Investigations into the Predictability of Volumes and Characteristics of Mine Waters in Coal Seams of the Sydney Basin

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ABSTRACT

Studies have been conducted into factors associated with the volumes and characteristics of influent and effluent waters at several underground coal mines operating in seams of the Sydney Basin.

It has been concluded that:

1. although the predominantly low sulphur coals of the Sydney Basin do not pose a threat of extensive acid mine water pollution, significant acidic mine water problems do arise during the mining of some of these coal seams if natural surface or ground waters are deficient in acid buffering constituents,

2. the prediction of qualities of mine waters requires investigation into various geological, hydrological and topographical factors in conjunction with chemical analyses of core samples and water leaching tests on samples of cores obtained during exploratory drilling, in order to establish their acidic or alkaline potential,

3. the extension of these investigations to additional coal mines and research into the morphology of pyrite are needed in order to establish relationships between the paleoenvironment of coal seams, the morphology of pyrite and the qualities of mine waters,

4. the ability to predict characteristics of mine waters prior to the commencement of mining could be a significant factor in establishing viable coal mining operations in areas where environmental factors require rigorous control of water quality.

1. INTRODUCTION

Mine waters may contain constituents which cause corrosion problems within the collieries or ecological problems when discharged on to land or into streams or lakes.

Substantial volumes of these mine waters may occur and require expensive treatment in order to render them suitable for discharge. Consequently the viability of a mining operation may be dependent upon the volume and characteristics of mine water which are encountered as extraction of the coal proceeds.

Acidic mine waters discharged from underground coal mines and coal refuse piles present one of the most persistent industrial pollution problems in the United States and over 10,000 miles of streams and rivers are adversely affected by these discharges. The cost of treatment of mine waters discharged from operating collieries in order to comply with current environmental requirements in that country exceeds $1,000,000 per day (Ref. 1).

Mine water is not only a potential environmental problem, it can also have an important influence on the economics of an underground coal mining operation as the depths of mines become greater. Groundwater is a hazard during shaft sinking and special mining methods may be necessary when mining is to be carried out in the vicinity of large aquifers.

The following questions have been addressed :-

(i) what are the causes of acidic mine waters in coalfields of the Sydney Basin?

(ii) are there correlations between the qualities of mine waters and individual coal seams?

(iii) how can the volumes and characteristics of mine waters be predicted?

The volumes and characteristics of mine waters associated with four coal seams of economic importance in the Sydney Basin of New South Wales were determined by sampling and measurements and the manner of entry of these waters into the underground workings were investigated.

2. The Sydney Basin

The Sydney Basin, the sedimentary basin in which these coalfields are located is filled by sediments deposited in the Permian and Triassic Periods, and it is about 3,000 metres deep in its central area. All of these rocks were laid down in fairly shallow water, with the Basin slowly subsiding to accommodate the in-flowing sediment. The sedimentary sequence, as a whole, has been uplifted by tectonic forces to varying degrees, such that in some places, the strata remain deep in the Basin and elsewhere are elevated to altitudes up to about 1,220 metres above sea level. Subsequent erosion in places, expose part of most units.

Shales and mudstones form the roof strata of several coal seams in New South Wales but in other cases the coals are directly overlain by sandstone (Ref. 2).

The principal coal bearing sequences of eastern Australia were deposited in fluvial and deltaic environments and only seams of the Greta and Collinsville coal measures show evidence of marine influence (Refs.2,3).

Geographic locations of the coalfields within the Sydney Basin are shown in Fig. 1 (Ref. 16) and stratigraphic sections of the western, south western and southern coalfields of the Illawarra coal measures are shown in Fig. 2 (Ref. 17).

2.1 Occurrences of Sulphur

In New South Wales, pyrite-rich coal, having high concentrations of sulphur, appears to be confined to the Greta and Tangarin Seams where the influence of marine waters has occurred (Ref. 2). Indicative sulphur contents of Australian coal seams have been published by the Joint Coal Board (Ref. 4). The total, pyritic, sulphate and organic contents of coals associated with some of these seams are given in Table 1.

TABLE 1

SULPHUR CONTENTS OF COAL SEAMS (Ref. 4)

Seam	Total S (%)	Pyrite S (%)	Organic S (%)	Sulphate (%)
Bulli	0.39 - 0.51	0.02 - 0.06	0.29 - 0.44	0.07
Fassifern	0.41	0.05	0.36	-
Great Northern	0.34 - 0.41	0.02 - 0.11	0.23 - 0.39	-
Greta	0.69 - 1.43	0.10 - 0.54	0.58 - 0.86	0.01 - 0.03
Katoomba	0.38	0.04	0.34 - 0.38	-
Lithgow	0.54 - 0.69	0.01 - 0.10	0.44 - 0.68	-
Tangorin	5.71	0.45	5.22	0.04
Wolgan	0.61 - 0.65	0.11 - 0.14	0.47 - 0.54	-

Experiments which have been conducted in Pennsylvania, U.S.A. have indicated that the most significant factor in the formation of acidic mine waters is the presence of framboidal pyrite, composed of crystals having diameters of 0.25 microns and that other forms of sulphur do not cause this problem (Refs.5,6).

In New South Wales, microscopic investigations conducted by J.G. Byrnes, and T.P. Zlotkowski (Ref. 7) detected no framboidal pyrite in several samples of coal obtained from collieries operating in the Bulli, Katoomba and Lithgow seams. The majority of occurrences of sulphide were reported to be smaller than ten microns with some grains being closer to five microns in size. They considered that framboidal pyrite would not be expected to be widespread in the coal measures of the southern and western coal fields in the Sydney Basin because of the very limited marine influence in their formation.

However, D.J. Swaine (Ref. 8) has referred to microscopic examinations of siltstone near Liddel which showed that pyrite, mainly framboidal, occurs ubiquitously in the matrix of the siltstone which showed concentrations of 1-1.5% iron disulphide (FeS_2).

To date, there is no evidence that framboidal sulphur is a significant factor in the generation of acidic mine waters in New South Wales.

3. Katoomba Seam

The Katoomba seam is the uppermost coal seam of the Illawarra coal measures in the western coalfield of New South Wales. This seam is being mined at Grose Valley and Clarence Collieries. Abandoned mines are located at Hartley Vale, Main Camp and Katoomba (Ref. 9).

Mining is conducted by bord and pillar operations using continuous miners at depths extending to 200 metres below the highly dissected Triassic sandstone of the Narrabeen series.

3.1 Ingress of Water

Flows of water into mines operating in the Katoomba Seam are within the range of one to seven megalitres per day.

Ground water flows through the roof of Clarence and Grose Valley Collieries by means of faults, fractures and shear joints which have been identified by Shepherd et al (Ref. 10).

Underground mapping of joints, fractures and faults by staff of Coalex Pty. Ltd. have confirmed these findings and it has been found the north-south lineaments are associated with the highest flows of waters into the Clarence Colliery (Ref. 11).

The presence of several shallow aquifers, which contribute to flow of minewaters at Clarence Colliery, has been established by drilling .

Generally the most significant flows of water into the mine are attributed to intensive fracturing, faulting and jointing in the rocks, allowing water to drain readily from porous overlaying strata, from infiltrating rainfall and from surface water courses and creeks.

Volumes of mine waters at Grose Valley are variable with rainfall and generally flow at the rate of one to two megalitres per day.

3.2 Characteristics of Waters

Characteristics of inflow waters, mine waters which have percolated through goafed areas and composite samples of mine waters associated with collieries operating in the Katoomba Seam are compared in Table 2 with natural surface waters.

It is evident that waters which enter the mines contain low quantities of dissolved solids and very low quantities of alkaline salts. Acidic liquors, formed by chemical reaction with oxidised pyrite within the

TABLE 2

NATURAL SURFACE WATERS, ROOF WATERS AND MINE WATERS ASSOCIATED WITH MINING OF THE KATOOMBA SEAM

Sample Origin:	Natural Surface Waters	Inlet (Roof) Waters	Goaf Waters	Composite Discharge
Number of Samples:	7	3	4	7
pH	5.1 - 7.3	6.4 - 7.1	3.0 - 4.2	3.7 - 7.2
Specific Conductance, at 25°C, microsiemens/cm,	27.9 - 234	40.4 - 74.3	127 - 789	114 - 231
Nonfiltrable residue, mg/L,	< 1 - 698	< 1 - 12	< 1 - 61	4 - 168
Total filtrable residue, 180°C, mg/L	21 - 160	30 - 32	79 - 314	90 - 151
Total Alkalinity, to pH 4.5, as $CaCO_3$, mg/L	< 2 - 89	12 - 13	Nil	Nil - 26
Total Acidity, to pH 8.3, as $CaCO_3$, mg/L	< 1 - 24	4 - 16	19 - 169	4 - 48
Calcium, Ca, mg/L	0.3 - 22.7	0.4 - 1.7	3.8 - 14.1	6.0 - 12.5
Magnesium, Mg, mg/L	0.4 - 10.6	1.0 - 1.9	3.0 - 16.0	2.4 - 12.8
Sodium, Na, mg/L	3.0 - 11.0	1.8 - 2.0	2.0 - 3.4	2.4 - 3.0
Potassium, K, mg/L	0.3 - 3.2	1.5 - 2.7	2.6 - 4.0	2.2 - 3.3
Total Iron, Fe, mg/L	< 0.1 - 41	0.1 - 11	0.5 - 8.1	0.1 - 1.8
Bicarbonate, HCO_3^-, mg/L	< 3 - 109	15	Nil	Nil - 32
Chloride, Cl^-, mg/L	3.2 - 9.2	2.7 - 4.7	0.7 - 3.5	2.0 - 4.2
Sulphate, $SO_4^=$, mg/L	0.6 - 98	0.9 - 2.7	32 - 220	33 - 87
Total Phosphorus, P, microgram/L,	5 - 380	< 2 - 30	< 2 - 35	9 - 160
Total Manganese, Mn, mg/L	< 0.005 - 1.2	< 0.005 - 0.52	0.70 - 6.3	0.011 - 2.1
Total Zinc, Zn, mg/L	0.024 - 3.4	0.006 - 3.4	1.5 - 8.3	0.66 - 6.9

< = less than

mines, when the waters percolate through fractured rocks and coal in goafed areas, are consequently not neutralised and become progressively more acidic as bacterial reactions occur.

Consequent upon the formation of these acidic liquors, iron, manganese and zinc, contained in the sedimentary rocks, are dissolved in the mine waters.

4. Lithgow Seam

The Lithgow Seam is the major economic coal seam of the Western Coalfield of New South Wales and is mined at twelve collieries. Both bord and pillar and longwall mining operations are employed.

Investigations into mine waters were conducted at Angus Place, Invincible, Baal Bone and Wallerawang Collieries. Longwall mining was being carried out at Angus Place whilst bord and pillar operations were conducted at the latter three mines.

The stratigraphic location of this seam, within the Cullen Bullen Sub-Group of the Illawarra Coal Measures, is approximately one hundred metres below the Katoomba Seam.

It is overlain by medium to coarse grained sandstones of the Wallerawang Subgroup but the interburden is predominantly claystone and mudstone.

4.1 Ingress of Water

Flows of water to mines operating in the Lithgow seam are within the range of approximately 0.2 to 2 megalitres per day and faults and fractures appear to be the main avenues of entry for both surface and groundwaters.

4.2 Characteristics of Waters

The characteristics of water entering the Lithgow Seam mines differ to those of the Katoomba Seam in that dissolved minerals are in much higher concentrations, as shown in Table 3. The waters entering these mines contain dissolved solids within the range of 216 to 351 milligrams per litre, compared with that of 30 to 32 milligrams per litre, in the waters entering the Katoomba Seam.

More significantly alkalinities of the waters entering these mines are substantially higher than those entering the Katoomba Seam mines. It appears that acid formation is being inhibited by these alkaline waters at Angus Place, Invincible and Baal Bone Collieries.

An exception to the alkaline waters associated with other Lithgow Seam Mines was apparent at Wallerawang Colliery, where acidic mine waters have been encountered.

The presence of acidic mine water at Wallerawang is attributed to:

(a) the relatively thin cover of thirty to forty metres of roof strata compared with fifty to two hundred metres at the other mines

(b) existence of a confined aquifer containing water of low alkalinity above the Lithgow Seam.

(c) The rapid ingress of surface water through joints, fractures and faults, permitting insufficient contact with carbonaceous sediments in overlying strata for the formation of alkaline liquors.

TABLE 3

NATURAL SURFACE WATERS, ROOF WATERS AND MINE WATERS ASSOCIATED WITH MINING OF THE LITHGOW SEAM

	Angus Place, Baal Bone and Invincible Collieries					Wallerawang Colliery	
Sample Origin:	Natural Surface Waters	Ground Waters	Inlet (Roof) Waters	Goaf Waters	Composite	Inlet (Roof) Waters	Goaf Waters
Number of Samples:	1	2	3	3	4	1	1
pH	7.5	7.8-7.9	7.0-7.7	7.0-8.4	7.4-7.9	6.0	3.2
Nonfiltrable residue, mg/L	8	<1-117	6-4550	26-668	38-800	7	10
Total filtrable residue, 180°C, mg/L	-	212-235	216-358	250-350	252-336	511	722
Total Alkalinity, to pH 4.5, as $CaCO_3$, mg/L	6	187-199	203-294	177-257	158-275	37	Nil
Acidity, to pH 8.3, as $CaCO_3$, mg/L	-	<1	<1	<1	<1	10.1	125
Calcium, Ca, mg/L	0.2	42-50	3.5-70	32-68	25-38	66	73
Magnesium Mg mg/L	0.3	18.5-20.0	7.2-26.0	16.2-28	9.5-19.0	25.0	46
Sodium, Na, mg/L	5.8	9.2-10.4	12.8-68	16.0-24.0	17.0-53	28	31
Potassium, K, mg/L	0.6	11.5-13.0	15.0-22.0	14.0-26	13.5-26	14.5	7.2
Total Iron Fe mg/L	1.4	N.T. (<0.04)	0.8 (<0.04)	0.07-12.1 (<0.04)	0.2-0.4 (0.04)	3.2 (1.60)	28 (8.6)
Bicarbonate, HCO_3^-, mg/L	7	228-243	248-359	216-314	193-336	45	Nil
Chloride Cl^- mg/L	4.5	8.3-9.1	2.6-12.5	4.9-23.4	6.7-17.1	6.0	9.0
Sulphate, $SO_4^=$, mg/L	3.1	3.6-5.9	0.6-6.2	24-76	19-40	280	530
Total Phosphorus, P, microgram/L,	20	13-23	11-290	4-22	82-410	4	4
Total Zinc, Zn,	<0.005	0.024-0.130	0.048-0.39	0.042-0.124	0.055-3.2	0.038	0.80

( ) = filtrable N.T. = not tested < = less than

5. Bulli Seam

The Bulli Seam is the uppermost seam of the Illawarra coal measures in the Southern Coalfields of New South Wales and is considered to be the Southern Coalfield equivalent of the Katoomba Seam. It is overlain by the sandstones of the Narrabeen group.

The sediments immediately above the Bulli Seam in the Burragorang Valley are argillaceous, the roof of the seam being composed of carbonaceous shale or mudstone which is transitional upwards into a hard, dark grey and black fracturing siltstone or shale. This material persists for up to twenty metres above the seam, succeeded by an abrupt transition to sandstone (Ref. 12).

The Bulli Seam is mined at seventeen collieries in the Burragorang Valley and South Coast areas of New South Wales.

Bord and pillar mining operations were being carried out at the five underground, Burragorang Valley collieries which were studied, namely, Brimstone No.1, Brimstone No.2, Oakdale, Tahmoor and Cordeaux.

These mines are deeper than those of the Western Coalfield, depths of roof rocks being within the range of 150 to 425 metres.

5.1 Ingress of Water

The flows of water into the mines vary from essentially zero at Cordeaux Colliery to about 1,300 litres per day at Brimstone No.2, 500,000 litres at Brimstone No.1, one megalitre per day at Oakdale and two megalitres per day at Tahmoor.

The origins of these mine waters are attributed to:

(i) groundwaters in confined sandstone aquifers which are intercepted by drifts and shafts

(ii) joints and fractures

(iii) volcanic dolerite dykes which intercept the sandstone aquifers

(iv) seepage from the coal seam

5.2 Characteristics of Waters

Waters entering underground workings of the collieries are composed primarily of alkaline waters, which have percolated through the carbonaceous shales and groundwaters containing carbon dioxide discharged from the sandstone aquifers, as shown in Table 4.

It is considered that the source of dissolved iron in these waters is siderite ($FeCO_3$) and not pyrite (FeS_2) because of the low sulphate contents of groundwaters and leachates from goafed areas.

TABLE 4

GROUNDWATERS, GOAF WATERS AND MINE WATERS ASSOCIATED WITH MINING OF THE BULLI SEAM

Sample Origin:	Groundwaters	Goaf Waters	Composite
Number of Samples:	10	3	5
pH	4.5-8.6	6.6-7.9	6.2-7.6
Specific Conductance, at 25°C, microsiemens/cm,	279-815	760-4400	662-3600
Nonfiltrable residue, mg/L,	<1-162	1-23	<1-60
Total filtrable residue, 180°C, mg/L	189-410	351-2830	348-2220
Alkalinity, to pH 4.5, as $CaCO_3$, mg/L	Nil-420	355-2750	307-2200
Total Acidity, to pH 8.3, as $CaCO_3$, mg/L	Nil-26	<1	<1-7.8
Calcium, Ca, mg/L	4.0-86	69-95	50-82
Magnesium, Mg, mg/L	4.4-37	36-39	23.5-33
Sodium, Na, mg/L	18.0-108	27-1120	24.0-900
Potassium, K, mg/L	0.91-23.5	37-57	27-47
Total Iron, Fe, mg/L	0.06-41 (0.04-3.60)	0.06-0.90 (0.04)	0.08-0.37 (<0.04-0.08)
Bicarbonate, HCO_3^-, mg/L	Nil-512	433-3360	375-2680
Chloride, Cl^-, mg/L	30-195	21.3-51	27-57
Sulphate, $SO_4^=$, mg/L	0.6-17	0.8-25	0.8-17
Total Phosphorus, P, microgram/L,	8-940	2-4	7-69
Total Manganese, Mn, mg/L	0.060-1.95 (0.020-1.48)	0.020-0.040 (0.020)	0.020-0.080 (<0.02-0.080)
Total Zinc, Zn, mg/L	0.042-0.215	0.014-0.056	0.030-0.056

( ) = filtrable < = less than

6. Variable Characteristics of Mine Waters

The characteristics of mine waters encountered in the collieries which have been studied are outcomes of the paleoenvironments of the different coal seams, the topography of the area in which each mine is located, the depth of each mine, the tectonic movements which have caused faulting and fractures, the volumes and characteristics of groundwaters which occur and the subsidence which has resulted from the mining operations.

6.1 Acidic Mine Waters

It is evident that acidic mine waters occurring in collieries operating in the Katoomba and Lithgow Seams are waters which have percolated from the surface or from aquifers with little or no contact with carbonaceous sediments. These waters react with oxidised pyrite in goafed areas of the mines, causing reductions in pH. Once the pH has reached a value of approximately 3.0 the growth of bacteria is promoted and the production of acid is accelerated (Ref. 1).

The reaction of water with pyrite in the coal of the Katoomba Seam is exhibited also in the acidic leachates of coal stockpiles which are encountered at Clarence Colliery. In addition, there are reports by C. Ward (Ref. 13) on acidic leachates from waste dumps in the Lithgow area, indicating the propensity of coal mined from the Lithgow and Katoomba Seams and associated rocks to promote the formation of acidic waters.

There is no evidence that either the amount or morphology of pyrite in the coal of the Katoomba Seam differ significantly to those in coals of the Lithgow, Bulli or Great Northern Seams.

It is considered that the shallow depth of the Wallerawang Colliery together with unbuffered groundwaters leads to similar conditions to those experienced at Grose Valley and Clarence Collieries.

6.2 Non-acidic and Saline Mine Waters

The non-acidic mine waters experienced at collieries in the Lithgow, Bulli and Great Northern Seams are considered to be caused by reactions of the varying amounts of carbonaceous rocks with the natural surface and groundwaters prior to their entries into the mines. These alkaline waters neutralise acids formed by reaction of water with pyrite preventing significant reduction in pH, thus inhibiting the formation of acid producing bacteria.

7. PREDICTION OF QUALITIES AND QUANTITIES OF MINE WATERS

It is evident that the volumes and characteristics of mine waters are determined by the processes which have caused the formation of coal seams, the deposition of overlying rocks and the tectonic events which have contributed to the geology, geochemistry and topography of an area associated with a specific underground coal mine, together with meteoric events and the occurrences of groundwaters.

7.1 Quality

Five main approaches to the prediction of the quality of mine water prior to the development of a colliery are proposed. They are:

(i) evaluation of quality based on qualities of mine waters discharged from adjacent collieries operating in the same coal seam.

(ii) prediction of quality based on sedimentary geology with particular reference to carbonaceous mineralisation

(iii) chemical analyses of core samples, obtained during exploratory drilling and calculation of acidic and alkaline components of the rocks.

(iv) laboratory investigations embracing water leaching tests with coals and rocks in order to simulate approximately, in an accelerated manner, the percolation of water through rocks and coal seams

(v) measurement, analysis and mapping of groundwaters encountered during drilling operations.

7.2 Quantity

As in the prediction of quality of mine water, the prediction of flow involves the collection of data embracing several scientific and engineering disciplines involved in exploration, drilling, meteorological and stream gauging statistics, surface subsidence, geotechnical surveys, aerial photography and lineament and fracture analysis.

Atkinson et al (Ref. 14) have reviewed the various hydrological, petrophysical, remote sensing and geotechnical techniques available for the quantitative determination of inflows to underground coal mines.

R.N. Singh, S. Hibberd and R.J. Fawcett have reported (Ref. 15) the development of mathematical models of groundwater inflow to longwall coal panels and of hydraulic conductivities induced by longwall mining.

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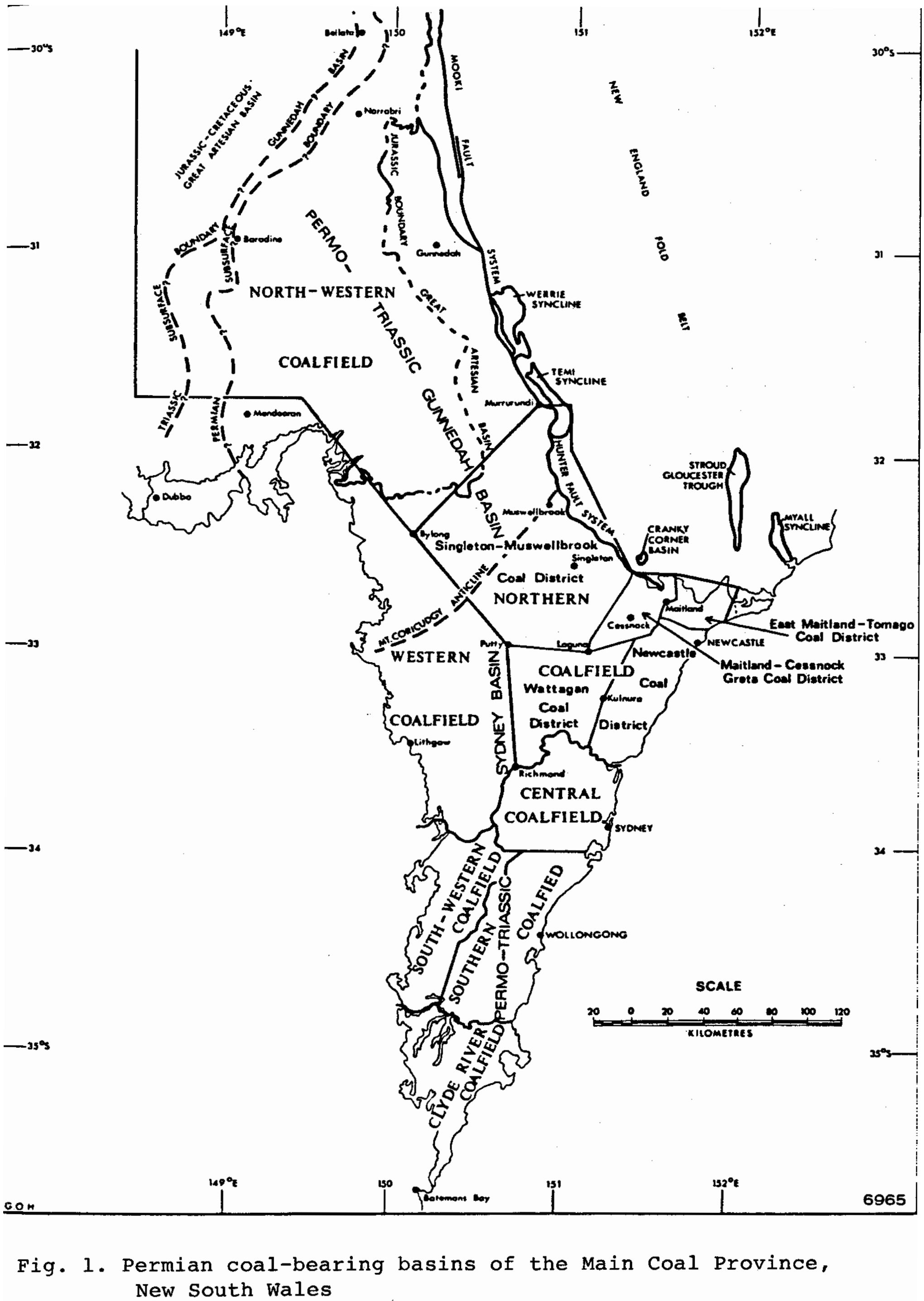
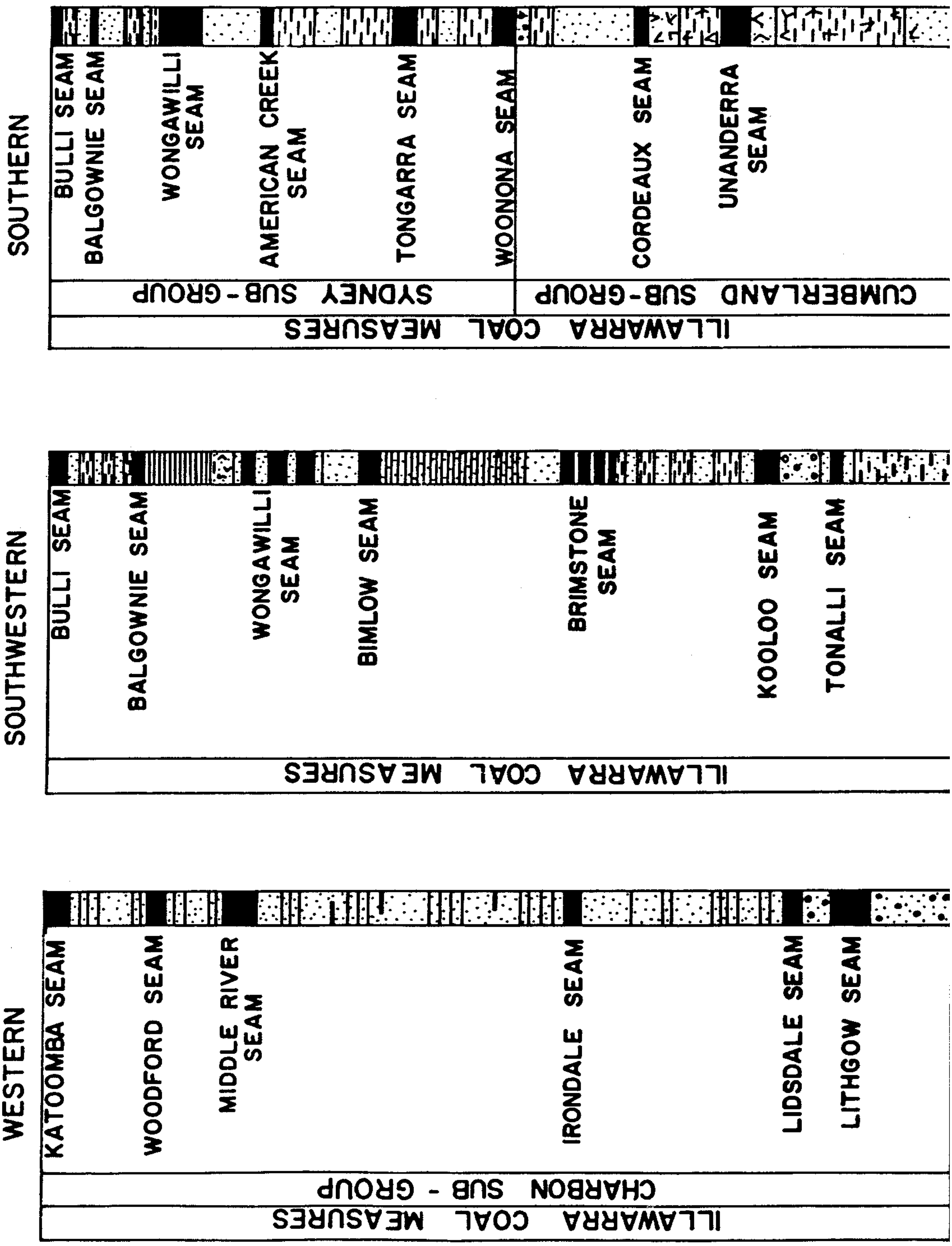


Fig. 1. Permian coal-bearing basins of the Main Coal Province, New South Wales

Ref. 16



Ref. 17

Fig. 2. Sections of the Illawarra Coal Measures and their equivalents.