contacts implies a 'dry' type of intrusion.

MAGNETOMETER SURVEY.

The survey was carried out with a Hilger Watts vertical magnetometer; the scale constant was 32.5 gamma per scale division, and the scale was read to the nearest 0.1 scale division or ± 3 gamma. Since only one instrument was available, it was necessary to return to the base-station every two hours to determine the diurnal variation. A small error, probably about ± 2 gamma, was introduced by not having a continuous record at the base-station, and together with the reading error gives a total error of ± 5 gamma. This is negligible compared with the anomalies, which are measured in hundreds of gammas. The regional correction is 16 gamma/mile southward and ±3 gamma/mile westward. A station in the northern part of the area (M81) was chosen as base, and given an arbitrary value of 300 gamma; values measured at all other stations were reduced to this datum.

Carrington Sill.

Without exception the magnetic anomalies indicate that the induced polarization of the Carrington Sill is normal, and not reversed; that is, the floor is magnetically negative, and the roof positive. The typical magnetic profile over the floor and roof exposed in dip sections (see sections HH_1, JJ_1, KK_1, Plate 4) is, from east to west, as follows: over sedimentary rocks it is almost flat with values in the range 300-500 gamma; near the outcropping floor of the sill, it drops to 200 gamma, and between floor and roof, the anomaly, though irregular in shape, increases to a maximum in the range 500-1200 gamma near the roof. In section DD_1 (Plate 2), the minimum value is carried well past the outcropping floor and is probably due to a local anomaly within the sill itself. Nevertheless, the roof of the sill in this section corresponds with a maximum value of the anomaly. The magnetic anomaly over section GG_1 (Plate 4) differs from those described above in having a second minimum a short distance down-dip from the maximum near the roof. This second minimum may be caused by a steeply inclined vein. This interpretation is shown in Plate 4.

The anomalies over sections LL_1, MM_1, NN_1, and PP_1 (Plate 4) are not associated with either the floor or the roof, and are probably due to concentration in veins of material of different magnetic susceptibility from that of the surrounding igneous rock, to differences in the shape of the floor, or to lightning. The anomaly of 1100 gamma over a distance of 10 feet in MM_1, and 700 gamma in PP_1, was probably caused by lightning. The anomaly occurs over a rocky hillock 650' high, the highest point in the neighbourhood. Booth (1936, p.53) considered a large, sharply defined magnetic anomaly at the summit of Mt. Gilbraltar, N.S.W., to have been caused by lightning; the biggest change he recorded is 5,500 gamma in a distance of 5 yards.

The anomalies measured over sections LL_1, and NN_1, (Plate 4) are possibly caused by a vein dipping to the west.

Howick Sill.

This thin sill is harder to detect, both geologically and magnetometrically, than the thick Carrington Sill. Only two sections are shown (FF_1 of Plate 4, and fig. 1). Both indicate that the floor of the sill is magnetically negative, and the roof positive, as in the Carrington Sill. That this condition, however, is not general was found by traversing across the exposed sill (19' thick) at loc. 33; the magnetic profile here has a range of only 17 gamma, from 325-342 gamma, indicating perhaps that the sill is deeply weathered. The profile shown in fig. 10 supports the interpretation stated above (p. 8) that the sill closely follows the ground surface. Over the sedimentary rock between 35, 35R and the outcrop of the sill (here 7½ feet thick), the intensity is 286 gamma. At the floor of the sill, the intensity falls to 229 gamma; farther west, on sedimentary rock again, it is 300-308 gamma over a distance of 600 feet. The minimum corresponds to the floor of the sill, and the maximum, which continues over a distance of several hundred feet, is interpreted as indicating the shallow depth of the roof.

Sedimentary rocks.

Only 43 stations were occupied in that part of the area away from the Carrington and Howick Sills, so the isogam map (fig. 11) gives only an approximate indication of the anomalies. Two appear on the map:

(1) Over the western half of the area, the isogams (lines of equal vertical magnetic intensity) run parallel to the structural contours of the base of the Tomago Coal Measures. As the actual thickness of coal measure strata increases down the plunge southward (for this purpose, the ground surface may be considered horizontal), the magnetic intensity increases. This relationship arises because the greywacke sandstone of the coal measures contains a considerable amount of mechanically derived igneous rock, and probably therefore a greater magnetic susceptibility than the underlying Mulbring Beds.

(2) Over the eastern part of the area, the isogams are elongated east-west. The Tomago Coal Measures of this area are known by boring, and since no source of a magnetic anomaly is found in these beds, the source must lie deeper. An igneous intrusion similar to the Savoy, Plashett, and Carrington Sills could cause this type of anomaly. If this theory is accepted, the problem of east-west elongation of an igneous body at right-angles to the axis of the Muswellbrook Anticline must be explained.

OBSERVATIONS ON ECONOMIC GEOLOGY.

The economic results of drilling in the Howick area are recorded by Veevers (1953). The present report contains some results that may be useful in future economic investigations in the Singleton-Muswellbrook District. These are :-

1. The recognition of cyclic sedimentation in the Tomago Coal Measures of the Singleton-Muswellbrook District, first noted by Booker, is a necessary step in the identification of coal seams from one area to another.

2. Likewise the redefinition of the Pond's Creek Formation as a clearly recognisable lithological unit facilitates the identification of the boundary between marine and freshwater rocks in bores and outcrop.

3. Limited magnetometric work on the surface reveals concealed igneous rocks, which commonly lower or rarely increase the quality of coal in the intruded coal measures.

4. The thinning of the marine Pond's Creek Formation along the axis of the Muswellbrook Anticline, caused by broad folding during deposition, has several implications in oil prospecting because potential oil traps, such as up-dip pinch-outs, may be formed in this way. Australian Oil and Gas Corporation Limited plan to make a deep test in the Camberwell area, 8 miles east of the Howick area. If the Permian rocks were broadly folded during deposition in the Camberwell area as by comparison with the Howick area may be expected, the prospects for oil would improve.

ACKNOWLEDGMENTS.

I am indebted to Professor J. McG. Bruckshaw, Imperial College, London, for helpful discussion of geomagnetic problems; to officers of the Joint Coal Board at Sydney and Cessnock, and to officers of the State Mines Department, Sydney, for valuable discussion of stratigraphical problems; and to Professor C.E. Marshall, Dr. H. Narain, and the late Dr. H. Rutledge, of Sydney University, for their help and co-operation. The work of the many vacation students who assisted in the magnetometer survey is acknowledged.

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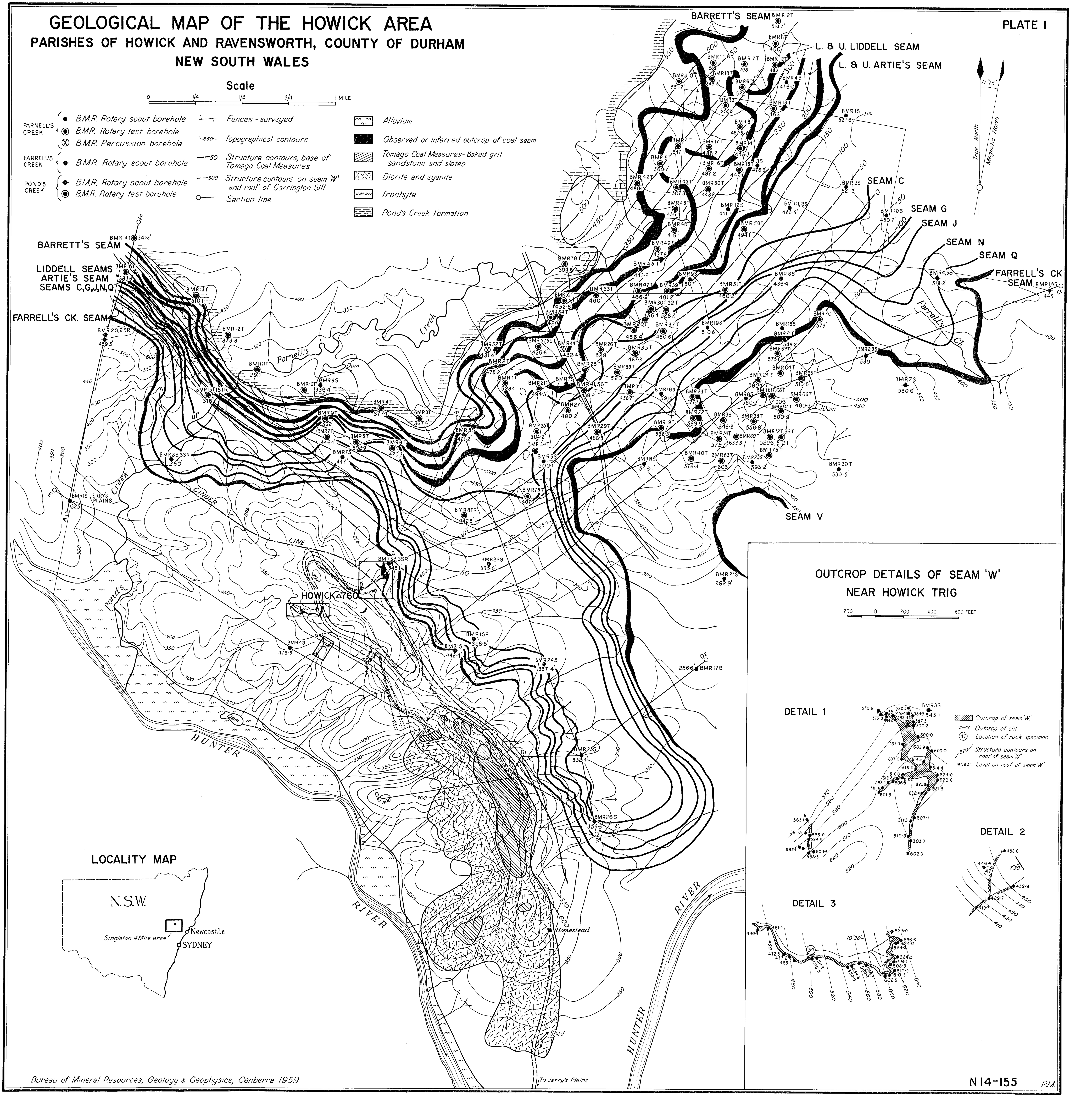
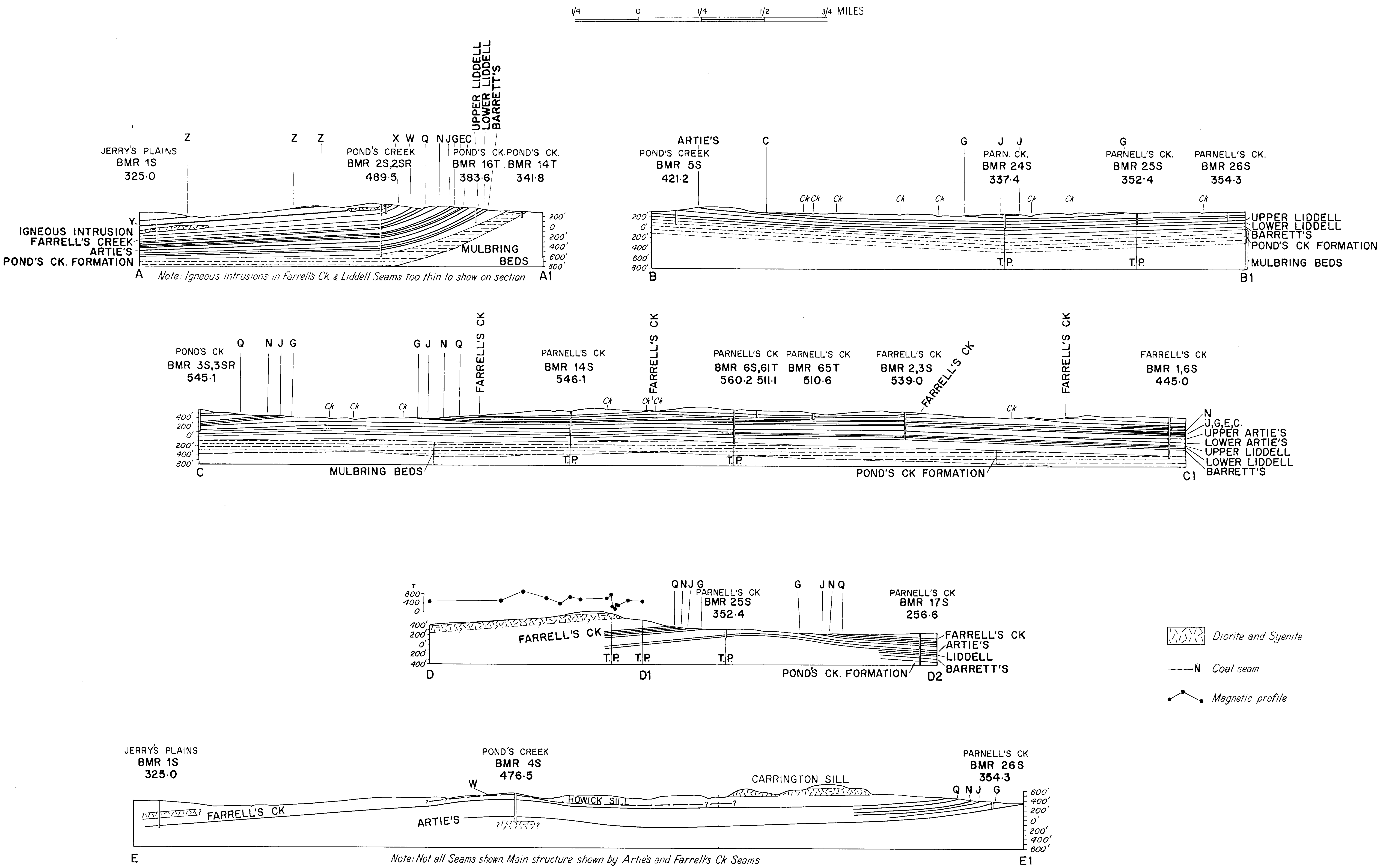
GEOLOGICAL MAP OF THE HOWICK AREA
PARISHES OF HOWICK AND RAVENSWORTH, COUNTY OF DURHAM NEW SOUTH WALES



GEOLOGICAL SECTIONS OF THE HOWICK AREA

NEW SOUTH WALES



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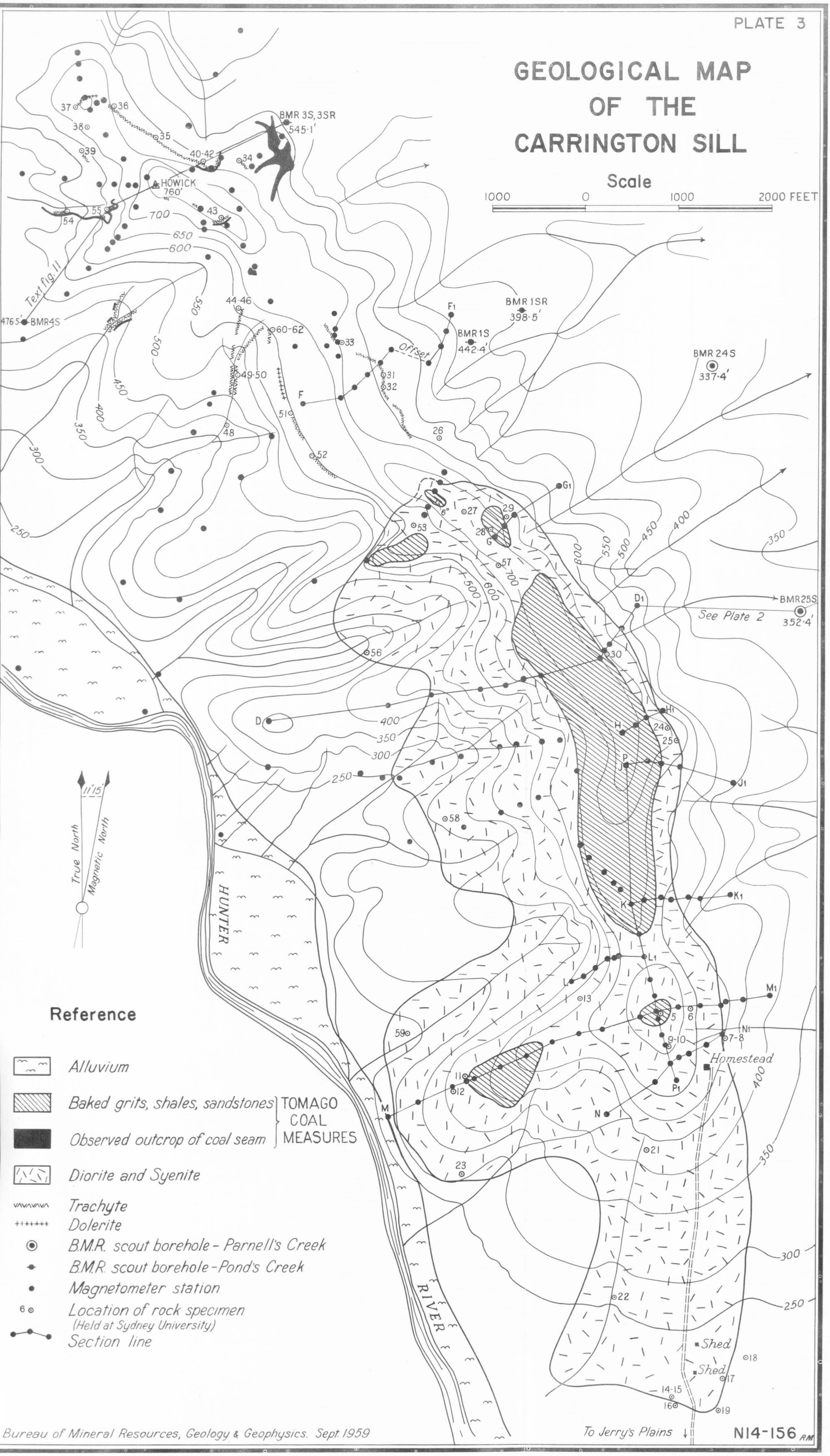
GEOLOGICAL MAP OF THE CARRINGTON SILL



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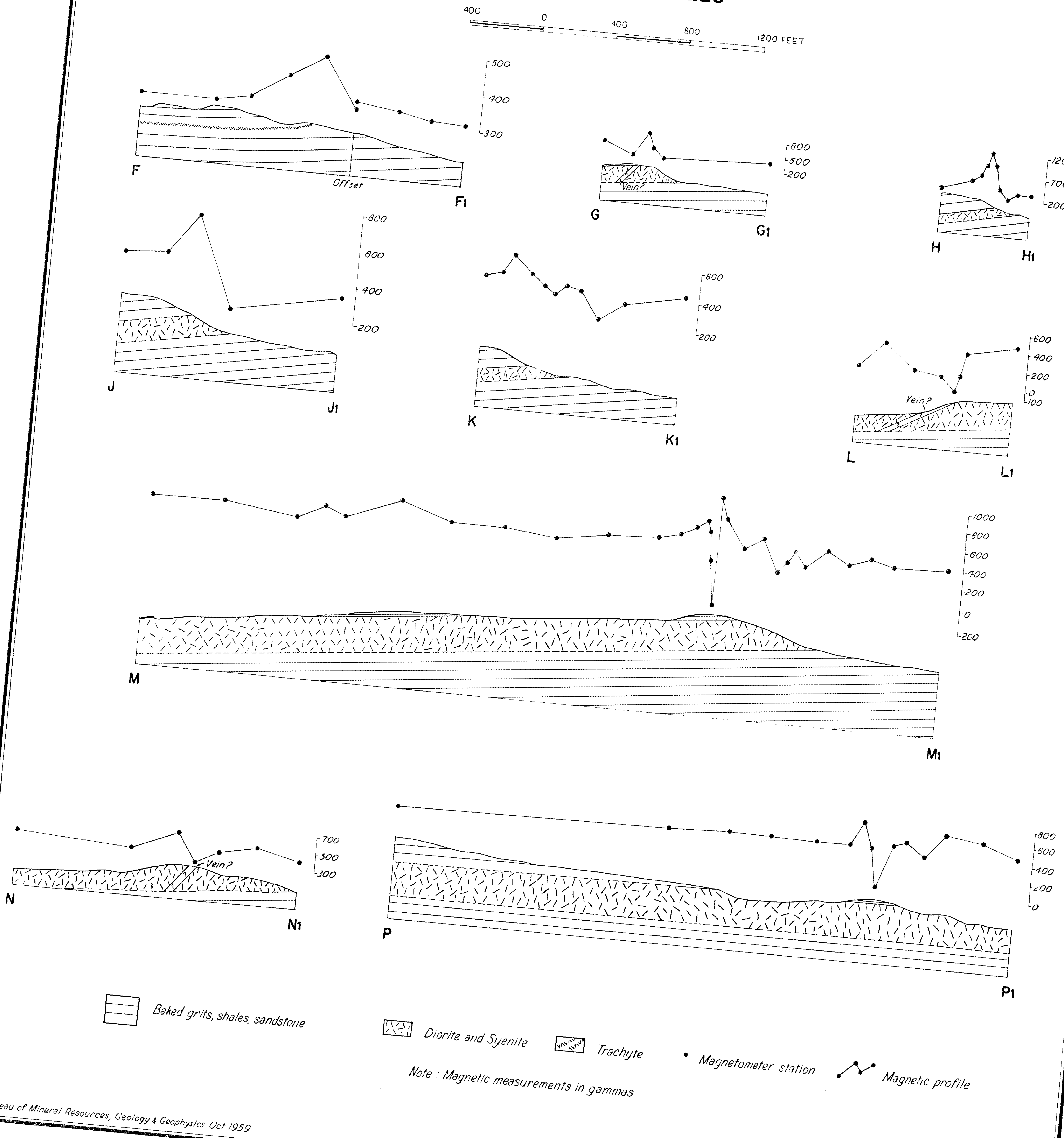
GEOLOGICAL SECTIONS OF THE HOWICK AND CARRINGTON SILLS

NEW SOUTH WALES

PLATE 4



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