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ADVANCES IN THE STUDY OF THE SYDNEY BASIN

PROCEEDINGS

of the

TWENTIETH SYMPOSIUM

DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF NEWCASTLE N.S.W.2308

PREFACE

Welcome to the 20th Newcastle Symposium!

Two decades ago the Department of Geology celebrated its transfer from the cramped conditions of Tighe's Hill to the then seemingly vast space of the new building on the Shortland Campus by holding a symposium on "Advances in the Study of the Sydney Basin". It was an instant success and most of the 64 participants agreed with Ken Mosher, who in a spontaneous vote of thanks, urged us to organise another such gathering in due course. However, not even he would have anticipated that the Newcastle Symposium, as it has become known since then, would become an annual event in the Australian geological calendar.

Although the title of the Symposium still acknowledges the Sydney Basin as its cradle, both participants and their contributions come from many parts of Australia and now, for the first time, from overseas as well. This broadening of scope has generated a wider interest in the Symposium, particularly for the published proceedings which attract a growing number of subscriptions by a variety of organisations. In response to the increasing reliance on the written text by people who are unable to attend the Symposium, we have extended the acceptable number of pages to five per contribution with the proviso of adding more pages should this be necessary.

Another innovation is the inclusion of the excursion guides in the Proceedings. In the past, such information used to be handed out as loose leaflets without any copyright cover. In a limited number of cases this led to some misuse of the information conveyed, whereas in other instances authors found it difficult to refer to the excursion synopses because of the lack of formal status. By including such material in the Proceedings it can be referred to in the same way as any other paper, e.g. name, year, title. Adv. Stud. Syd. Bas., 20th Newcastle Symp., Proc., pp. xx-yy.

Finally, I wish to thank our many friends for their continuing support and I extend a particularly warm welcome to those of you who attend the Symposium for the first time. May there be many happy returns.

Glückauf!

Claus F.K. Diessel
Convener

FOREWORD

Welcome to the Twentieth Newcastle Symposium, which is the longest running annual geological event in Australia. Suggestions for an annual symposium on "Advances in the Study of the Sydney Basin" were first aired by this year's Convener more than twenty years ago and if it were not for his energy we would not have been able to continue the Symposium. It is very pleasing that we continue to have a large number of participants.

The Friday excursions cater for those interested in engineering geology and coal measure sedimentation. Because of the large number of papers to be presented, we have organised parallel technical sessions on the Saturday afternoon and Sunday morning. The programme attempts to provide for a variety of interests both on the broad and more detailed scale.

The Keynote Address is by Professor Phillipa Black of the University of Auckland, who will be talking on the coalfields of New Zealand. She is well known for her work on geochemistry, metamorphism and coal geology - an unusual combination. Her address is an opportunity to learn about coals which are so different from those in Australia. I wish to thank the Vice-Chancellor, Professor George, for providing funds to enable Professor Black to address the Symposium.

Immediately before the Symposium is the Meeting of the Working Group MN/1/1 (Petrography) of the Standards Association of Australia. The official dinner is being held again at the Newcastle City Hall which enables participants to meet congenially, enjoy the company or possibly even forget everything. On the Sunday afternoon of the Symposium, the Coal Geology group of GSA has its Annual General Meeting.

Not only is 1986 the 20th Symposium, but it is also the year of the 75th birthday of Arthur Ritchie, the first appointment to the Department of Geology at Newcastle. Arthur Sinclair Ritchie was born at Richmond, N.S.W. on 2nd March, 1911 and attended Parramatta High School. He won a scholarship to Sydney Teachers' College and later began studies at Sydney Technical College. In 1938 he came to Newcastle, where he taught science in high schools until 1945, and became part-time lecturer in diploma classes in Geology and Mineralogy at the Technical College. In 1947 he became full-time lecturer at the College, later to become supervising lecturer in the School of Mining and Applied Geology. With autonomy, he continued on the staff of the University of Newcastle, attaining the position of Associate Professor in Geology.

Arthur Ritchie published a book, "Chromatography in Geology", published five chapters in books with joint authors, five book reviews and 23 articles in Australian and international journals. His publications covered the topics of glaciology, strandline processes, the Tomago Sand Beds and chromatography.

I.R. Plimer
Head of Department

20TH NEWCASTLE SYMPOSIUM

P R O G R A M M E

THURSDAY, 15TH MAY, 1986

10.00	Meeting of Working Group MN/1/1/1 (Petrography) of the Standards Association of Australia.

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FRIDAY, 16TH MAY, 1986

08.30-17.00	**Excursion 1**, Leader: Assoc. Prof. K.H.R. Moelle This excursion will concentrate on engineering geological aspects in the Newcastle and Lake Macquarie area.
08.30-23.00	**Excursion 2**, Leader: Assoc. Prof. C.F.K. Diessel The second excursion will deal with coal measure sedimentation at Saxonvale Mine and Permian geology of the Lower Hunter Valley. Included is a wine tasting and a dinner at the Pokolbin Cellar Restaurant.

SATURDAY, 17TH MAY, 1986

08.30-09.00 **REGISTRATION** in the foyer of the GEOLOGY BUILDING

LECTURE THEATRE E01

09.00-09.05 Welcome by the Head of the Geology Department

09.05-09.10 OPENING of the 20th NEWCASTLE SYMPOSIUM by the Vice-Principal and Deputy Vice-Chancellor of the University of Newcastle, Professor K.R. Dutton.

TECHNICAL SESSION 1: Regional and Sedimentary Geology

Chair: Mr. G.N. Sharrock, General Manager, Bayswater Colliery Company Pty Ltd.

09.10-09.40 The SYDNEY AND GUNNEDAH BASINS - A REAPPRAISAL
P.H. West, E.K. Yoo and G.M. Bradley, N.S.W. Department of Mineral Resources

09.40-10.20 NEW DATA ON THE STRUCTURAL STYLE AND SUBSURFACE GEOLOGY OF THE BELLATA AREA, SURAT/GUNNEDAH-BOWEN BASINS
L.T. Etheridge, Department of Mineral Resources

....

10.20-10.50 MORNING TEA in the Foyer of the Great Hall

....

10.50-11.20 THE COAL RESOURCES OF TASMANIA
C.A. Bacon, Department of Mines, Tasmania

11.20-12.20 ***** **KEYNOTE ADDRESS** *****

NEW ZEALAND'S COALFIELDS, THEIR GEOLOGY, PETROLOGY AND INORGANIC GEOCHEMISTRY.
Professor Philippa Black, Department of Geology, The University of Auckland, New Zealand

12.20-12.25 **CHAIR:** SUMMING UP AND VOTE OF THANKS

....

12.25-13.45 LUNCH in the Staff House of the University

....

SATURDAY, 17TH MAY, 1986

LECTURE THEATRE E01

TECHNICAL SESSION 1 (continued):

Chair:	Mr. A.M. Robinson, Regional Manager - Northern Coalfields, Department of Mineral Resources.
13.45-14.15	THE STRUCTURE AND SEDIMENTATION OF THE NORTHERN GUNNEDAH BASIN M. Hill, N.S.W. Department of Mineral Resources
14.15-14.45	EARLY PERMIAN SEDIMENTATION PATTERNS IN THE WEST GUNNEDAH SUB-BASIN S. Thomson, Vickery Joint Venture
14.45-15.15	ON THE RELATIONSHIPS BETWEEN COAL FACIES AND DEPOSITIONAL ENVIRONMENTS C.F.K. Diessel, The University of Newcastle
15.15-15.45	THE RELATIONSHIP BETWEEN SEAM SPLITTING, COAL FORMING ENVIRONMENTS AND COAL PROPERTIES IN THE NEWCASTLE COAL MEASURES P.R. Warbrooke and M.J. Roach, BHP Collieries Division

....

15.45-16.15 AFTERNOON TEA in the foyer of the Great Hall

....

16.15-16.45	COAL EXPLORATION BY THE NEW SOUTH WALES ELECTRICITY COMMISSION C.R. Weber, N.S.W. Electricity Commission
16.45-17.15	THE GEOLOGY AND COAL DEPOSITS IN THE WYONG REGION M.A. Bocking and M.S. Howes, N.S.W. Electricity Commission
17.15-17.45	LATE PALAEOZOIC AND EARLY MESOZOIC "OROGENY" IN EASTERN AUSTRALIA J.M. Dickins, Bureau of Mineral Resources
17.45-17.50	**CHAIR:** SUMMING UP AND VOTE OF THANKS

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19.00 for 19.30 SYMPOSIUM DINNER at the City Hall

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SATURDAY, 17TH MAY, 1986

LECTURE THEATRE B01

TECHNICAL SESSION 2: Structural and Engineering Geology

Chair: Dr. G.R. Shafto, Seniro Mining Engineer, De Beers Research Establishment, Charters, U.K.

13.45-14.15 TUNNEL BORING OR BLASTING IN COAL MEASURE STRATA AND TRIASSIC ROCKS OF THE SYDNEY BASIN
B.A. Chappell, Bureau of Mineral Resources
K.H.R. Moelle, The University of Newcastle and

14.15-14.45 CLAYSTONES OF THE NEWCASTLE COAL MEASURES - ENGINEERING ASPECTS
R. Seedsman, C.S.I.R.O.

14.45-15.15 REACTIVATION OF AN ANCIENT LAND-SLIP NEAR WALLSEND, N.S.W
R. Rigby, Newcastle Wallsend Coal Co. Ltd. and
K.H.R. Moelle, The University of Newcastle

15.15-15.45 ENGINEERING GEOLOGICAL ASPECTS OF THE MAIN NORTH HEADINGS AT ULAN No 2 COLLIERY
M.A. Johnstone, Ulan Coal Mines Limited and
K.H.R. Moelle, The University of Newcastle

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15.45-16.15 AFTERNOON TEA in the foyer of the Great Hall

....

16.15-16.45 ROAD MAINTENANCE PROBLEMS IN SOME LITHOLOGICAL UNITS OF THE NEWCASTLE COAL MEASURES
M.F. Lambert, Lake Macquarie City Council
K.H.R. Moelle, The University of Newcastle

16.45-17.15 THE EL CENTRO EARTHQUAKE AND ITS RELEVANCE TO EARTHQUAKE STUDIES IN THE SYDNEY BASIN REGION
I.A. Mumme, C.S.I.R.O. and R. McLaughlin, A.A.E.C.

17.15-17.45 COLUMNAR JOINTING IN HAWKESBURY SANDSTONE
G.R. Poole BHP Central Collieries and A.C. Hutton, Wollongong University

17.45-17.50 **CHAIR:** SUMMING UP AND VOTE OF THANKS

....

19.00 for 19.30 SYMPOSIUM DINNER at the City Hall

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SUNDAY, 18TH MAY, 1986

LECTURE THEATRE E01

TECHNICAL SESSION 3: Coal quality and technology

Chair: Professor Philippa Black, Department of Geology, The University of Auckland, New Zealand

09.30-10.00 QEM*SEM (Quantitative Evaluation of Materials by Scanning Electron Microscope): A NEW TOOL FOR ASSESSING MINERAL MATTER IN COAL, AND THE ASH PRODUCTS OF COAL COMBUSTION
R.A. Creelman, R. Greenwood-Smith, C. Paulson, Macquarie University

10.00-10.30 THE INFLUENCE OF OXIDATION ON THE FLUORESCENCE PROPERTIES OF COKING COALS
E.A. McHugh, The University of Newcastle

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10.30-11.00 MORNING TEA in the Foyer of the Great Hall

....

11.00-11.30 THE CORRELATION BETWEEN MICROFLUORESCENCE AND CARBONISATION PROPERTIES OF COALS
C.F.K. Diessel, The University of Newcastle

11.30-12.00 FUSIBLE SEMI-INERTINITE IN AUSTRALIAN COKING COALS
C.D.A. Coin, BHP Central Research Laboratories

12.00-12.30 STRATA GAS EMISSIONS FROM SURFACE BOREHOLES AT APPIN COLLIERY
S. Battino and J.F. Doyle, BHP Collieries - Illawarra

12.30-12.35 **CHAIR:** SUMMING UP AND VOTE OF THANKS

....

12.35-14.00 LUNCH in the University Staff House

....

AFTERNOON: General Meeting of the G.S.A. Coal Geology Group

SUNDAY, 18TH MAY, 1986

LECTURE THEATRE B01

TECHNICAL SESSIONS 1, 2 and 3 (continued):

Chair: Mr. B.W. Vitnell, Consultant

09.30-10.00 THE PIONEER KEROSENE OIL SHALE WORKS MT KEMBLA: A CRITICAL REVIEW
J.F. Doyle, BHP-Collieries-Illawarra and
A.C. Hutton, University of Wollongong

10.00-10.30 SYNDAX 3 - A NEW FORM OF POLYCRYSTALLINE DIAMOND TO REVOLUTIONISE CORE DRILLING
G.R. Shafto, De Beers Industrial Diamonds
Division (Pty.) Ltd.

....

10.30-11.00 MORNING TEA in the foyer of the Great Hall

....

11.00-11.30 NEW DEVELOPMENTS IN SYNDRILL POLYCRYSTALLINE DIAMOND DRILLS FOR THE PETROLEUM AND MINING INDUSTRIES
P.N. Tomlinson, De Beers Industrial Diamond
Division (Pty.) Ltd.

11.30-13.00 COMPARATIVE MINERALOGY OF METAMORPHIC INCLUSIONS IN BASALTIC DYKES FROM BLACK JACK AND NEWCASTLE COAL MEASURES
D.R. Mason, The University of Newcastle and
D. French, C.S.I.R.O.

12.00-12.30 GEOLOGICAL INVESTIGATIONS AT DUNCAN COLLIERY, TASMANIA
R.J. Williams, A.C.I.R.L. and C.A. Bacon,
Department of Mines, Tasmania

12.30-12.35 **CHAIR:** SUMMING UP AND VOTE OF THANKS

....

12.35-14.00 LUNCH in the University Staff House

....

AFTERNOON: General meeting of the G.S.A. Coal Geology Group

THE SYDNEY AND GUNNEDAH BASINS – A RE-APPRAISAL

P.H. West   Department of Mineral Resources
G.M. Bradley   Esso Australia Ltd

The Sydney-Bowen Basin is a major structural basin extending onshore from Batesman Bay in the south to Collinsville in northern Queensland. Within New South Wales, Bembrick et al (1973) defined a southern Sydney Basin, over which there was a relatively high degree of knowledge and a northern, less well known basin named the Gunnedah Basin. The boundary between the two was delineated as the Mount Coricudgy Anticline. It must be emphasised that the main reason for Bembrick et al's paper was "to subdivide the southern part into lower category structural basins and other structural units".

Veevers (1984) discussed the Gunnedah and Newcastle Sub-basins of the Sydney Basin with a boundary of "approximately 32°s latitude". The Newcastle Sub-basin introduced in Veever's paper is equilibrated with the Sydney Basin of Bembrick et al (1980) but with a different, and non-defined northern boundary.

The defining of a northern boundary to the Sydney Basin has long been a contentious issue. The Sydney Basin 1:5000 000 Geological Sheet published in 1969 shows a boundary of convenience based on the southern part of the Liverpool Range. "A Guide to the Sydney Basin" (Herbert & Helby, 1980) concentrates very heavily on the Sydney Basin as defined by Bembrick et al (1973) with a few of its papers, e.g. McClung 1973 and Herbert 1975, talking briefly about the Sydney Basin including areas north of the Mount Coricudgy Anticline. "Geology of the Sydney Basin - A Review" (Mayne et al, 1974) uses the boundary defined by Bembrick et al's (1973). Both publications however, use the 1969 Sydney Basin 1:500 000 Geological Sheet as their base map. Recent analysis of drilling and mapping across the line of the Mount Coricudgy Anticline in the Western Coalfield has revealed that the stratigraphy of the Illawarra Coal Measures is identifiable from Lithgow north to Coolah (Yoo et al, 1984).

Similarly, there is no significant change in Singleton Super Group strata between Singleton and Aberdeen in the Hunter Coalfield (Beckett and McDonald, 1984).

The aim of this paper is to reappraise the concept of the basins and to examine the validity of the northern boundaries of the Sydney and Gunnedah Basins.

NEW DATA ON THE STRUCTURAL STYLE AND SUBSURFACE GEOLOGY OF THE BELLATA AREA, SURAT/GUNNEDAH-BOWEN BASINS

L.T. Etheridge Geological Survey of NSW, Dept. Mineral Resources

During May 1985 the Petroleum Section of the Department of Mineral Resources recorded a 55 km seismic survey centered on Bellata, north of Narrabri (Figure 1). The aim of the survey was to investigate the extent, thickness and structural style of the Permo-Triassic sedimentary sequence of the Bowen-Gunnedah Basin between Narrabri and Moree. A stratigraphic hole, DM Bellata DDH1, is to be sited on line 1 of this survey.

Initial results from the Bellata survey suggest that continuity exists between the Gunnedah and Bowen Basins. An interpreted section of line 1 of the survey is given in Figure 1. Line 1 portrays a number of significant features.

1 A relatively thick Permo-Triassic (Gunnedah-Bowen Basin) section underlying the Surat Basin sequence, in the area formerly considered to represent the "Narrabri High".

2 The western extent of both the Permian and Triassic sequences.

3 A major unconformity at or near the top of the Permian. The unconformity is angular in the west but becomes disconformable in the east. The unconformity is thought to be between the Black Jack Formation and Digby Formation depositional periods.

4 Evidence of compressional (and related slip-strike) tectonics at the end of the Permian period resulting in the folding of the Permian sediments.

5 A major unconformity at the end of the Triassic Period following further compressional structuring.

6 Minor drape over compaction of the above features within the basal Surat sequence.

Line 2 of the Bellata survey also revealed a relatively thick continuous Permo-Triassic sequence. Two major igneous intrusives dominate the northern half of the line. The main feature in the southern part of line 2 is a monocline-fault structure with associated rollover. Little vertical displacement is evident and a slip-strike origin is postulated.

The section revealed by Line 3 is basically an eastern continuation of the eastern part of line 1. However, the presence of surface volcanics has resulted in poorer data quality and a drop-off in energy penetration.

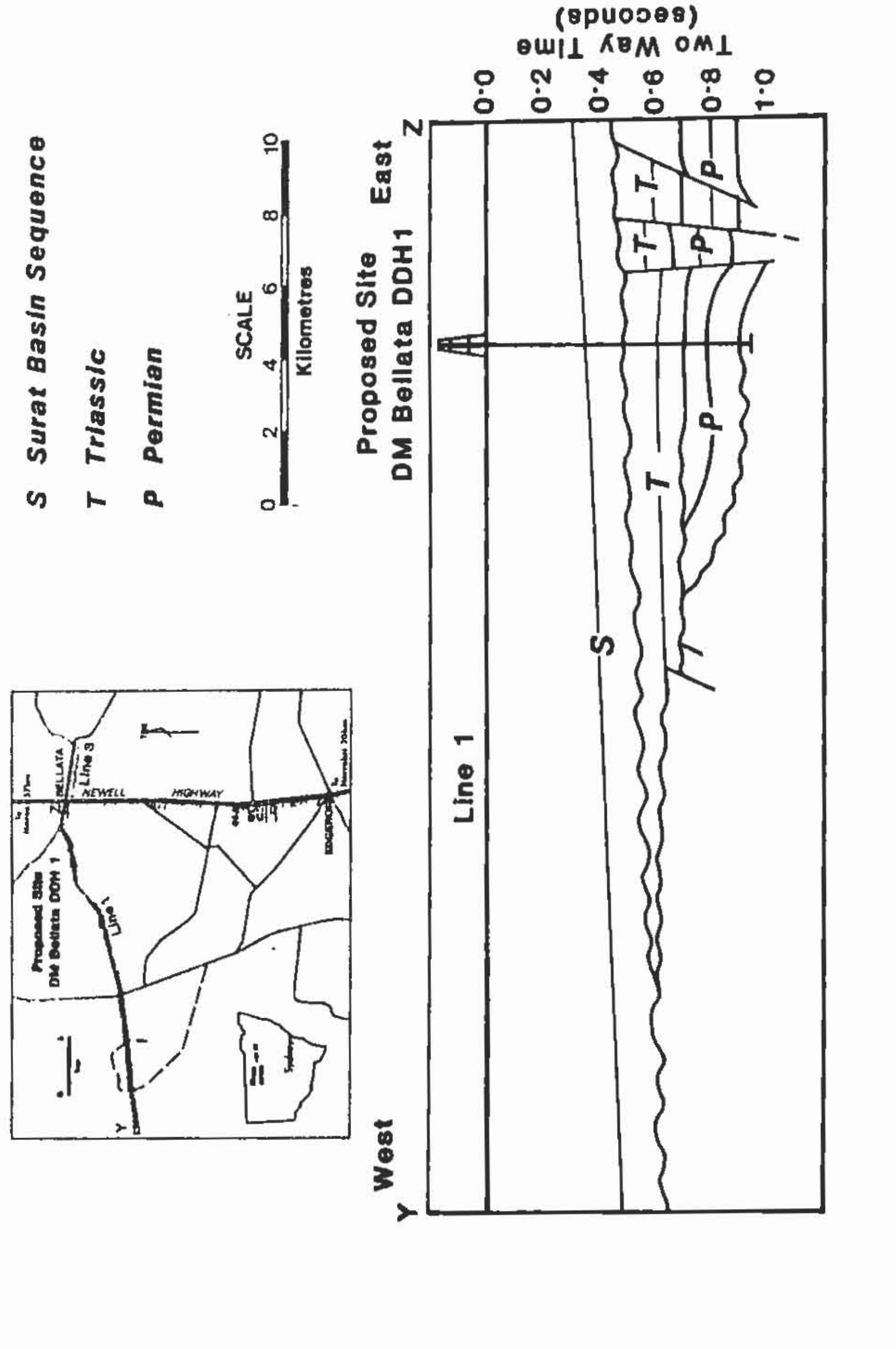

FIGURE 1 Bellata Seismic Survey, locality and cross section illustrating Line 1 interpretation

COAL IN TASMANIA

C.A. Bacon Department of Mines

Coal seams are known from three stratigraphic intervals within the Tasmania Basin. The coal bearing intervals are of Early Permian, Late Permian and Late Triassic age.

Whilst mining of seams has occurred in each of these horizons, the bulk of the State's reserves are found in the coal measures of Late Triassic age.

The coal bearing sequences were all deposited in a reasonably tectonically stable environment. The seams are all thin and discontinuous, with the two intervals of Permian age hosting only very thin seams of around 0.5 m thick. Petrographically the coals are quite different. The thin Permian coals typically have vitrinite contents of 50-60% while the Late Triassic coals are very low in vitrinite, high in inertinite and have probably been subject to oxidation.

Secondary industry in Tasmania supports a small black coal industry with two collieries currently in operation together producing some 400,000 tonnes of raw coal annually.

The term Tasmania Basin refers to a structural basin which contains the remnants of a thick sequence of flat-lying rocks ranging in age from Late Carboniferous to Late Triassic, known as the Parmeener Super-Group (Banks, 1973). The Super-Group is typically one kilometre thick and has been divided into two divisions (Forsyth *et al.*, 1974). The Lower Division Group is predominantly of marine and glacio-marine origin while the Upper Division is wholly of fresh-water origin. The Parmeener Super-Group overlies a folded basement of Siluro-Devonian metaquartzite, greywacke and granite.

Within the Lower Parmeener Super-Group is a thin freshwater interval represented by the Preolenna and Mersey Coal Measures in the northern part of the State. The coal seams in this sequence are thin; discontinuous, none being greater than 0.5 m thick, and these coals are of Early Permian (Late Sakmarian - Early Artinskian) age and so pre-date the Greta Coal Measures of New South Wales. (Noldart, 1975).

The coals contain 40-60% vitrinite and 10-25% exinite, whilst a significant proportion of alginite has been found in some coals.

The dominant exinite maceral is usually sporinite. Pyrite crystals are commonly seen in these coals which have a high sulphur content of 5%.

The largely marine and glacio-marine Lower Parmeener Super-Group is overlain by a sequence of fluviatile origin, the Upper Parmeener Super-Group. Whilst coals are found sparsely throughout the Upper Parmeener Super-Group, two horizons within the sequence contain most of the known coal seams. At the base of this Division, is the Cygnet Coal Measures and equivalents, of Late Permian age. The host sandstone is immature and very micaceous. Few analyses are available from the Cygnet Coal Measures but the few available indicate that the coal has less vitrinite than the Early Permian coals. No seams greater than 1.0 m in thickness are known from this interval.

At the top of the Upper Parmeener Super-Group is a lithic sandstone sequence in which all the economically important black coal is found. Seams are usually 1.0-3.0 m thick, but are often banded. Some of the bands have been recognised as being derived from volcanic ash. These coals are characteristically low in vitrinite with very high concentrations of inertinite. The State's measured and indicated *in situ* reserves of 530 mt of black coal are confined to this coal bearing sequence.

The Parmeener Super-Group has been extensively intruded by, and is now capped by a series of dolerite sheets and sills.

Faulting has further disrupted the sequence, and lack of persistent marker horizons in the lithic sandstone sequence make correlation difficult. Exploration for coal typically involves drilling through 100-300 m of dolerite prior to reaching the coal bearing sequence.

The whole of the Parmeener Super-Group was deposited in a reasonably stable tectonic environment, although some instability during the Early Permian (coinciding with part of the Hunter-Bowen Orogeny in New South Wales) caused uplift, downwarping and movement of the zones of maximum thickness (Banks, 1962).

As a result of the stable tectonic environment deposition was slow and the seams thin. However, there are distinct petrographic differences between coals in the three stratigraphic intervals.

The Tissue Preservation Index (TPI) and Tissue Gelification Index (TGI) can be used to interpret environmental conditions within a coal swamp, with the TPI (wood ratio) contrasting the volume of macerals derived from cell tissue with the macerals derived from the destruction of cellular tissue. The TGI is a measure of the moisture available in a swamp (Diessel, 1983).

Using the TGI and TPI indices as defined by Diessel (1983), the environment of deposition of the Late Triassic coals is indicated as being very dry, with a substantial proportion of material being derived from woody tissue. These coals probably formed in a forest moor habitat.

The Early Permian (Mersey Coal Measures) were evidently deposited in a much wetter environment than the Late Triassic coal; but the coal has virtually no woody tissue. These coals have a TGI of around 1.0 and a very low TPI of 0.25-0.75. The environment of deposition of the Early Permian coals was a wet, treeless moor environment. The presence of alginite and high sporinite contents also support this interpretation.

In addition to the Permian and Triassic coals, lignite of Tertiary age occurs throughout the State. The largest deposit is at Rosevale, in northern Tasmania, where recent exploration has defined an *in situ* indicated reserve of 118 mt.

The only coal currently extracted in Tasmania is of Late Triassic age. Two collieries operate in north-eastern Tasmania, producing some 400,000 tonnes of (raw) coal annually, all of which is consumed by domestic secondary industries.

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NEW ZEALAND'S COALFIELDS, THEIR GEOLOGY, PETROLOGY AND INORGANIC CHEMISTRY

P. Black The University of Auckland

With the exception of a few thin, dirty and uneconomic coal seams in the Upper Jurassic, all New Zealand coals are Upper Cretaceous to Mid Tertiary in age. They range in rank from lignite (brown coal) to semianthracite. The location, age and rank-range of New Zealand coalfields are shown in Figure 1 and the New Zealand Ministry of Energy's 1982 estimation of production and reserves shown in Figure 2.

Their age, rank ranges, style of deposition and deformation and geographic location cluster New Zealand coals into three groups:

(1) South Island coals, of subbituminous to bituminous rank and Upper Cretaceous to Eocene age.

(2) North Island coals, subbituminous and Upper Eocene to Lower Miocene in age.

(3) Otago and Southland (South Island) Lignites of Oligocene to Miocene age.

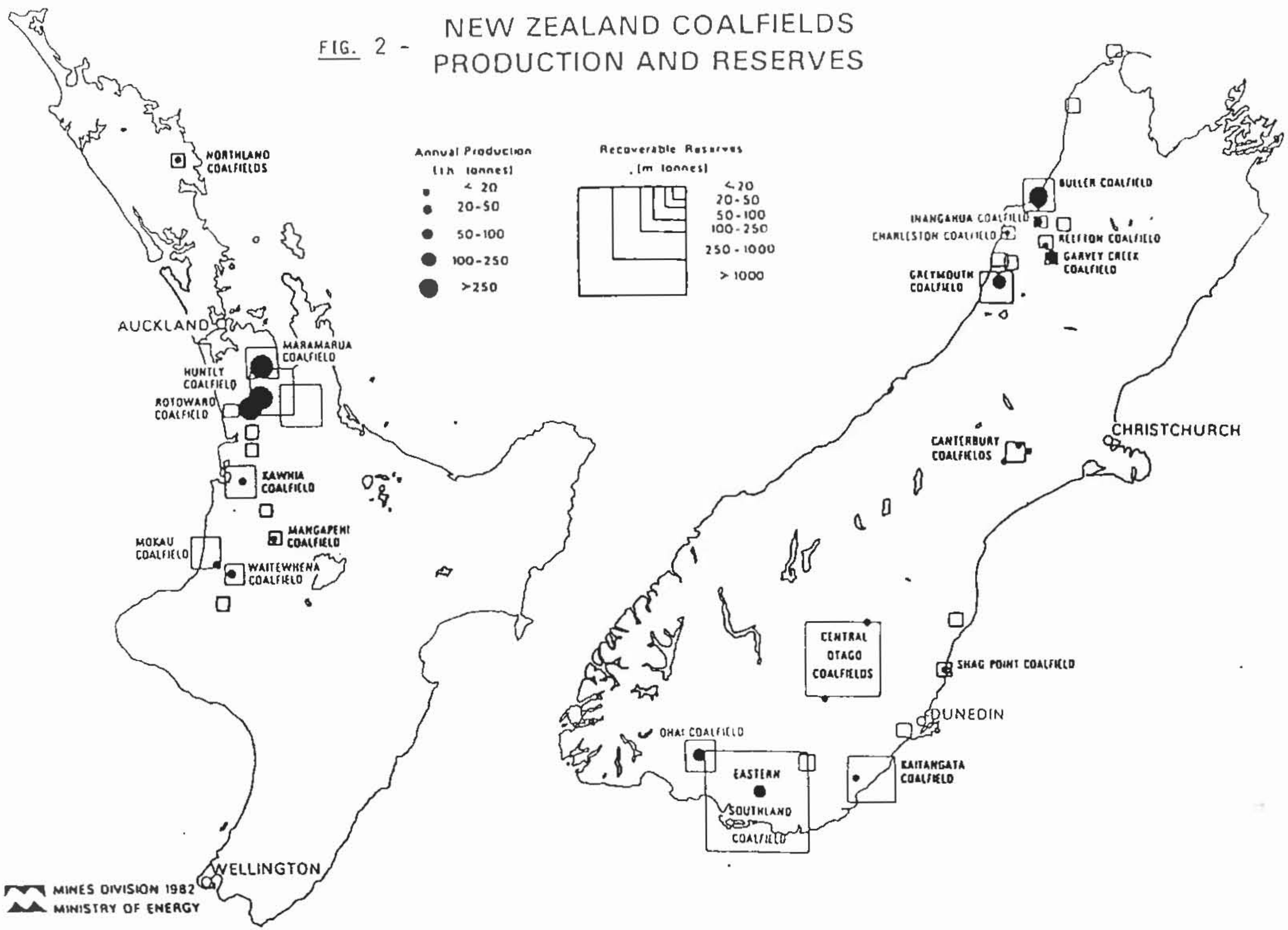
(1) South Island Subbituminous and Bituminous Coals

The subbituminous and bituminous rank coals of the South Island are for the most part in coal measures of Upper Cretaceous to Upper Eocene in age, deposited in a transgressive environment directly on Torlesse or other basement rocks that had been deformed and uplifted by the Rangitata Orogeny (c. 80 my bp).

Upper Cretaceous coals are confined to tectonic depressions in the basement and show very little or no marine influence. Minor Cretaceous coals occur in the Collingwood coalfield (Pakawau Coal Measures) and in small coalfields in Canterbury and Otago (Shag Point Coal Measures). The important fields of Cretaceous coal are Ohai, Kaitangata and the Greymouth and Pike River coalfields on the West Coast.

The Cretaceous (Paparoa Group) coal measures of the Greymouth and Pike River coalfields are believed by Canterbury University workers to have been confined to a narrow fault bounded basin in which peat swamps developed adjacent to a meandering axial river system. Syndepositional tectonic subsidence allowed exceptionally large thicknesses (up to 1000m) of Paparoa Coal Measures to accumul-

FIG. 2 - NEW ZEALAND COALFIELDS PRODUCTION AND RESERVES



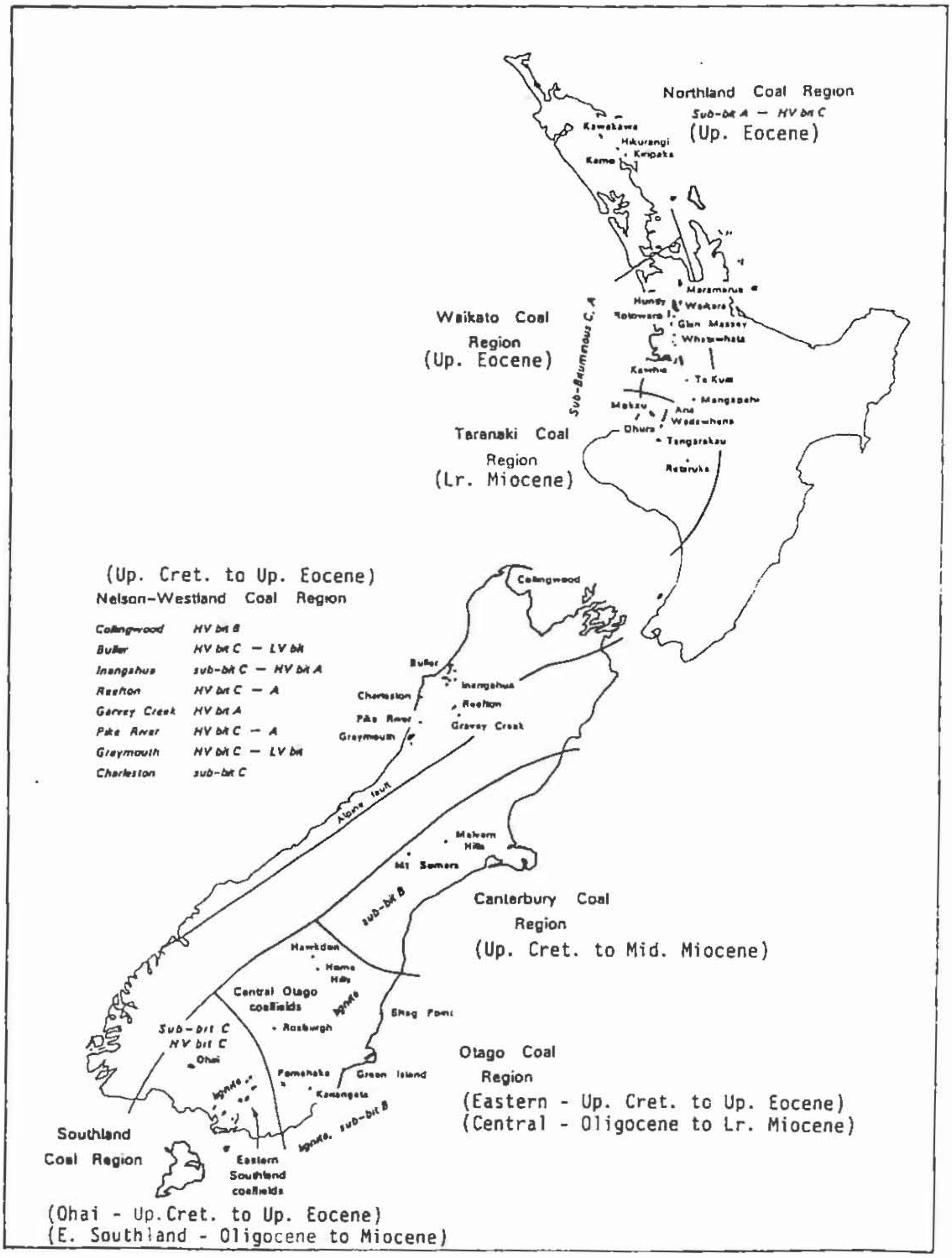


FIG. 1 - NEW ZEALAND COALFIELDS

(after Harris et al (1985) 'Coal in New Zealand' NZERDC Report 87 ate. A similar environment probably existed at Ohai but there tectonic movements were less regular and a sudden and major subsidence produced a second Cretaceous coal measure sequence (Morley Coal Measures) overlying the earlier Wairio Coal Measures; the combined thickness of the Ohai Coal Measures is probably not much greater than 180m.

At least six economic coal seams occur in both the Paparoa and Morley Coal Measures but the seams are very discontinuous and lensoid. Coals from the Ohai and the Paparoa Group are low in sulphur and show no marine influences. Both are high in vitrinite (in excess of 80%), but the Ohai coals are more telinitic and the Paparoa coals are more detrital. In the Ohai area the Morley Coal Measures were followed by uplift and erosion during which time many of the coal measures were removed, while in the West Coast area sedimentation almost ceased and a long period of tectonic quiescence followed the Paparoa Coal Measures.

In the Kaitangata coalfield, Cretaceous Taratu Coal Measures accumulated initially in a fault angle depression within basement semischists and ultimately filling the depression, spreading out over the eroded basement surface and passing conformably up into marine sediments. The coal measure sequence at Kaitangata reaches 300m thickness, and contains up to 10 seams although the seams are discontinuous and frequently split. The Kaitangata coals vary from lignite to subbituminous C in rank and have variable sulphur content (sometimes up to 6%). Petrographically Kaitangata coals are high in inertinite group macerals (up to 30%) in comparison with other New Zealand Cretaceous coals where inertinite doesn't usually exceed 5%.

The Eocene brought a period of renewed tectonic activity, subsidence and further coal measure sedimentation.

In the Ohai area a third period of fluviatile sedimentation deposited the Beaumont Coal Measures on the eroded Morley Coal Measure surface and these younger Eocene coal measures extended out beyond the Ohai region to cover most of west Southland before finally passing up into marine sediments.

In the Nelson-Westland coal region a major Eocene transgression deposited coal measures in many parts of Nelson and Westland (Quartzose Coal Measures) and on the West Coast the Brunner Coal Measures lapped onto basement (Buller Coalfield) and only Paparoa Coal Measures in the Greymouth and Pike River coalfields. Most of the Eocene coals have some marine influence and variable amounts of sulphur. The Eocene coal seams are thinner and much more extensive than those of the Cretaceous coals. The most economically important of the Eocene coal measures is the Brunner sequence in the Buller coalfield. Brunner coals have a strong marine influence, a high organic sulphur content (often in the 5-7% range) and have a notably canneloid appearance which results from their strongly degraded petrographic nature. A particularly notable, but not understood, feature of the Brunner coals, and particularly those in the Buller coalfield, is the rapid rank changes that occur within these coals over very short distances.

The Cretacous-Lower Tertiary coals in the South Island have all been deformed and compressively folded and faulted. The most intense deformation is in the Westland-Nelson coal region where coal measures are extensively folded and faulted. Deformation is less intense in the Kaitangata, Ohai and Canterbury coalfields, but the coal measures are all faulted and, at best, broadly folded.

(2) North Island Subbituminous Coals

Coal measures in the Northland and Waikato Coal Regions are all Upper Eocene in age and deposited transgressively on eroded Permian-Jurassic basement rocks.

The Northland Kamo Coal Measures are paralic (medium to high sulphur) and form the base of the Whangarei Group. Infaulted remnants are found in several localities around Northland, but they now have little economic importance. The Kamo Coal Measures are rarely more than 20 m thick and usually contain two workable seams of only a few metres thickness.

The Waikato Coal Region contains New Zealand's major subbituminous coal resource. The Waikato Coal measures lie at the base of the Te Kuiti Group and although not thick (usually 30-100 m) are extensively developed from South Auckland to Kawhia. The coal measures contain two significant coal seams which are very discontinuous and locally very thick (up to 30 m). The Waikato coals, at least as far south as the Rotowaro Coalfield, show no evidence of marine influence and are both low sulphur and low ash (usually less than 0.5% S and 6% Ash). The Southern Waikato Coalfields (Glen Massey, Whatawhata, Kawhia) are marine influenced, contain on average 2-3% organic sulphur and the coal seams are directly overlain by marine sediments.

Petrographically the Waikato coals are very monotonous and high in huminite (vitrinite) group macerals particularly telinite although locally thin canneloid bands rich in sporinite occur. A particularly notable feature of the Waikato coals is the abundance of resinite frequently forming fist-sized chunks or concentrated in discontinuous bands in the coal. The Waikato coals appear to have originated in a tectonic depression in a forest swamp environment adjacent to ponded lakes and a major river system - a situation not unlike that of the contemporary Waikato Valley.

The Taranaki Coal Region contains some exposures of the Eocene coal measures at the base of the Tei Kuiti Group but these coal measures are found only in the north (Aria coalfield) and are insignificant. The economically important coal measures of the Taranaki Coal Region are the Miocene Maryville Coal Measures enclosed within the marine Mokau Group. The Taranaki coals are all paralic and have variable sulphur contents. The Maryville Coal Measures are characterised by many thin (usually less than 3 m) but extensive coal seams. Coals on the eastern margin of the Taranaki coal basin are very degraded and unusually liptinite rich and, although only subbituminous A in rank, secondary bitumen (exsudatinite) are a notable feature of the Mokau coalfield. The western Taranaki coals are less degraded and contain more telinite.

The North Island coalfields have a deformational style characterised by faulting and regional tilting. The faulting is usually normal except in Northland where major reverse faulting occurs. The individual coalfields are usually outlined by block faulting or major fault boundaries.

(3) Otago and Southland (South Island) Lignites

The South Island lignites occur in two distinct depositional and tectonic environments:

The Central Otago lignites are limnic and enclosed within the fluviatile and lacustrine deposits of the Manuherikia Group (Miocene) which were deposited and preserved in block faulted depressions. Roxburgh is a single seam deposit but the other fields (Hawkdun and Home Hills) are multi seam. The Central Otago lignites contain notably more inertinite than the Southland lignites and locally have very semifusimitised microlithotypes suggesting dry conditions. The Roxburgh lignite is abnormally liptinite (sporinite) rich and degraded. The Otago lignites are weakly deformed and usually only faulted, however against the margins of the depositional basins reactivation of marginal faults have caused intense local deformation of the lignites.

In Eastern Southland, the Gore Lignite Measures were deposited during the Upper Oligocene to Lower Miocene in a regressive paralic environment over an eroded and leached Mesozoic basement. The oldest lignites are in the Pomahaka field and the lignites young to the SW. The Gore Lignite Measures contain multiple lignite seams, sometimes intercolated with shallow marine sediments. The lignites contain a considerable amount of xyllite and undegraded plant tissue material. The environment of deposition of the Southland Lignites was almost certainly a deltaic coastal swamp. Gentle regional warping and some faulting is the characteristic deformational style for the Southland Lignite fields.

Since low-rank coals are New Zealand's major energy resource and are likely to be used as power station feedstocks and in direct reduction steel making — two uses which can be greatly affected by inorganics — a reconnaissance study has been made of the inorganic constituents of North Island coals and South Island lignites. Ca is the major inorganic ion in all low-rank New Zealand coals with Na and Mg occurring in lesser amounts; in low-ash Waikato coals Ca may constitute 1% of the total coal composition. Detailed studies have been made within individual coalfields and the inorganics show distinct and systematic variations within the fields but variations have not been recognised with depth in individual seams. In the Eastern Southland lignite fields the lignites show an increase in Mg and Na and a decrease in Ca from NE to SW. In the Waikato coalfields an unpublished thesis by Hames (1984) has shown Na to decrease and Ca and Mg to increase going SW from the Maramarua to Huntly coalfield.

THE STRUCTURE AND SEDIMENTATION OF THE NORTHERN GUNNEDAH BASIN

M.B.L. Hill   Coal Geology Branch, Dept. Mineral Resources

The Gunnedah Basin regional drilling programme (carried out by the Department of Mineral Resources in 1981-82) proved the existence of a full Permian sequence in the Boggabri-Narrabri area. However, the results of the drilling did not clarify the following issues:-

- The nature of the Boggabri Ridge,
- the relationship between the Upper and Lower Permian sequence to the west of the ridge, and the lower Permian sequence to the east of it,
- the structure and stratigraphy of the units to the north of Baan Baa, (the northernmost known outcrop of the ridge), and
- the presence of a structural high in the Bellata area, dividing the Gunnedah and Bowen Basins.

In 1984-85 the Department of Mineral Resources conducted a drilling programme in the Narrabri-Boggabri area, and the opportunity was taken to map the Deriah Forest area north of Baan Baa.

The results of the mapping show that:-

- the Werrie Basalt forms a basement high in the Deriah Forest area,
- the Maules Creek Formation and the lower part of the Porcupine Formation onlap onto the high, and
- the Digby Formation (Narrabeen Group) has eroded the Black Jack, Watermark and the Upper Watermark in the area.

Waterbore data from the area south of Deriah Forest show that the "Deriah High" is connected to and is part of the Boggabri Ridge. Drill core data and additonal mapping within the valleys of the Nandewar Ranges show that:-

- the Boggabri Ridge extends northward from the Hunter-Mooki Thrust at least as far as Bellata; and may extend further towards the Queensland border,

- most of the ridge was covered during the deposition of the marine Porcupine Formation, but the higher parts were covered during the deposition of the Triassic Napperby Formation. The ridge formed a major source of sediment for the Maules Creek and lower part of the Porcupine Formation, and

- the Maules Creek Sub-basin extends northwards at least as far as Killarney Gap, and may extend northwards towards the Queensland border.

The data suggests that the West Gunnedah Basin (to the west of the Boggabri Ridge) extends north as far as Bellata, and possibly to the Queensland border, and also that there is no evidence that the Narrabri structural high exists. These suggestions were recently confirmed by a seismic survey shot by the Department of Mineral Resources in the Bellata area.

EARLY PERMIAN SEDIMENTATION AND PROVENANCE STUDIES IN THE GUNNEDAH BASIN, N.S.W.

S. Thomson   Vickery Joint Venture

Early Permian sedimentation in the Gunnedah Basin was influenced by a remnant NW-SE trending magmatic arc (the Boggabri Ridge) and a largely denuded cratonic complex to the W (the Lachlan Fold Belt). Rates of subsidence were significantly different E and W of the arc. To the E subsidence rates were greater, and in excess of 1000m of Early Permian sediment accumulated, whereas to the W, the sedimentary sequence is of the order of 100m.

Sedimentation was contemporaneous on either side of the arc although essentially independent. The eastern section has been termed the Maules Creek Sub-Basin by Thomson (1984). Hill (1986) introduced the term West Gunnedah Sub-Basin to describe the rocks W of the Boggabri Ridge. The stratigraphy of the two sub-basins are presented in Figure 1.

The sequence in the Maules Creek Sub-Basin is:-

(i) An Early Permian (Stage 3 to 4) diachronous, pelletoidal claystone unit called the Leard Formation (Brownlow, 1981), a colluvial derivative of the Boggabri Volcanics.

(ii) A lacustrine facies (Stage 3) termed the Goonbri Formation (new name, Thomson in prep.).

(iii) An alluvial-fluvial coal bearing facies (Stage 4), the Maules Creek Formation (Brownlow, 1981) derived from the Boggabri Volcanics and including a minor amount of quartz arenite clasts supplied from the Lachlan Fold Belt (Thomson and Flood, 1984).

In the West Gunnedah Sub-Basin the sequence is:-

(i) An alluvial, fine grained pelletoidal claystone (Stage 3?) derived from the Boggabri Volcanics called the Baan Baa Formation new name, Thomson in prep.).

(ii) An alluvial-fluvial coal bearing facies (Stage 4), a Maules Creek Formation equivalent which can be subdivided into -

. a northern fine-grained quartz and quartz arenite rich facies derived from the Lachlan Fold Belt

. a central conglomeratic facies derived from the Boggabri Ridge

. a southern fine-grained facies with a high proportion of coal relative to non-coal strata.

A schematic depositional setting is provided in Figure 2.

In both areas Early Permian sedimentation is terminated by the onset of the marine Porcupine Formation. The Porcupine Formation marks the end of the influence of the Boggabri Ridge as a sediment source as rising sea level "drowns" any remaining isolated topographic highs on the Ridge. It is suggested that the acid volcanic clasts of the lower Porcupine Formation are derived from the Boggabri Ridge. The absence of Lachlan Fold Belt detritus within the Lower Porcupine Formation is due to the termination of supply from the W as marine conditions enveloped the basin.

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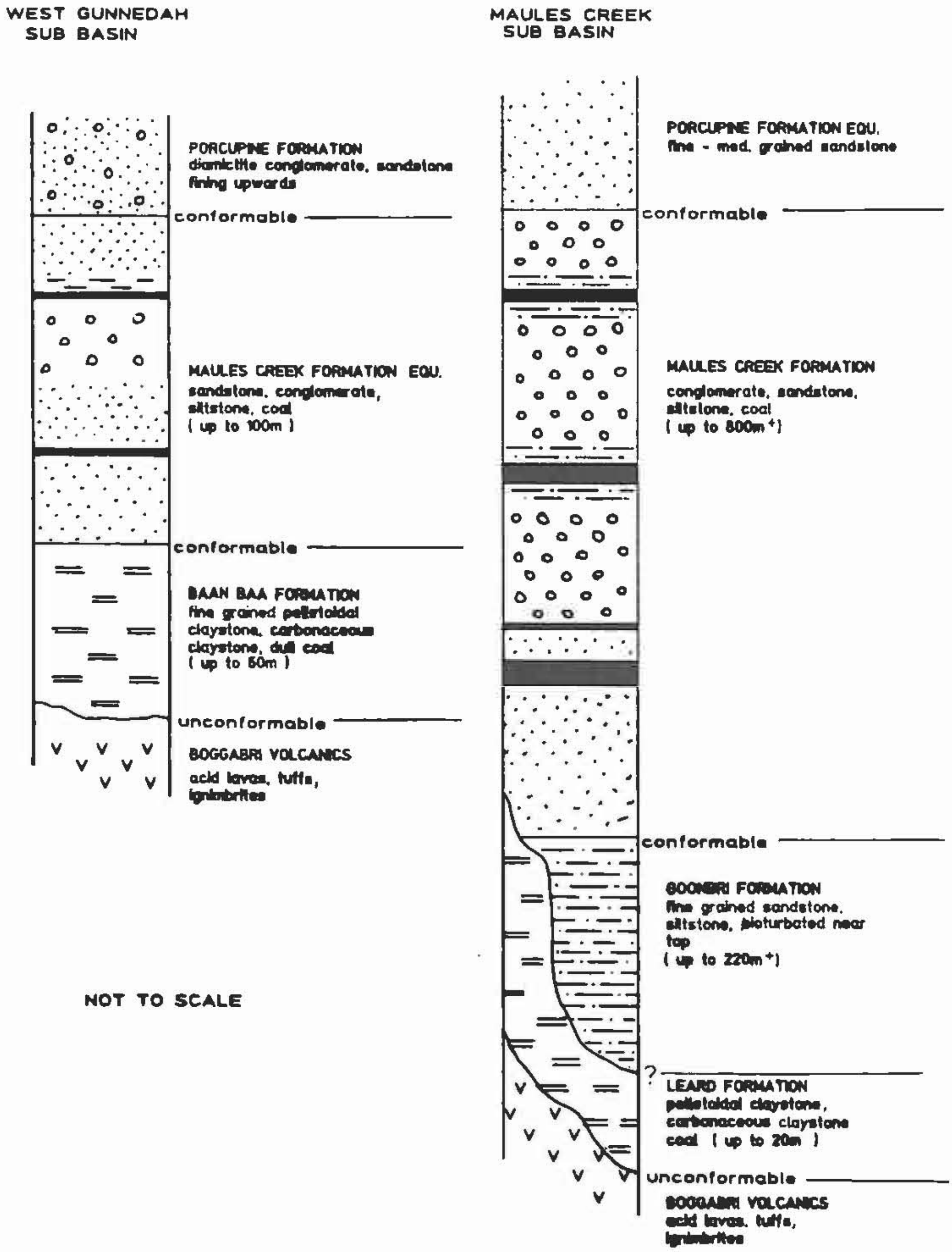

FIGURE 1 : EARLY PERMIAN STRATIGRAPHY GUNNEDAH BASIN

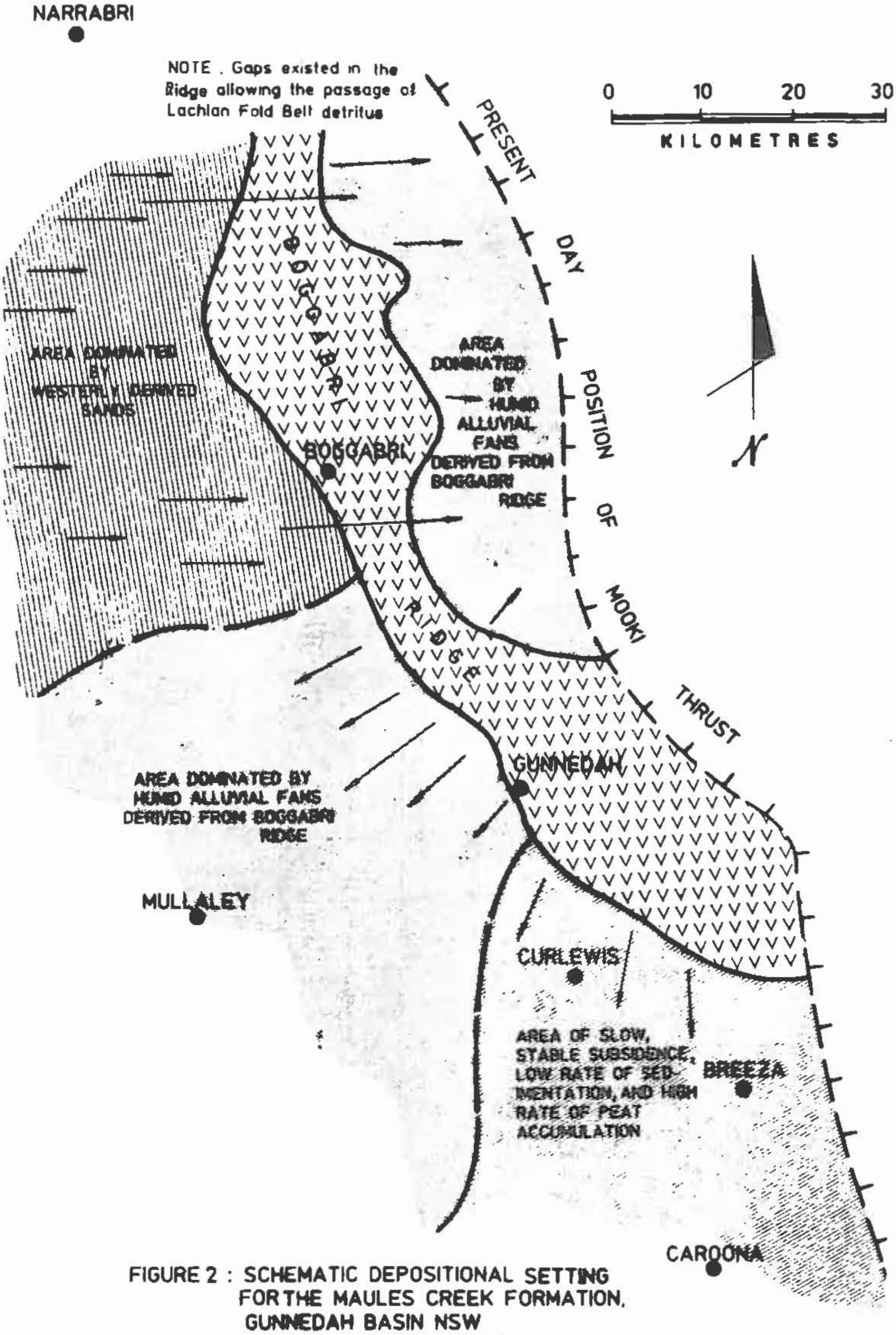

FIGURE 2 : SCHEMATIC DEPOSITIONAL SETTING FOR THE MAULES CREEK FORMATION, GUNNEDAH BASIN NSW (from Thomson , in prep.)

ON THE CORRELATION BETWEEN COAL FACIES AND DEPOSITIONAL ENVIRONMENTS

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Recent drilling activity in the coal measures of the Hunter Valley and Gunnedah area has provided a sound basis for both strata correlation and palaeoenvironmental interpretation (Beckett and McDonald, 1984; Hamilton and Beckett, 1984; Tadroz, 1985; and others).

The depositional conditions most frequently referred to are the lower and upper delta plains but any random check of the associated coals reveals substantial compositional differences for coals allocated to the same environment. In order to investigate this unexpected result further, a systematic study has been initiated which aims at establishing a correlation between coal facies indicators and the environment of coal formation.

So far, only whole seam sections have been used of coals whose depositional environment could be established on the basis of an extensive study of outcrops or a combination of bore cores and outcrops. The examples used include the lower portion of the Tomago Coal Measures at Buchanan Tunnel, the Thornton Brick Pit, R.W. Miller's DDH 54, the Wittingham Coal Measures at BHP Saxonvale Colliery (see Diessel and Stoddard in Excursion Guide, this issue), the Newcastle Coal Measures in the Newcastle area, the Greta Coal Measures at Bayswater, Muswellbrook, Drayton, Hebburn No.2, Aberdare North, Pelton and Ellalong Collieries, and the Black Jack Formation in the Gunnedah Basin.

The results are illustrated in Figure 1 in which the gelification index

$$GI = \frac{\text{Vitrinite + Macrinite}}{\text{Semifusinite + Fusinite + Inertodetrinite}}$$

has been plotted against the tissue preservation index

$$TPI = \frac{\text{Telinite + Telocollinite + Semifusinite + Fusinite}}{\text{Desmocollinite + Macrinite + Inertodetrinite}}$$

of different coals. Their respective depositional environments are discussed below.

Coal measures of the LOWER DELTA PLAIN are underlain by bioturbated delta front sediments which grade downward into fossiliferous marine sediments and are separated from the coal bearing sediments by a sandy distributary mouth bar.

The following identifiers have been used:

1. Occurrence of frequent intercalations of bioturbated interdistributary bay laminites containing numerous crevasse splay deposits.
2. Bar-finger-sands, i.e. sandstone filled distributary channels of low sinuosity as verified by their lenticular nature in outcrop, en echelon stacking, mild to severe basal erosion contacts with upward coarsening interdistributary bay deposits.
3. Coal seams of the lower delta plain (circles in Figure 1) rarely exceed a thickness of 1 m. The marine influence is indicated by a high pyrite content, whilst the wet conditions of peat formation are demonstrated by a high gelification index GI. The latter is based either on a high content of wood-derived structured vitrinite A (telinite and telocollinite) which results in a likewise high tissue preservation index TPI (area above TPI 1 in Figure 1), or the high degree of gelification is based on unstructured vitrinite B (mainly desmocollinite) resulting in a low TPI (below 1 in Figure 1). In the latter case there is usually evidence of a high contribution to the coal by cuticles although often they have been chemically corroded by the alkaline sea water such that the recorded cutinite percentage does not fully represent its original input. The combination of unstructured vitrinite and cutinite and the lack of any wood-derived macerals suggests that such coals have been formed from soft-tissued herbaceous or reed-like plants in a marsh environment.

In the course of delta progradation the tree-less marshes will be replaced by forested peat swamps as indicated by a rise in TPI because more wood-derived macerals with a better preservation potential will contribute to the coal. Because of intermittent dry conditions the proportion of semifusinite and fusinite will increase thus lowering the GI values. In general, coal composition will follow the trend indicated by the solid arrow in Figure 1. Should the already high water table rise further, hypautochthonous conditions are established leading to the formation of pyrite-rich sapropelites in interdistributary bays (wavy arrow in Figure 1).

The UPPER DELTA PLAIN is commonly situated between the lower delta plain and an alluvial valley association. In present-day mature deltas the upper delta plain is distinguished from the lower delta plain by a lack of tidal (i.e. marine) influence, by the replacement of interdistributary bays by flood plains and fresh water flood basins, and extensive forested peatlands. Distributary sinuosity is high resulting in laterally drawn-out point bar sands with characteristic lithosome geometry. The same criteria apply also to coal measures formed in ALLUVIAL VALLEY settings, no distinction has therefore been made between the two environments which both produce very thick coal seams under optimum conditions of tissue preservation (triangles in Figure 1).

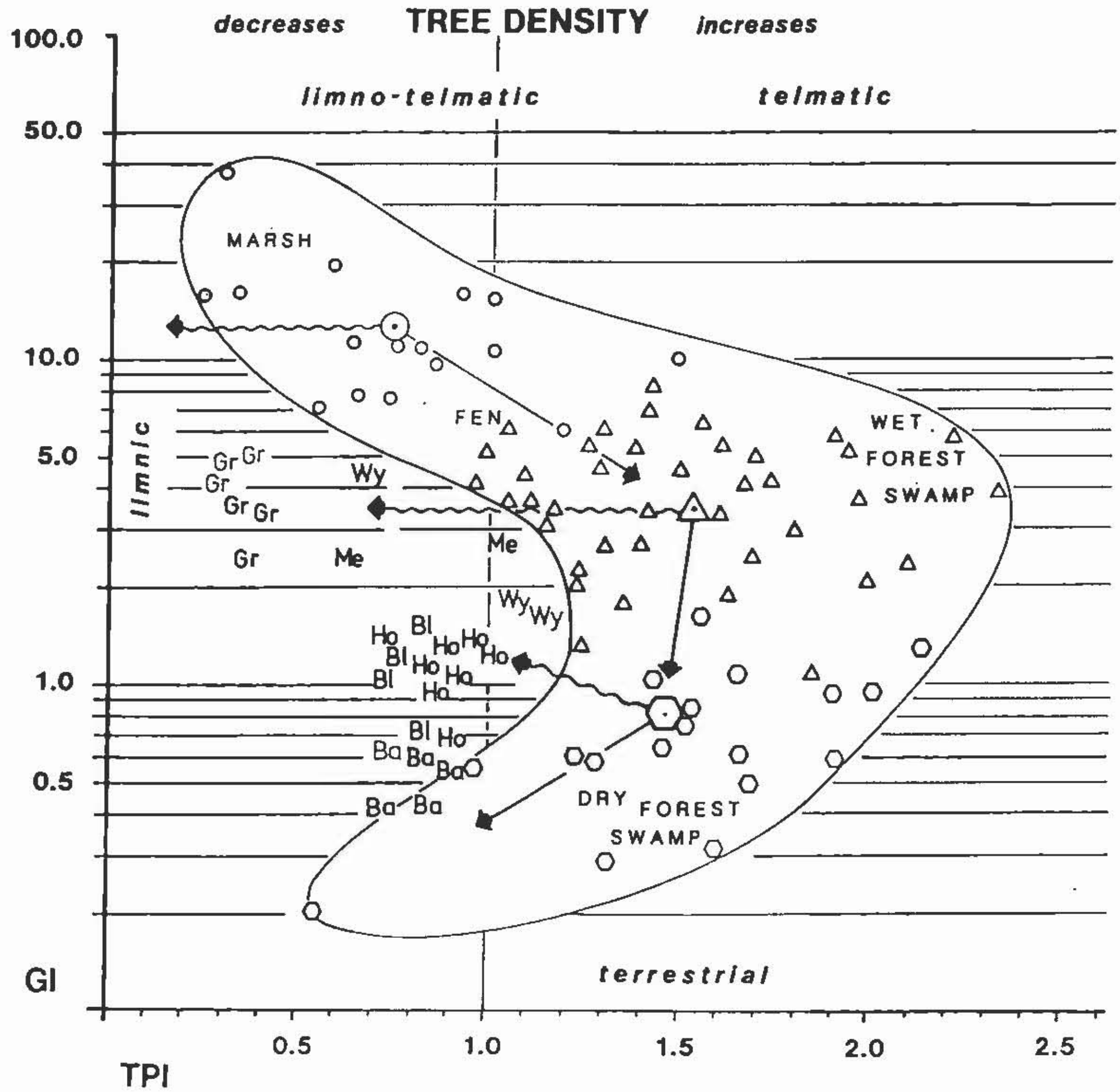

Figure 1: Coal facies diagram for a variety of depositional settings. See text for explanations.

A gradual shift towards dryer conditions will cause the coal to increase its proportion of structured inertinite at the expense of telinite and telocollinite. TPI values are therefore largely maintained under mildly oxidising conditions, even when the gelification index drops towards the mean for the piedmont association (solid arrow in Figure 1). A rising water table may reverse the trend and re-establish lower delta plain conditions but if the water table rises because the delta has been abandoned the trend indicated by the wavy arrow in Figure 1 may be followed, i.e. prolonged peat formation may take place on the defunct delta plain in front of the invading sea and under conditions of almost complete sedimentary by-passing. The result is a thick coal seam characterised by low TPI and fairly high GI of low ash content, and containing no or few stone bands but increasing in pyrite content towards a marine roof. The latter rests directly on the coal under low energy conditions but the two may be separated by a barrier beach in a wave dominated setting. A perfect example of this kind is the Greta Seam in the Hunter Valley (Gr in Figure 1).

The PIEDMONT PLAIN as used here ranges from proximal alluvial fans to distal braid plains. Intermittent high energy conditions as indicated by the deposition of coarse clastics, alternate with periods of quiescence which permit the establishment of forested peatlands in which dull coals are produced (hexagons in Figure 1). Severe oxidation will restrict the formation of telinite and telocollinite, and under conditions of falling water table even structured inertinite will disintegrate to form in-situ inertodetrinite commonly coupled with an increase in inherent ash and the rather resistant sporinite. Under such conditions both GI and TPI are reduced (solid arrow in Figure 1).

A gradual rise in water levels will result in a shift back to the wet forest conditions but a fast rise, as may be caused by a rapid marine transgression, will form increasingly large areas of open water in which dispersed inertodetrinite collects, possibly together with algae and syngenetic pyrite. The underlying formerly relatively dry peat will be soaked with humic acids and fine plant attritus which forms desmocollinite in the coal. The result is a decrease in TPI and a slight increase in GI following the trend indicated by the wavy arrow.

Coals which belong to the three depositional settings discussed above are encircled in Figure 1. Apart from the Greta Seam already referred to there are other coals which also do not fit the established pattern. They constitute a separate group formed in a back barrier environment, the Melville (Me) and Wynn (Wy) seams formed under transgressive (high GI) and the Bayswater (Ba) and Hoskisson (Ho) under regressive conditions (low GI).

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THE RELATIONSHIP BETWEEN SEAM SPLITTING, COAL FORMING ENVIRONMENTS AND COAL PROPERTIES IN THE NEWCASTLE COAL SEAM

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Coal seam splitting within the Newcastle Coal Measures may be classified as being controlled predominantly by either tectonic or sedimentary processes. Tectonic splitting, primarily the result of differential subsidence associated with movement of the Lochinvar Anticline, is characterised by single well defined epiclastic wedges with little apparent alteration of the character of the coal plies, indicating rapid, restricted pulses of fluvial sedimentation. An example of this style is the eastwards splitting of the West Borehole seam into Borehole, Yard, Dudley and Nobbys seam components (Fig. 1). Sedimentary splitting is the result of epiclastic material deposited in the coal swamp by long term fluvial processes active throughout seam deposition. Repeated flooding of the swamp results in intercalation of coal and clastic sediments and distinct changes in the nature of the coal plies. This style is exemplified by the westward splitting of the Borehole seam beneath Lake Macquarie (Fig. 1).

Recent bore and subsurface information including comprehensive analysis of coal seams enabled a detailed study of the variation of about 40 coal properties associated with both types of splitting. While a number of examples of each style were investigated only the Dudley and Borehole seams, representative of the tectonic and sedimentary types respectively, are presented here.

TECTONIC SPLITTING - Dudley Seam

Lateral variations in swamp environments were determined from petrographic examination of coal samples. Environmental subdivision based on microlithotype analysis, (modified after Hacquebard and Donaldson, 1969) and maceral analysis (Diessel, 1986) indicate a transition from dry forest swamps to wet forest swamps in the direction of the splitting (Fig. 2). Maceral groups show an increase in vitrinite and corresponding decrease in inertinite (Fig. 3). Total coal thickness variation (Fig. 1(a)) shows a thinning away from the split axis, the result of less rapid subsidence towards the anticline. In this forested area plant growth outstrips the subsidence rate and a high proportion of this plant matter decays or is partially decayed causing an increase in inertinite macerals and concentration of inorganic plant material. Maximum coal thickness occurs in the split axis where the subsidence rate and peat accretion are balanced, while in the split area peat accretion associated with the wetter conditions, only just keeps pace with subsidence resulting in a slightly thinner seam. Inorganic material released through plant decay contains many compounds that are water or acid soluble (swamp pH can be as low as 3.5) and these may be recycled by the plants or washed away. However a proportion of this material is relatively insoluble (eg. SiO_2 & Al_2O_3) and remains in the peat where it eventually reacts to form minerals such as quartz, montmorillinite and feldspar. These minerals tend to be finely disseminated throughout the coal and this is reflected in the CF1.60 ash trend (Fig. 1(b)) which increases in areas where decay was a significant factor. As the proportion of mineral matter increases the coal density increases and as a consequence the relative washing recovery decreases (Fig. 1(c)). The relative washing recovery is defined as:- $\frac{\text{CF1.40 Washing Recovery}}{\text{CF1.60 Washing Recovery}} \times 100$ and is a measure of the washing characteristics of the coal without the effect of the bands. SiO_2/Al_2O_3 ratio (Fig. 1(d)) increases away from the split because of silica concentrated from inorganic plant material. This trend is supported by an increase in quartz (Fig. 1 (g)) and expandable clay content (Fig. 1(h)) while kaolinite decreases because unfavourable chemical conditions prevent its formation. The trend exhibited by CaO (Fig. 1(e)) is similar to that for P_2O_5 and a plot of P vs Ca (Fig. 4) suggests that the bulk of these elements are tied up as apatite. Maximum concentrations occur where element availability and chemical conditions are suitable for apatite formation. Variations in K_2O (Fig. 1(f)) appear to be related to feldspar concentration with highest values occurring in the western area where chemical conditions favour feldspar formation. Figure 5 shows the SiO_2/Al_2O_3 ratio of three seams along the same line. The Borehole seam shows little effect of differential subsidence however the Dudley and Nobbys seams show progressively stronger trends, suggesting a change in the regional subsidence rate with time.

SEDIMENTARY SPLITTING - Borehole Seam

Microlithotype (Fig. 2) and maceral analysis (Fig. 3) of the Borehole seam show slight changes towards drier conditions in the split area. Peat accumulation is slowed by the presence of less compactable clastic sediments in the area adjacent to the river. This results in drier conditions and a significant decrease in the total coal thickness (Fig. 1(i)). The active fluvial system responsible for the splitting is also a major source of material (both soluble and detrital) entering the swamp as shown by the increase in CF1.60 ash (Fig. 1(j)). Unlike the Dudley seam example, most of the mineral matter appears to be detrital, present in thin layers within the coal and composed mainly of clay minerals. This increase in ash causes a density increase and hence a decrease in relative washing recovery (Fig. 1(k)). The SiO_2/Al_2O_3 ratio increases towards the split (Fig. 1(l)), the result of increasing quartz and expandable clays (Fig. 1(o) and 1(p)) and decrease of kaolinite. CaO and P_2O_5 are again present as apatite and increase away from the split (Fig. 1(m)) indicating the apatite to be of authogenic rather than detrital origin. The K_2O trend (Fig. 1(n))

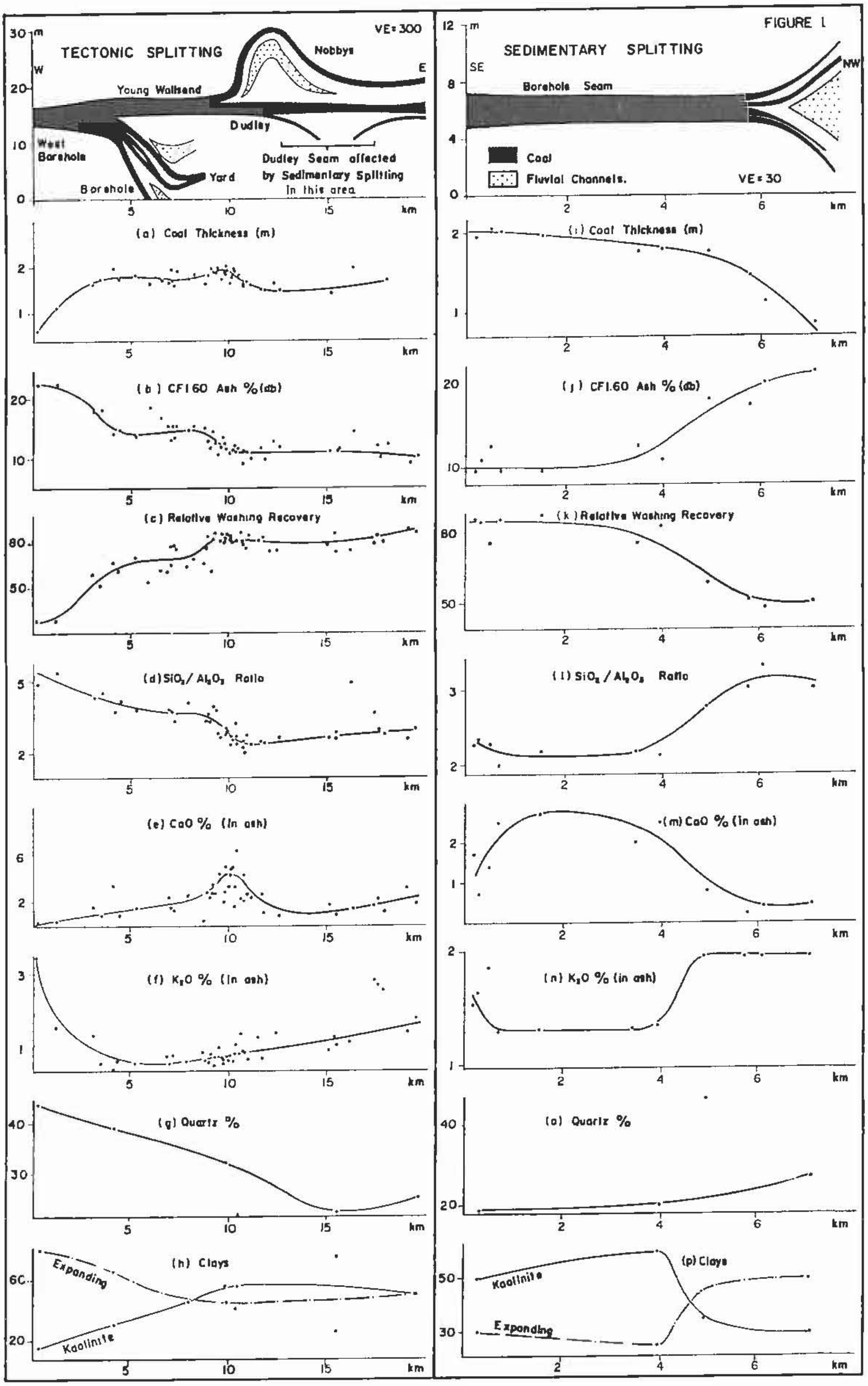


FIGURE 1
TECTONIC SPLITTING
VE=300
W
E
Nobbys
Young Wallsend
Dudley
West Borehole
Yard
Borehole
Dudley Seam affected by Sedimentary Splitting in this area
km
(a) Coal Thickness (m)
(b) CF1.60 Ash %(db)
(c) Relative Washing Recovery
(d) SiO_2/Al_2O_3 Ratio
(e) CaO % (in ash)
(f) K_2O % (in ash)
(g) Quartz %
(h) Clays
Expanding
Kaolinite
SEDIMENTARY SPLITTING
SE
NW
Borehole Seam
Coal
Fluvial Channels.
VE=30
(i) Coal Thickness (m)
(j) CF1.60 Ash % (db)
(k) Relative Washing Recovery
(l) SiO_2/Al_2O_3 Ratio
(m) CaO % (in ash)
(n) K_2O % (in ash)
(o) Quartz %
(p) Clays
Kaolinite
Expanding

FIGURE 2

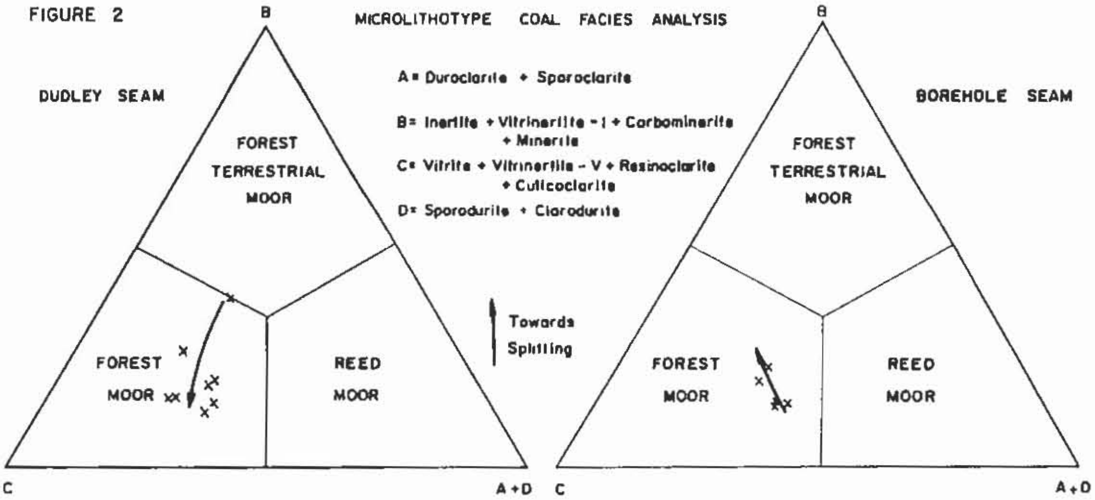


FIGURE 3

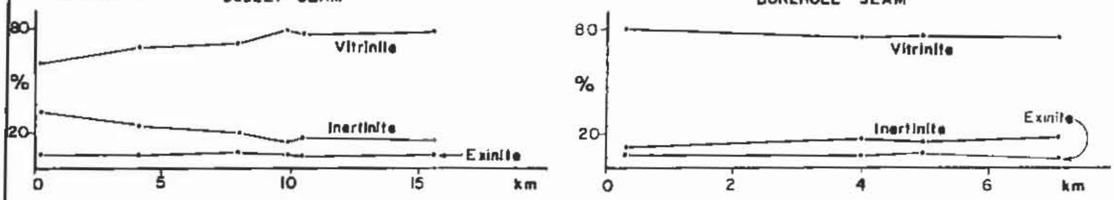


FIGURE 4

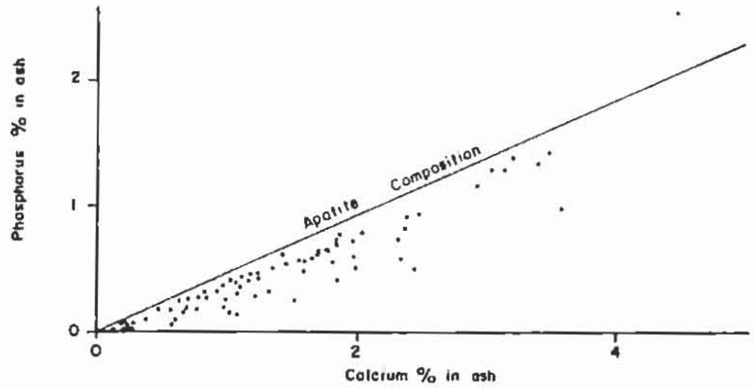
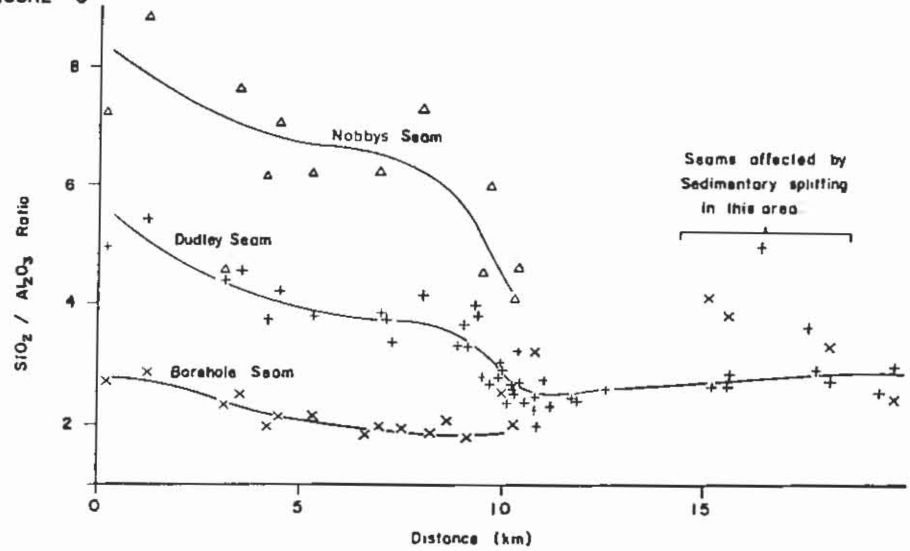


FIGURE 5



is related to the detrital feldspar from the river and decreases away from the split.

The following properties also showed trends that could be related to splitting:- volatile matter, C, H, N, S, MgO, TiO_2, CSN and ash fusion.

Changes in many coal properties result from variations in vegetation type, subsidence rates, swamp water levels, the chemical environment and the source of material. The splitting processes may be a dominant factor controlling these parameters and hence the swamp environment and this is manifest in the trends exhibited by the different split styles. From the figures it is clear that most trends shown by tectonically split seams are the reverse of those apparent in sedimentary split seams. This is largely a result of the way in which mineral matter is deposited. Tectonically split seams show the greatest effect away from the split axis where minerals are formed from solution either by direct precipitation or through biological activity hence the mineral assemblage is very different from the detrital material deposited in the split. In contrast sedimentary split seams are affected in the split zone where detrital mineral matter from the adjacent river is deposited. Consequently the mineral assemblage in coal associated with sedimentary splitting is similar to that for the intercalated lutites. It is also apparent that many of the properties now shown by the coal are predetermined during the depositional stage and that lateral variations in coal seams are no accident, but are related to the depositional processes.

Practical implications arise from the ability to predict variations in coal properties from a knowledge of the location and type of splitting affecting a seam.

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COAL EXPLORATION BY THE ELECTRICITY COMMISSION OF NEW SOUTH WALES

C.R. Weber Electricity Commission of New South Wales

A large, modern, coal-fired, power station which contains 4 x 660 MW generating units can be expected to consume 120 million tonnes of coal over one lifetime. After one lifetime, the power generating plant can be fully refurbished for a second life, during which a further 120 million tonnes of coal will be consumed. Such refurbishing is quite cost-effective and serves to maximise the use of the site, infrastructure, and transmission facilities.

Consequently, for every planned large power station, sufficient suitable coal resources must be identified and set aside to guarantee the availability of 240 million tonnes of recoverable coal. If demand for electricity continues to grow at the present 3% per annum (and in the 1970's it was nearly 6%), there will be a need to develop eight new power station sites by the year 2030.

To date, only four, Mardi near Wyong, Foybrook near Singleton, Mount Piper (Stage 2) near Lithgow, and Tallawarra (Stage 2) have so far been identified as possible sites. Exploration and assessment of coal resources which can be allocated for consumption in these power stations is well under way:

- Indicated Resources have been identified in the upper Newcastle Coal Measures in the Tuggerah - Wyong area,

- Measured and Indicated Resources have been identified in the Wittingham Coal Measures at Mount Arthur, Ravensworth, and Swamp Creek East,

- Measured and Indicated Resources have been identified in the Lithgow and Katoomba seams in the Lithgow - Newnes area,

- Indicated Resources have been identified in the Wongawilli and Tongarra seams in the Robertson area.

In addition, the Commission is, or has been, exploring for coal to identify economically mineable fuel supplies for possible new power station developments in the following areas:

- The Gunnedah Basin near Narrabri,
- The area between Scone and Murrurundi,
- The Wollar area in the Upper Goulburn Valley,
- The Rylstone area,
- The far South Coast region south of the Shoalhaven River.

THE GEOLOGY AND COAL DEPOSITS IN THE WYONG REGION

M.A. Bocking and M.S. Howes Electricity Commission of New South Wales

The Wyong Region lies on the east coast of Australia midway between Sydney and Newcastle. The coal deposits form part of the Late Permian Newcastle Coal Measures of the Sydney Basin. The coal measures do not crop out in the area but are overlain by a cover of Quaternary alluvium and Triassic rocks of the Narrabeen Group. The total cover varies from 130 metres in the north-east to over 800 metres in the south-west. The principal coal resource has been found to occur in the Moon Island Beach Sub-group at the top of the Newcastle Coal Measures.

HISTORY

Intermittent exploration of the coal deposits in the Wyong Region has taken place since 1882 and a number of mining proposals have been suggested. More recently bores were drilled by the Electricity Commission of New South Wales from 1960 to 1968 during which time the area formed part of "a reserve of coal for power generation purposes". The Joint Coal Board and the Department of Mines further evaluated the area following drilling in 1975.

In February 1981 the Electricity Commission of New South Wales was granted Authorisation 255 to prospect for coal in an area of about 440 square kilometres centred on Wyong (Figure 1).Since that time 47 boreholes have been completed and the coal quality more thoroughly evaluated.Borehole spacing across A 255 is currently between 1 and 8 km. Exploration to date, by all parties, includes 76 bores, aggregating 40,000 metres. Many of thes bores were non-cored through the Triassic sequence and for most the target depth has been the Fassifern Seam. Ten bores, with a fair areal coverage, extend through the Newcastle Coal Measures to the Borehole Seam.

STRUCTURE

The regional dip, of approximately 1^{o} south-west, is modified by a number of broad, shallow, south-westerly plunging folds, the limbs of which dip at less than 2^{o}. Some variations in dip occur associated with local structural and depositional features.

The Kulnura Anticline lies 4 km to the west of A 255 and the Lake Macquarie Syncline appears to reach the coast north-east of A 255.

The Yarramalong Syncline and the Awaba-Morisset Anticline trend south-west and south-east respectively, across the Wyong Region. These features are evident in structure contours near the base of the Newcastle Coal Measures but higher in the sequence they become obscured by large scale depositional features such as thick conglomerate deposits, especially those present in the Moon Island Beach Sub-Group.

THE NARRABEEN GROUP

The Triassic sequence present consists of rocks of the Narrabeen Group extending from the Terrigal Formation to the Dooralong Shale. The Terrigal Formation, which consists of sandstone and mudstone, crops out in the hills west of Wyong. The Patonga Claystone is less resistant and forms the low lying areas surrounding Wyong. The Tuggerah Formation and the Munmorah Conglomerate are comprised of more resistant sandstone,mudstone and conglomerate and form the coastal headlands and rock platforms north of Bateau Bay.

THE NEWCASTLE COAL MEASURES

The Newcastle Coal Measures are comprised principally of sandstone, conglomerate, mudstone and tuffaceous? claystone in addition to coal. The sequence thickens from north-west to south-east across the Wyong Region, from about 150 m at Yarramalong to 250 m at Terrigal. The upper seams of the Newcastle Coal Measures, being the Vales Point, the Wallarah, the Great Northern and the Fassifern Seams, (Figure 2), are well developed over parts of the Wyong Region. These seams have been correlated with a high level of confidence. Many marker beds and characteristic seam profiles can be traced from Lake Macquarie to Somersby. The seams below the Fassifern show little potential for mining being generally thin and/or very banded.

The Vales Point Seam, where it is a separate seam, is thin and not considered economic in A 255. It forms the top part of the Wallarah Seam north and east of Wyong. The Wallarah Seam extends across much of A 255 as a potentially mineable seam. It coalesces with the underlying Great Northern Seam and forms a thick almost unbanded coal development unequalled in the Newcastle Coal Measures. This occurs in two broad tracts to the east and west of a major conglomerate channel deposit that formed contemporaneously with the Great Northern Seam. This channel deposit, which is an extension of the Teralba Conglomerate, is 5 km across, up to 80 m thick and extends over 55 km between Teralba and Ourimbah. Similar channels are recognisable in the Wallarah Seam to the north-east of Wyong. The Great Northern Seam, where split from the Wallarah, has potential for mining north-east of Wyong and near Yarramalong.

The Awaba Tuff underlies the Great Northern Seam and the channel conglomerate of the same age, as is shown on Figure 3. The Awaba Tuff, which varies in thickness from 1 to over 20 metres, is comprised of 3 distinct, epiclastic and/or pyroclastic members which cover an area in excess of 1200 km^2. Isopachs of the Awaba Tuff suggest it may have originated in the north-east.

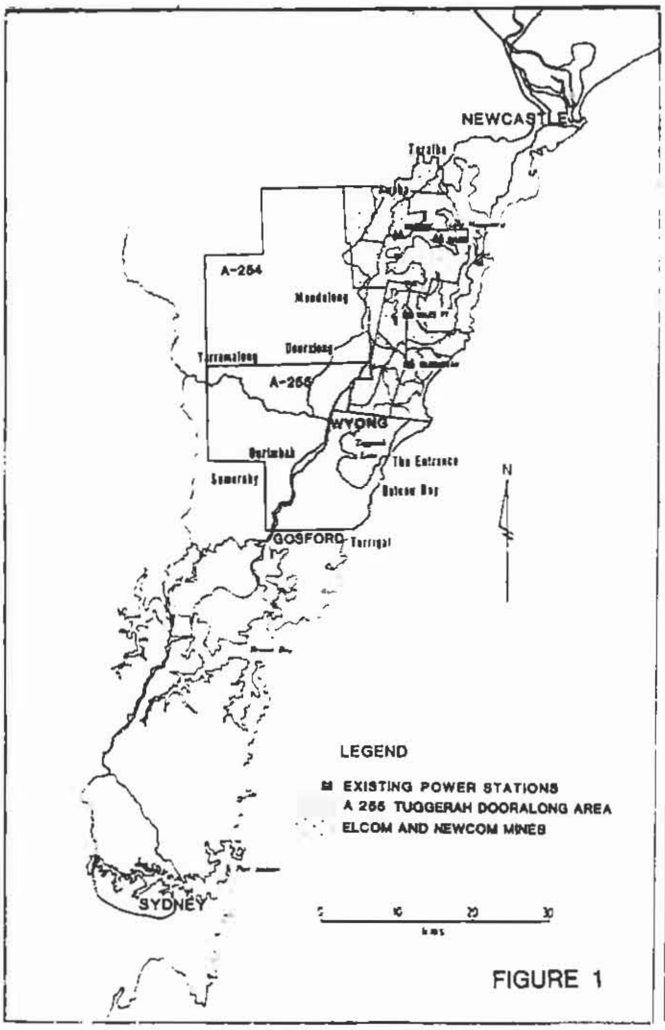

Figure 1. Location Map

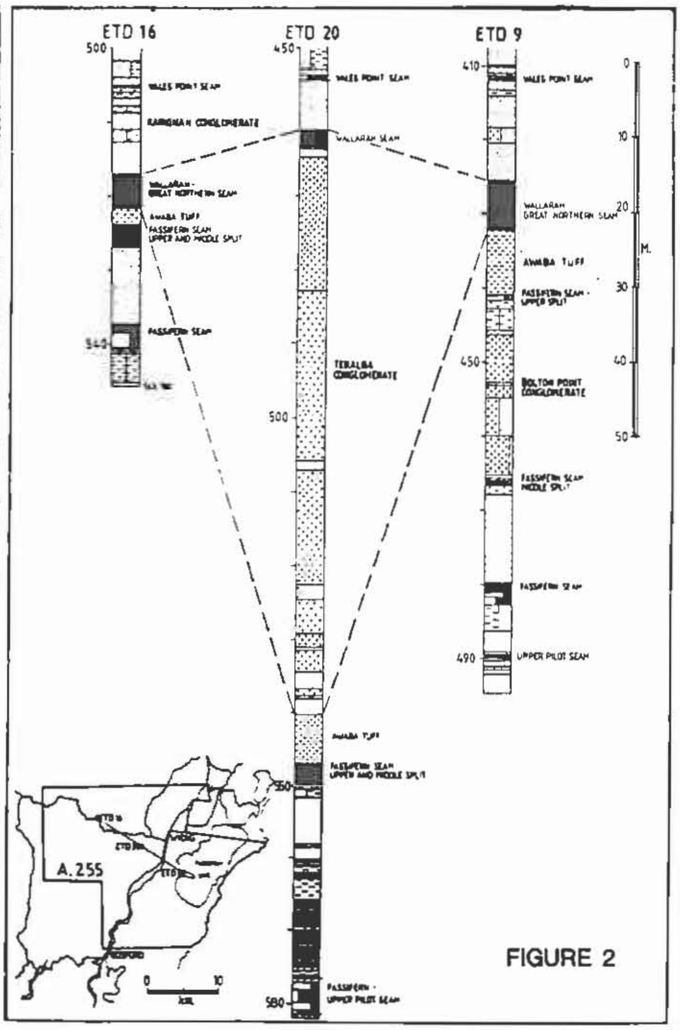

Figure 2. Representative borehole intersections of the Moon Island Beach Sub-Group

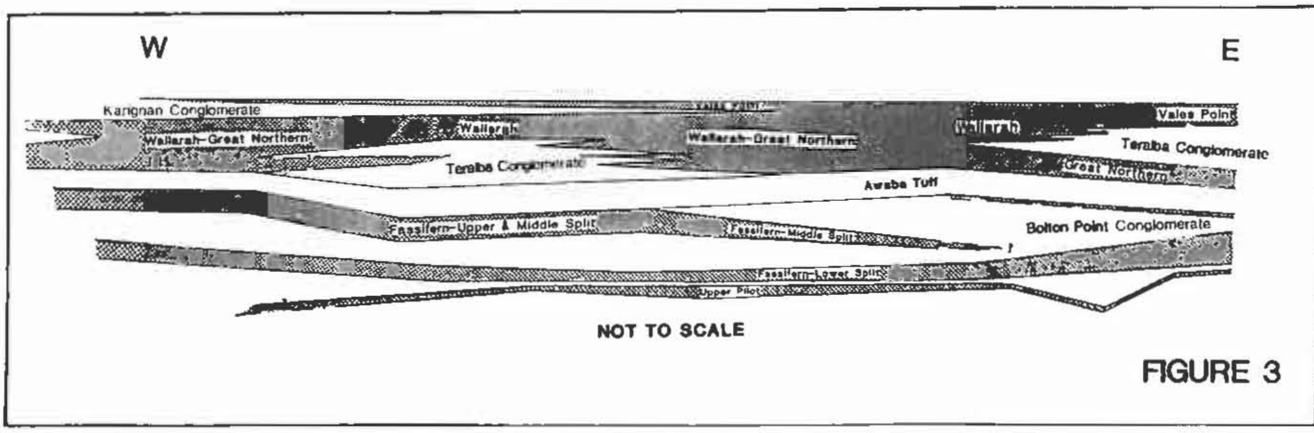

Figure 3. Diagrammatic cross section near Wyong

The Fassifern Seam lies immediately below the Awaba Tuff across much of A 255. Three distinct splits can be recognised, separated by conglomerate channels that make up the Bolton Point Conglomerate, (Figure 3). Potentially mineable Fassifern coal exists west of Wyong, where the upper and middle splits are combined from Dooralong to Somersby, being best developed in the south. The Fassifern Seam is also well developed under The Entrance where the middle and lower splits are combined to form a thick relatively unbanded seam. Across the remainder of the Wyong Region the lower split of the Fassifern Seam is combined with the top of the Upper Pilot Seam. The two seams form a sequence of coal and bands, 4 to 6 m thick.

IGNEOUS INTRUSIONS AND FAULTS

Dykes and sills of "doleritic" composition have been intersected in a number of bores or observed in surface mapping in various parts of the Wyong Region. Sills, which are believed to be extensive, occur in the Wallarah-Great Northern and Fassifern Seams in the western part of A 255. Strike directions of dykes observed in outcrop are predominantly south-easterly (130°). A few strike north-east.

Faults of varying magnitude have been intersected in a number of bores but to date only minor faulting has been observed in outcrop.

COAL SEAMS

The Wallarah/Wallarah-Great Northern Seam varies in thickness from 1.2 to 8.6 m. It generally has a competent sandstone roof and acceptable mudstone floor but the thickness of coal and proximity to the Awaba Tuff might restrict the "mineable" section. The seam contains only minor bands except near seam splits. It consists of bituminous coal with medium ash and volatiles and low sulphur content. It is suitable for domestic power generation without beneficiation.

The Great Northern Seam varies in thickness from 1.0 to 3.3 m. The seam's proximity to the overlying Wallarah might limit it's extraction in the east. In the west the Wallarah deteriorates but the Great Northern persists. The seam consists of bituminous coal with medium to high ash and volatiles, and low sulphur. The presence of a mudstone roof in some areas might increase "run of mine" ash levels.

The Fassifern Seam-Upper and Middle Split, which occurs west of Wyong, is up to 3.3 m thick. The seam is overlain in most parts by the Awaba Tuff which might reduce the thickness of the possible working section. It consists of high ash raw coal with medium to high volatiles and low sulphur. It may require beneficiation or blending to be suitable for domestic power generation. The Fassifern Seam-Lower Split which occurs in the east, is of similar quality. It ranges up to 3.6 m in thickness near The Entrance but is restricted where the raw coal ash of the seam increases. The Fassifern Seam-Lower Split has for the most part a competent sandstone roof and a floor of coal and claystone bands.

RESOURCES

The in situ resources are large but the proportion of coal that could be recovered from these resources will vary from place to place and be limited by a number of factors including possible lease constraints, depth to seams, seam thickness, mining methods and conditions, foreshore and lowland subsidence constraints and cultural factors such as urban, rail and road developments.

It is estimated, by the Commission, that some 360 million tonnes of recoverable coal are present in the Wallarah, Great Northern and Fassifern Seams within A 255.

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LATE PALAEOZOIC AND EARLY MESOZOIC "OROGENY" IN EASTERN AUSTRALIA

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The Carboniferous of eastern Australia shows features of classical compressional alpine geosyncline development. In the Lower Carboniferous both platform and flysch development can be identified (Roberts and Engel, 1980). The formation of troughs and ridges was accompanied by strong acidic (felsic) plutonism and volcanic activity. This continued into the Upper Carboniferous with late stage formation of molasse and withdrawal of the sea. As a result of the "orogenesis" high mountains were formed. Apparently the Permian events took place within the craton already developed at this stage but from the amount of acidic igneous material and the occurrence of terrestrial deposition already in the Carboniferous in eastern New England, (Hamilton, 1982), the geosyncline was probably developed on continental crust. On this basis steep longitudinal troughs and ridges might be expected rather than bathyal ocean.

The Lower Permian is characterised by tensional conditions (volcanic rift of Scheibner, 1976) and platform deposition. Deep water deposition appears to be absent. The Nambucca Slate Belt for example has been found to be overlain by relatively undeformed fossiliferous Lower Permian with angular unconformity (Degeling and Runnegar, 1979) and the deep-water Permian north of Drake has been found to be Upper Carboniferous (McCarthy et al., 1974). On the basis of such structures as the Denison Trough (half graben), the probable half grabens occupying the Lochinvar and Muswellbrook Anticline areas and similar structures elsewhere at this time, similar graben structures could be expected (Dickins & Malone, 1973, Konecki et al., 1958) in the Lower Permian in New England and south-eastern Queensland. The igneous activity is predominantly basic and intermediate and thus radically different to that of the Carboniferous.

Another distinctive change in tectonic conditions takes place at the mid-Permian with the onset of the Hunter-Bowen compressional phase - the Hunter-Bowen Orogeny. This continues into the Triassic with a strong movement with overthrusting beginning at about the Permian-Triassic boundary at the top of the Newcastle Coal Measures. At the mid-Permian the Lochinvar Dome begins to appear (the uplift is marked by the appearance of the Muree, Megalong and other highly distinctive conglomerates) the Mimosa Syncline begins to develop and to the east of the Bowen Basin a number of steep flysch troughs are formed with spilitic pillow lavas at the base of the sequence (the "ophiolites"). The igneous activity is predominantly intermediate and acidic and widespread ignimbritic volcanism is accompanied by large-scale batholithic intrusion.

The onset of the Hunter-Bowen phase is also marked by a strong thermal event causing regional metamorphism of earlier rocks including the Lower Permian. The earlier plutons are overprinted by the thermal event and their radiometric ages are affected. Presumably also the palaeomagnetism was affected.

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TUNNEL BORING OR BLASTING IN COAL MEASURE STRATA AND TRIASSIC ROCKS OF THE SYDNEY BASIN

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K.H.R. Moelle The University of Newcastle

Tunnelling in the Sydney Basin has been performed with a variety of results ranging from good to very poor. These results, though dependent on tunnelling technique, are, without doubt, primarily a function of the rock mass response. The important thing is to apply the correct technique to the predicted response of the rock mass. Experience and results show that the rock masses of the Sydney Basin have a wide range of responses.

Future major tunnelling operations will involve the Hawkesbury Sandstone as well as the Narrabeen Group sequences. The formation of these rock masses, largely by fluvial depositional processes, and their subsequent history, have imposed a variety of characteristics which are going to be most important to any major tunnelling effort. Aspects which are of prime importance are material type, anisotropies, water conditions, in situ stresses and tunnelling method.

For example, some sandstones and shales have been described as "sheet sandstone facies" and "massive facies." The clastic and matrix characteristics with regard to weathering of these two facies are very different. Any exposure of the material may induce rapid deterioration and swelling phenomena which will have a profound effect on any full-face tunnel borer operation.

Anisotropies, varying from the primary non-diastrophic features of the depositional environment, subsequently diagenetically affected, to those mechanically induced, will affect the response of the rock masses. These anisotropies vary greatly in the rock units of the Sydney Basin especially between the "sheet type sandstone facies" and "massive facies." Induced and inherent joint formations in rock masses have a marked influence on the "drill and blast" methods of tunnelling.

When shale and clay layers are encountered, another type of rock mass response is introduced. The exposure of these clays, especially to a humid atmosphere, has to be considered as well as the method or technique of imposing the support system.

In situ stresses are a prime factor in affecting the rock mass response. There is a requirement for much discussion on this aspect, because of the inadequacies in measuring technique and interpretation. Nevertheless, it is accepted that the principal maximum stress is nearly horizontal although its direction is often doubtful, especially if the tunnel traverses a fault- or shear zone.

These are some aspects or criteria which will affect tunnelling in the Sydney Basin. The wide variety of conditions to be expected on a big project such as the proposed Sydney Harbour Tunnel, calls for much flexibility to be incorporated in the design criteria as well as in the construction process. Tunnelling techniques using shield-road header type machinery and the New Austrian Tunnelling Method could possibly satisfy the flexibility requirements.

CLAYSTONE OF THE NEWCASTLE COAL MEASURES — ENGINEERING ASPECTS

R. Seedsman C.S.I.R.O.

Eighteen claystone horizons have been identified in the Newcastle Coal Measures - eight have been given stratigraphic names. These claystones are associated with many civil engineering problems (slope stability, tunnels, excavations and foundations). Of particular concern are the strata control problems experienced in mines developing the Wallarah, Great Northern and Fassifern Seams. Floor heave has occurred in parts of the Wallarah and Great Northern Seams and roof support has been difficult in the parts of the Great Northern and Fassifern seams. To allow the economic extraction of the very large coal reserves presently sterilized because of the presence of claystones, much work is needed to (a) better predict the distribution of claystone properties ahead of mining and (b) develop suitable mining procedures to account for claystone properties. In the latter context, ACIRL have recently completed successful trials of a Voest Alpine AM-75.

The claystones of the upper Newcastle Coal Measures are reported to be highly variable and of unpredictable performance. Preliminary investigations have indicated that facies changes within the claystone units and the confusion of different stratigraphic units could explain the differing performance of claystones. In addition, part of the variability may be attributed to a lack of a detailed geoengineering examination of the claystones. A study of bore core records is planned to identify the degree of variability within the claystones. This study will produce maps of roof and floor lithologies. In addition, it should produce models for the depositional environment/diagenesis of the interseams that will allow prediction of lithologies in areas of poor bore coverage.

Before traditional mining procedures are adapted to account for the presence of the claystones, the cause of the existing problems should be identifed. In the absence of mine site instrumentations of roof and floor, the causes of instability can be determined by back analysis of known cases of instability. Back analysis requires a detailed knowledge of claystone behaviour over a range of stress conditions. The claystones of interest are very weak rocks and contain a large amount of montmorillonite. On immersion in water the claystone may undergo extensive slaking and dispersion of the clay. This behaviour can be interpreted in two ways. Firstly, claystones will lose strength and swell in the presence in water and so lead to instability. Such an interpretation leads to the control of water as the main remedial measure. Alternatively, slaking/dispersion indicates that the claystone has low strength (wet tensile strength < 1 MPa) suggesting that the claystone can be overstressed even at low depths. This interpretation leads to a complete re-examination of mining induced stresses and mining techniques. The remainder of this paper discusses preliminary data on the behaviour of the claystones in water and analyses roof and floor instability in terms of a 'low strength' interpretation.

REACTIVATION OF AN ANCIENT LAND-SLIP NEAR WALLSEND, N.S.W.

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K.H.R. Moelle The University of Newcastle

The toe of an ancient landslip has recently been exposed in a box-cut excavation at Gretley Colliery, near Wallsend, NSW. The existence of the landslip had not been recognised prior to the trial mining operation in August 1985, and consequently no allowance had been made in the pit design. The combination of very heavy rainfall in late 1985, inadequate drainage, and the removal of the toe of the landslip led to renewed movement and the progressive failure of the highwall of the box-cut.

The landslip is located on the southeastern side of a steep north-east trending ridge, capped by conglomerate and sandstone of the Kotara Formation of the Newcastle Coal Measures. The basal slip surface is at the top of the Nobbys Tuff, which dips to the southeast at 2° near the toe, and at 5°-10° beneath the ridge. The Nobbys Tuff is 14m thick and overlies the Young Wallsend Seam, the mining target. The original failure involved at least 300 000 cubic metres of sandstone, conglomerate, mudstone and coal, and extended for 350m along the side of the ridge. The ridge crest is 40m above the slip surface. XRD analyses show the presence of random mixed layer swelling clays (illite, montmorillonite) in a 15m thick layer at the level of the movement horizon.

The Nobbys Tuff, in the vicinity of the movement plane, appears "layered" under the microscope. It is suggested that some "layering" in the microfield represents a secondary feature and can be attributed to the mechanical effects of the sliding movements of the fabrics of the layers involved.

The toe segment of the slide is sharply inflected upwards and fabrics of the topmost Nobbys Tuff layer in that segment have undergone ductile deformation. The functional fabric elements indicate a slow distortion process resulting from a "stacking" of tuffaceous layers. Further fabric analyses, involving other rocktypes as well, may point eventually to the likely trigger mechanism for the ancient slide. The landslip debris includes large blocks of sandstone and conglomerate up to 15m long and 5m thick, with many smaller blocks showing at least 90° rotation. There is an apparent increase in the size of the intact blocks from the edges of the slip toward the centre. The line of the toe has been traced laterally for 250m, and

The so-called "C-Marker" horizon in the Ulan Seam (Fig. 3) has shown several variations over the length of the Main North Headings, mainly in thickness and lithology. Significant changes in its coherence as well as in the mixed-layer claymineral content have been experienced, which caused problems in the definition of a reliable bolting horizon. The "C-Marker" had on occasions acted as an aquifer and as a "sub-surface watershed" resulting in significant water inflow at the face. The presence of a dolerite sill in the southern extremity of the development brought about a hydrological problem with major water intake as well as roof failure in the form of bed separation along the bottom surface of the sill. This sill has also caused difficulties whenever it was encountered in the bolt anchoring horizon. Chemical resin set bolts were difficult to anchor within this material due to its lack of coherence as well as to the relatively low temperature of the water in the roofstrata, which prolonged the normal setting time for the resin.

The existing joint sets have shown no significant changes in their spatial attitudes for the length of the Main North Headings other than in the vicinity of the major lineament traces as identified on satellite imagery. The major joints have been measured with the following attitudes:

Strike	Dip
N 21° E	near vertical
N 82° W	near vertical

and minor joints

N 88° W	vertical
N 02° E	near vertical
N 13° W	near vertical

The joints constitute a rock mechanics problem, as they are planar discontinuities, along which mining induced shear forces do act preferentially along the NNE trending sets. In addition, it has been found that any opening of the tensional joints has not only led to instability problems in the roof and floor strata but has also on occasions facilitated the entry of substantial quantities of water into the headings. Large amounts of water were encountered in several areas of the Main North Headings, some water-bearing zones were indicated on satellite imagery.

The mining conditions at the face and the conditions in the roadways have ranged from fair to very good, but with some particularly difficult occurrences that could be attributed either to facies changes, igneous phenomena or hydrological features.

The Main North Headings will now act as a subsurface link between the two collieries and the production from Ulan No. 2 Extended Colliery will be conveyed along them to the pit top facilities of Ulan No. 2 Colliery. Record mine production levels on development are currently being achieved in the new area.

Four major geological aspects were examined in considerable detail; hydrogeological investigations centred on likely groundwater movement in the shallow 40 to 60 metres cover area between Ulan No. 2 Colliery and Ulan No. 2 Extended, whereas sedimentological work dealt with the possible effects of a palaeochannel system on the Main North Headings and with a detailed identification of roof- and floor-rock types. The previously suspected thickening of the so-called "C-Marker" brought about by the deposition of pyroclastic material was investigated in this context together with the weathered sill in the roof sequence. Structural analyses focused on the definition of the existing pervasive and penetrative joint systems, as well as on those structural attributes that could influence the mechanical performance of overburden strata to a significant extent. The fourth and probably most important aspect was the assessment of mining geological effects that would be caused by the formation of headings and cut-throughs at a shallow depth in anisotropic sedimentary sequences with considerable lateral facies changes, and a rather complex hydrological setting.

III. ENGINEERING GEOLOGICAL ASPECTS

The engineering geological problems of the project, which has now been completed, were chiefly brought about by the presence of groundwater in significant quantities, lateral facies variations in the immediate roof-strata and in the Ulan Seam, as well as by the brittle deformation patterns in the thin overburden sequence.

The shallow cover in the designated open cut area has led to an unusual distribution of mining induced stresses that manifests itself in a minor floor heave, rib spalling and guttering. In addition, the superimposition of mining induced fractures upon the existing state of strain led to roof failures in several cases. The shallow cover precluded the development of a tertiary arch, as well as the support benefits normally provided by strata beaming in deeper coal mining developments.

The palaeochannel segment of a larger braided stream system (Fig. 2) has influenced the performance and behaviour of the roof strata by deposition of different rock types over short vertical and lateral distances. Alternating depositional and erosional phases during the fluvial regime have resulted in a complex arrangement of sandstones, siltstones, mudstones and laminates as well as conglomerate layers. This lithological diversity is responsible for variations in strength parameters, porosity values and consequently in the general mechanical competence of the roof strata. An additional important aspect of the fluvial depositional pattern is the presence of confined aquifers, which are most difficult to predict even with a fairly dense drilling pattern. The only reliable indicator for the definition of lenticular bodies is the directional primary anisotropy in the rockmass formed by current and gravity vectors. The problem was accentuated by the narrowness of the Main North Headings.

The Main North Headings are rectangular in cross section; four parallel headings have been driven by a Jeffrey continuous miner connected by cut throughs at 50 metre intervals.

To compare the advantages or disadvantages of a "panel," like the Main North Headings, with a "tunnel" as a subsurface link between a newly developed high production colliery separated from existing pit top facilities by a future open cut area, one has to assess the geological, mining engineering and economic factors. It would appear that engineering geological problems can be solved at acceptable cost.

The advantage of a "linking panel" is that it has a multiple opening confirmation which could accommodate more than one conveyor system, allows for conventional ventilation and, in this particular instance, it eliminated the need for a new pit top installation.

It has been demonstrated that a panel can be driven (first workings only) under shallow cover without major difficulties. This may have implications for the solution of rock mechanics problems associated with shallow mine openings under stored water or lakes, as well as at greater depths. The analysis of all data is complete at this stage.

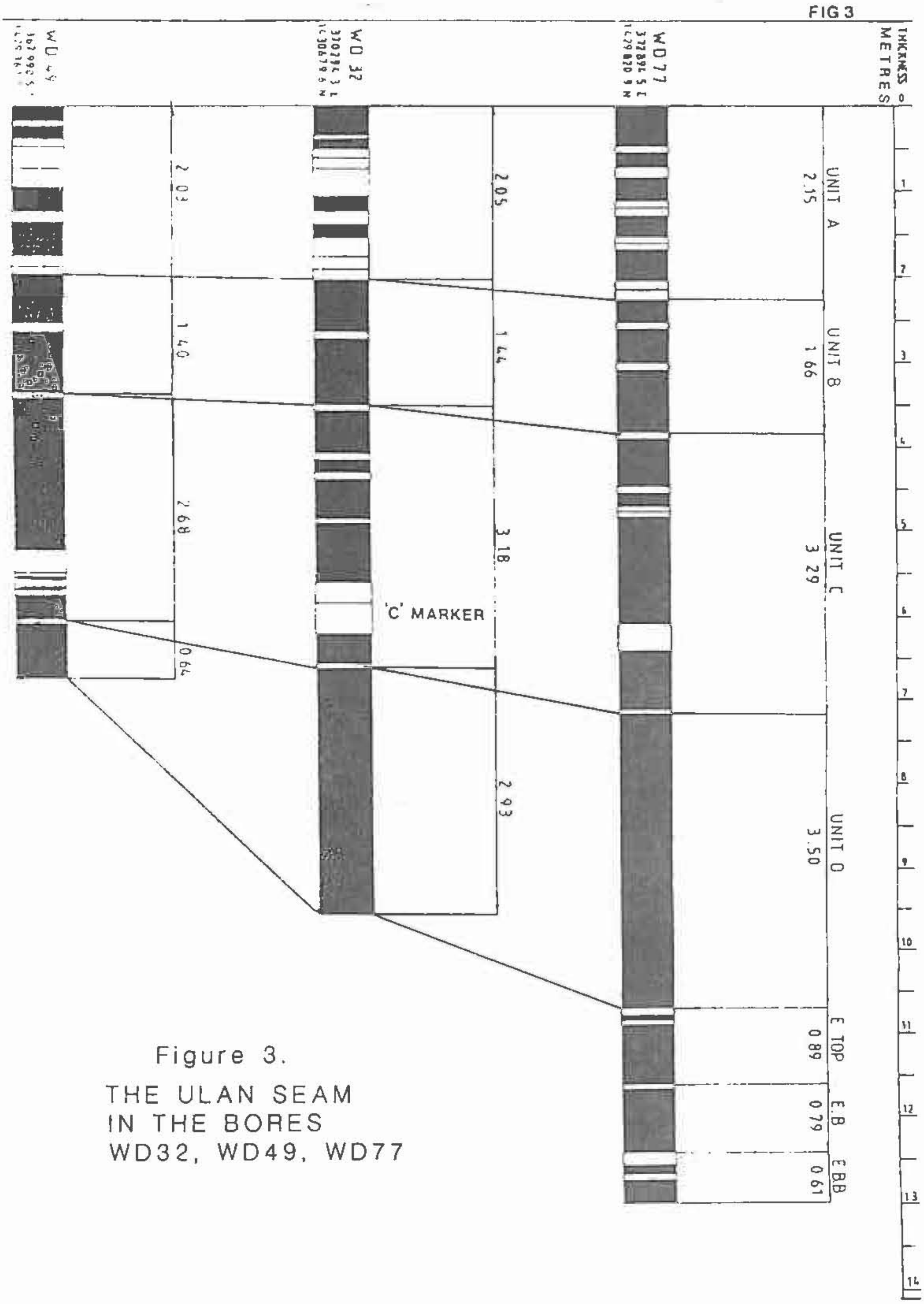

Figure 3.
THE ULAN SEAM
IN THE BORES
WD32, WD49, WD77

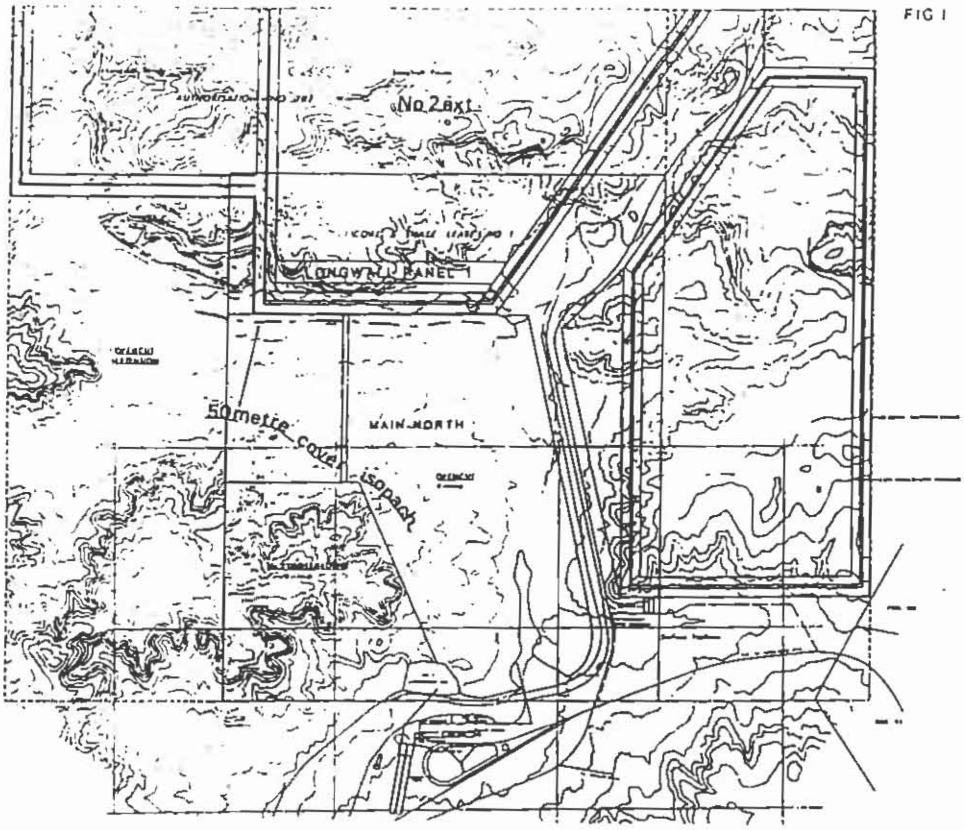
No 2ext
LONGWALL PANEL 1
50metre cover isopach
MAIN NORTH

FIG I

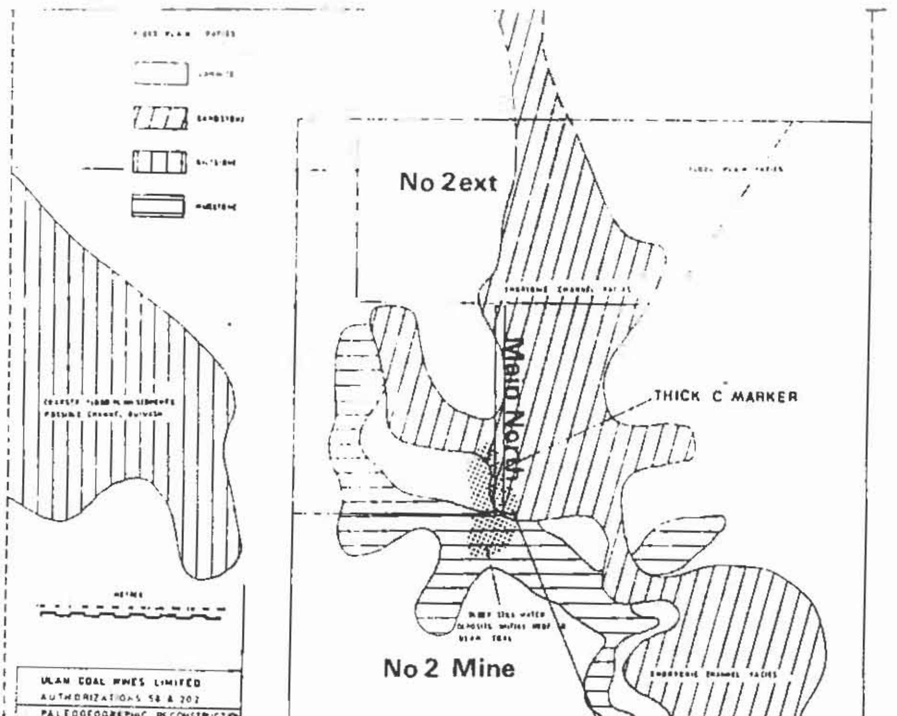
No 2ext
Main North
THICK C MARKER
No 2 Mine
ULAN COAL MINES LIMITED
AUTHORIZATIONS 58 & 202
PALEOGEOGRAPHIC RECONSTRUCTION OF THE ROOF OF ULAN SEAM
AUTHORIZATION 202
AUTHORIZATION 58

FIG 2

ROAD MAINTENANCE PROBLEMS IN SOME LITHOLOGICAL UNITS OF THE NEWCASTLE COAL MEASURES

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A range of geological features, and their significance as a contributing factor to road deterioration in the Newcastle and Lake Macquarie areas has been examined. Frequent and repeated damage to existing roads in these areas demonstrates that design and maintenance criteria may not always consider geological attributes adequately.

An important aspect for road design and construction in the Greater Newcastle area is a commonly thin soil profile, which ranges from 0.0 - 0.5m on the ridge areas to 0.5 - 1.0m thickness on gentle slopes. Total or partial removal of soil prior to construction leaves the pavement either on or near to a subgrade of in-situ geological materials. The conventional range of engineering tests deals exclusively with the analysis of soil materials and tends to ignore geological features such as outcropping coal seams (lateral facies variation), small scale faulting, jointing and degrees of weathering, all of which should be considered if the engineering performance of roads is to be fully understood.

The deposition of the Newcastle Coal Measures occurred in an area adjacent to the New England Fold Belt, a tectonically active region, from which it is separated by the Hunter-Mooki Thrust System. The tectonic setting of the Macquarie Snycline led to fairly rapid subsidence and thus to greatly varying depositional conditions. Sedimentary intervals with high and low energy environments are now portrayed by conglomerates and by coal seams, respectively. Volcanic activity, on a moderate scale, is evidenced by the many tuffaceous layers in the coal seams as well as in the inter-seam sediments.

Twenty seams occur in the Newcastle Coal Measure sequence. The relatively shallow dip values associated with the Macquarie Syncline and the gently to moderately undulating topography in the Newcastle-Lake Macquarie region provide many coal seam outcrops. There are over 1000 troublesome intersections of outcropping coal seams and roads in the Lake Macquarie area. Associated with the majority of these seams is either a tuff, tuffite or argillaceous laminate layer above as well as below the coal seam. Road failures have been examined and some results of these investigations are discussed here.

It has been found that some areas of distress and failure within road pavements do occur in areas that coincide with the outcrops of coal seams. Thus, a situation exists, where a small or relatively large area of the road pavement (depending on the relative dip and strike of the geological body) is underlain by a mechanically incompetent and actively swelling argillaceous material which is in turn underlain by a highly weathered coal seam, itself incompetent and acting as an aquitard.

Figure 1 shows the typical vertical lithological succession in the Newcastle Coal Measures from stronger rocks to weaker tuff/coal seam subgrades. These changes are quite rapid and may appear to be relatively insignificant, when considered in the context of a construction site of, say, 300m length or more, and are thus easily overlooked.

Apart from being less competent as a subgrade, areas with coal outcrops are affected by the shrink/swell characteristics of the enveloping argillaceous material. The variations of moisture content, both seasonally and during heavy rainfalls, will result in an appreciable change in volume of the subgrade, thus inducing strains into the pavement which a flexible pavement may not be able to compensate for, resulting in distortion and cracking. Shoulder areas are most susceptible to moisture changes and failure is most common in these areas. Initially, failure may occur only as a deformation associated with the shrink/swell activity; however, the bitumen, especially once aged, is frequently not ductile enough to accommodate such movements, and cracks appear. Moisture is then no longer prevented from entering the pavement and failure is accelerated.

Several standard tests and analyses of engineering properties have been done on over 1000 claystone and on clay specimens, sampled at the sites of road failures and reconstruction sites.

Their Plasticity Index (P.I.) values have been plotted against Lower Liquid Limit (L.L.L.) values as a first attempt to define the likely performance and behaviour of the rocks and sediments as a road support medium.

A classic linear relationship has been established within the Recent alluvial and colluvial accumulations, with most points plotting well above Casagrande's A-line. The medium to high plasticity and low to medium ranking L.L.L. values most probably represent mixed layer clays. Those values are fairly rare in outcropping claystones but are found preferentially in soil accumulations. The average distribution of the Lower Liquid Limit and Plasticity relationship is illustrated by a characteristically uniform plot in the diagrams in Fig. 2, with most points plotting above the Casagrande A-line. This indicates the predominance of argillaceous materials in the Triassic and Permian subgrades as well as in the accumulated soils, here described as Recent. The Plasticity Index (P.I.) indicates the moisture content range over which the soil remains plastic; all plots which consist of more than 50 measurements indicate an extra-ordinary large range. The established P.I. range is remarkable because it depends on which exchange ions are present. The higher limits occur with low valency ions. The P.I. Values are thus indicative of the relative amounts of water absorbed on the particles' surfaces.

The modification of clay-rich subgrades by the addition of lime has not been tested for clays in the Newcastle Coal Measures. The typical effect of lime-treatment on Atterberg Limit values is an increase in Lower Liquid Limit as well as in the Plastic Limit with a corresponding decrease in the Plasticity Index, resulting in a transition from the "clay side" of the "A" line into the "silt region" of the plot (Abdelkader & Hamdani, 1985). Other effects, such as a decrease in Linear Shrinkage and increased Compressive Strength make this method of stabilization very attractive.

Pavement cracking associated with this shrink/swell activity is usually longitudinal, however, lateral cracking is also possible, due mainly to the effect of vegetation (tree roots). "Alligator" style cracking occurs where local subsidence due to shrinkage has occurred and strains are introduced into the pavement in two or more directions to accommodate the increase in length due to the now induced curvature.

Results of X-ray diffraction analyses of claystones from the upper portion of the Newcastle Coal Measures are shown in Table 1.

Coal seam related claystone layers in the middle and upper portion of the Newcastle Coal Measure sequence become increasingly more "volcanigenic" and then show a decrease in volcanic components after a peak towards the middle of the Boolaroo Subgroup. Although the proportion of montmorillonite minerals in Table 1 may seem relatively small when compared to other highly expansive claystones with 40% or greater montmorillonite content, the Linear Shrinkage tests done on claystone subgrades in the Lake Macquarie area reveal values ranging from 10 - 23%. This demonstrates that the clays in question are susceptible to changes in moisture content. Foundation design does not ignore this factor but it is now given due consideration.

Movements of these clays do not seem to result in heaving of large areas, however, movements are still sufficient to damage pavements and should in future be considered in the design, construction and maintenance of pavements in areas of coal outcrops.

Very small faults are often not shown on geological maps; this is due to their size which cannot be plotted on the large scale geological maps commonly used. Their effect on engineering structures, however, can be quite marked. Small scale thrust and strike-slip faulting are more common in the Lake Macquarie area than is generally shown.

Shear zones produced by these faults often contain many closely spaced joints which diminish the competency of the rockmass and, more importantly for road construction, allow increased water volumes to migrate into the subbase.

Cuttings made in such fault affected areas should be examined closely to determine an optimum batter angle. The joint system should be analysed to determine whether blocks are likely to detach from the cutting face.

Intermittent gouge zones associated with the larger fault zones, (from 5 to 25m in width), can cause a local change in the coherence of subgrade material. The natural removal of this soft material by erosion and its subsequent replacement by natural fill can result in the formation of drainage channels which can conduct much water and may become unstable if material is removed, selectively.

Shear zones associated with the faulting provide an excellent means for water to gain access to the pavement as they are highly jointed. Being generally 0.5 - 2.00m wide, they can sometimes be identified by the presence of tree roots exploiting the high fracture porosity. If recognised, such areas can easily be drained by subsoil lines.

The exposure of tuffaceous and claystone rocks in a road cutting can develop into a "nuisance"-type problem in which weathering and resultant failure of the cutting slopes may occur. The weathering of these rocks is often very rapid and undercutting of the overlying material is the cause of such failures. Failure to protect these areas by means of grassing or shotcreting, as part of the construction process, results often in the necessity to return to the site to effect stabilization measures.

The presence of impermeable volcanigenic layers is frequently indicated by the presence of stratum springs. The elevated water levels in hilly areas such as at Speers Point, have resulted in many stratum springs, some of which occur below existing roads.

Recognition of the larger springs is relatively easy. Smaller occurrences, that may not flow permanently, are frequently ignored during construction. Road deteriorations after heavy rainfalls mark those areas as well as clay stains appearing on the road surfaces.

CONCLUSIONS

A direct causal relationship exists between the performance of roads and the outcrop patterns of coal seams and their argillaceous roof and floor strata in the Newcastle and Lake Macquarie areas.

It is very likely that overlooked geological features are a significant factor contributing to the generally high cost pavement maintenance requirements.

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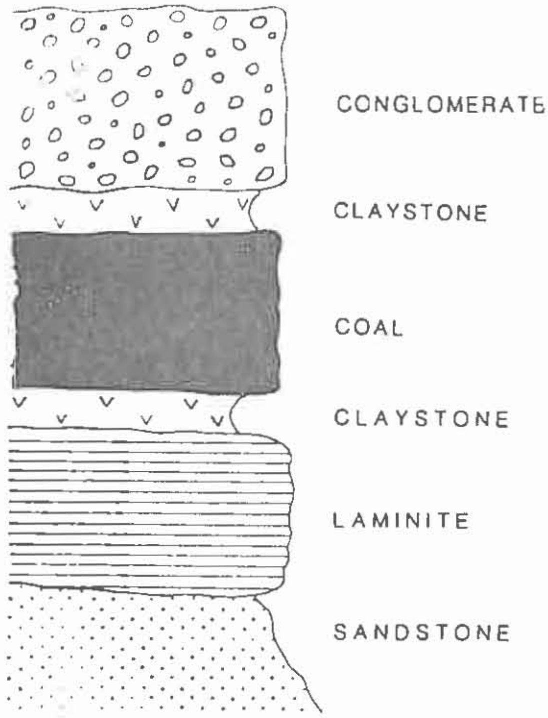

FIGURE 1.

CHARACTERISTIC PROFILE (SCHEMATIC)
AT MANY ROAD PAVEMENT FAILURE SITES

TABLE ONE

GENERALISED RESULTS OF CLAYSTONE COMPOSITION ANALYSES

(UPPER PORTION OF NEWCASTLE COAL MEASURES)

KAOLINITE	50% + 70%
ILLITE	20% + 30%
MONTMORILLONITE	8% + 14%
NONTRONITE	2% + 5%
CORRENSITE	2% + 4%
QUARTZ detrital	10% + 15%

The claystone layers become increasingly more "volcanigenic" going stratigraphically up the Newcastle Coal Measure Sequence, and then decreases after a peak towards the middle of the Boolaroo Subgroup.

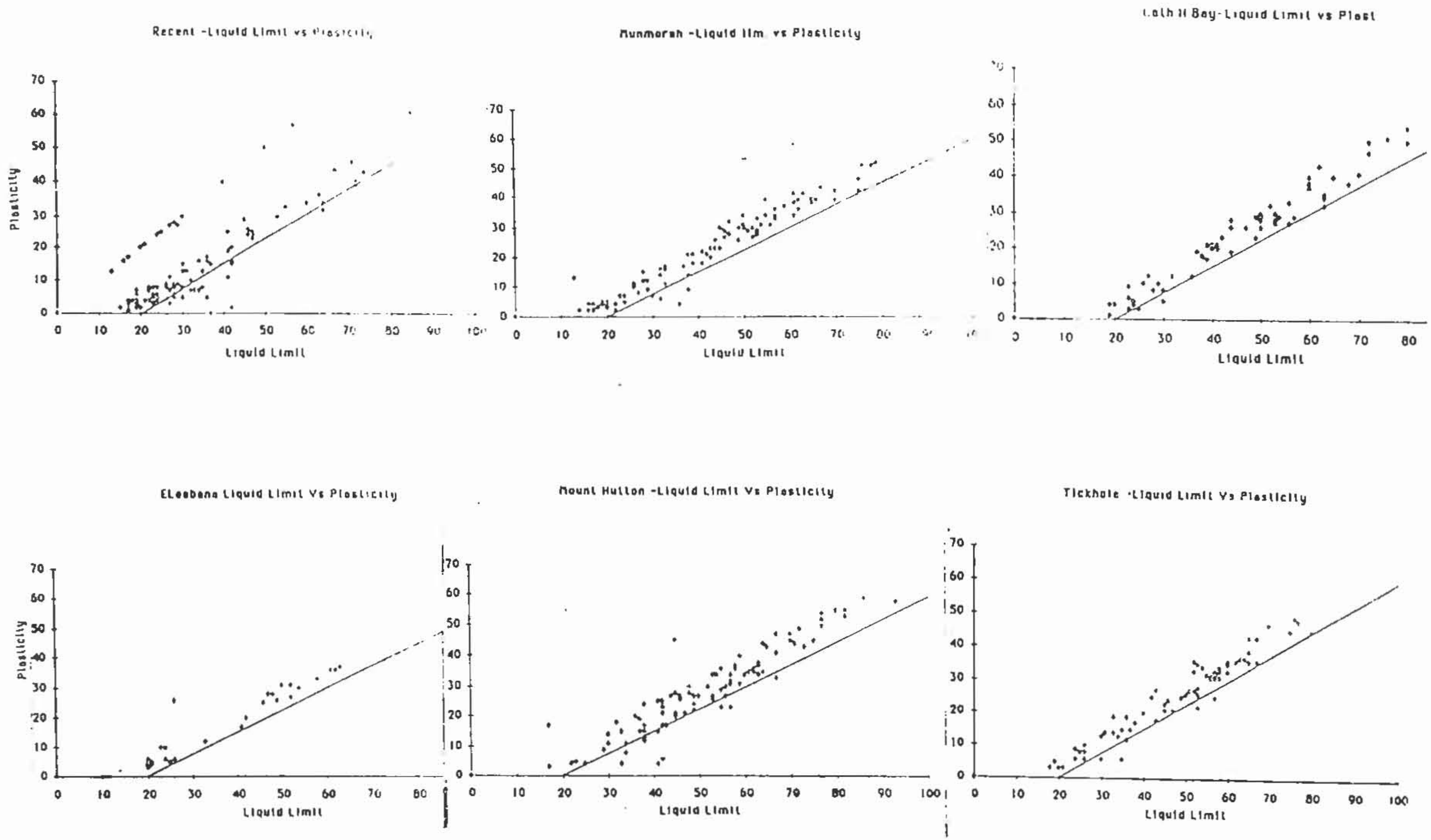
Recent -Liquid Limit vs Plasticity
Plasticity
Liquid Limit
Munmorah -Liquid lim. vs Plasticity
Liquid Limit
Lath II Bay-Liquid Limit vs Plast
Liquid Limit
Eleebana Liquid Limit Vs Plasticity
Plasticity
Liquid Limit
Mount Hutton -Liquid Limit Vs Plasticity
Liquid Limit
Tickhole -Liquid Limit Vs Plasticity
Liquid Limit

FIGURE 3

THE EL CENTRO EARTHQUAKE AND ITS RELEVANCE TO EARTHQUAKE ENGINEERING STUDIES IN THE SYDNEY BASIN REGION

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Because of only a limited amount of strong motion earthquake data being available for the Sydney Basin region, the El Centro earthquake record (18 May, 1940) which is frequently referred to in the American earthquake engineering literature, has often been used by design engineers during the last few decades for studying the dynamic response of important structures in Australia.

In this paper, a look is made at the response spectra of this particular earthquake, and a comparison made with those derived from some actual earthquake recordings obtained from the Sydney Basin region, and adjacent areas.

The removal of errors from the earthquake records using dynamic programming principles is discussed, while the differences in the features of the El Centro and Australian Response Spectra are explained on the basis of different earthquake source mechanisms.

COLUMNAR-JOINTED SANDSTONE — A REVIEW

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INTRODUCTION

Occurrences of columnar jointing in Hawkesbury Sandstone have been noted since 1895 when Curran (1895) reported an outcrop at Bondi. Later authors, such as David (1897), Curran (1899), Morrison (1904), Jensen (1908), Sussmilch (1914), Osborne (1950) and Branagan and Packham (1970) attributed the phenomena either to metamorphism, metasomatism or hydrothermal alteration associated with an igneous intrusion.

Outcrops with columnar jointing range in area from less than 10 to approximately 200 m^2 and commonly occur in undulating terrain near tops of ridges and hills. Columns are generally polygonal with side dimensions ranging from less than 5 cm to a maximum of 30 cms. Bedding, including cross-bed laminae, is clearly preserved at many localities. Outcrops with columnar jointing are consistently harder than other nearby outcrops of Hawkesbury Sandstone and are more resistant to weathering.

Apart from those at Bondi, outcrops of columnar-jointed Hawkesbury Sandstone have been reported previously at Bundeena, West Pymble, Cronulla Lane Cove River near East Ryde and Bullio (near Mittagong). Reconnaissance mapping for geophysical surveys of the southern Sydney Basin in 1981 also discovered several outcrops, the largest being approximately 200 m^2, 10 km NW of Bulli, a northern suburb of Wollongong.

This paper investigates the nature and possible mode of origin of columnar-jointed sandstone at Bulli and Bullio and discusses the significance of this phenomenon to coal geology.

LITHOLOGY

The columnar structures at Bulli occur in the upper part of the Hawkesbury Sandstone which, as indicated by drill hole data, is at least 150m thick. At Bullio, the Hawkesbury Sandstone unit is much thinner with an estimated thickness of 15 m. The parent sandstone is composed of subrounded to subangular, quartz framework grains with a kaolinite-illite groundmass (Table 1).

Three of the four major joint directions of the columns (095°, 138° and 170°) are coincident with the three prominent regional joint directions (093°, 144° and 173°) and this suggests that the columns may have formed under the same tectonic regime as the regional joints and consequently a temporal association between columnar-jointed sandstone and the regional joints.

Whereas the common texture of non-columnar Hawkesbury Sandstone is that of quartz framework grains surrounded by a clay matrix, columnar sandstone is composed of remnant primary quartz framework grains rimmed by microcrystalline secondary quartz. Many of the primary quartz cores have undulose extinction and the secondary quartz is in optical continuity with the framework grains. Clay minerals generally constitute less than 3% of the bulk rock.

Optical continuity between quartz grains and quartz overgrowths has been attributed to the precipitation of secondary, mobilized quartz growing in phase with the primary quartz (Williams et al., 1954).

The percentage of secondary quartz ranges from 26 to 77% (Poole, 1983). Columns containing the highest percentage of secondary quartz are generally harder than those with less secondary quartz and show a greater degree of regularity of prism shape.

Table 1 Aspects of Columnar Jointed Sandstone at Bulli

Axis of Elongation of Columns	
- Dip	60° to 83°
- Direction	NE to S
Cross-bed Laminae within Columns	
- Strike	202° to 232°
- Dip	16° to 25°
Joint Directions	
- Regional	093°, 144°, 177°
- Local	098°, 139°, 174°
- Columnar Sandstone	030°, 095°, 138°, 170°
Composition:	
Non-columnar Sandstone	quartz, kaolinite, illite
Columnar Sandstone	primary quartz secondary quartz minor clay minerals

MAGNETOMETER SURVEY

A ground magnetometer survey comprising a grid of thirteen traverses and 2160 stations, at 2 m intervals, was carried out over the Bulli outcrops. Combined length of the traverses was 4.2 km. Data were corrected for diurnal and other drift using a base station where readings were taken four times an hour.

Three zones of magnetic anomalies were found. The zones trend at 310° and 325 and these are the same trends as those of known dykes which are exposed on the surface, 3 km east of the study area. Dykes have also been intersected in underground workings of the Bulli Colliery, 1.5 km to the south east. Projection of some of the known dykes coincides with the trends of the zones of magnetic anomalies.

The magnetic expression of the zones of anomalies is not constant suggesting that the suspected dykes are either discontinuous and/or thin laterally. This mode of occurrence is the same as that of the dykes which have been intersected in the underground workings.

A maximum width of 2 to 3 m is predicted for the suspected dykes and this is of the order of width of the known dykes.

MODE OF ORIGIN

The relationship between Hawkesbury Sandstone that exhibits columnar jointing and igneous material has been expressed by many authors. Curran (1895) suggested that the columnar-jointed sandstone at Bondi "was no doubt induced by the proximity of the igneous rock". He also stated that some of the Hawkesbury Sandstone which is exposed had been in contact with the "molten basalt" and had developed columnar jointing whereas for other parts of the exposure this did not hold.

Morrison (1904) suggested "that mere contact with the molten material had not produced the changes. It is probable that heated vapours coming from the molten magma, combined with the varying composition and texture of the rocks affected, were the principal cause of the metamorphic effects."

Sussmilch (1914) stated "that where the Hawkesbury Sandstone has been intruded by basalt-dykes, prismatic structure had been developed in many cases, the most notable being that at Bondi. This has been produced in what were porous sandstone beds, saturated with water at the time the intrusions took place; unequal heating started convection currents which heated the particular sandstone bed for some distance away from the contact, and caused the rock to expand. Subsequent contraction on cooling developed the joints whose intersection resulted in the prismatic structure. This prismatization is always accompanied by a variable amount of secondary silicification which has converted the sandstone into an imperfect quartzite."

Osborne (1950) when discussing basic igneous intrusions, pointed out that "two types of metamorphism have affected the Hawkesbury Sandstone:

(i) Purely thermal (non-additive) metamorphism has been operative, causing the baking of sandstone with some mineralogical and textural modifications.

(ii) Addition of siliceous solutions has been associated with thermal change, contributing to the development of glassy, quartzitic derivatives." He went on to discuss the occurrence of the quartz derivative tridymite.

Goldberry and Fishburn (1964) suggested that the magmatic volatiles heated groundwater which, after cooling, had produced columnar jointing adjacent to the Bondi diatremes.

Columnar jointing has been observed in buchites which outcrop at Apsley, Tasmania. The columnar jointing was presumed to result from heating of the sandstone by a basalt neck, causing grain melting and subsequent cooling and repacking. Contraction at the time of cooling, gave rise to the jointing.

In summary, most authors have attributed the columnar jointing to either contact metamorphism or to hydrothermal alteration associated with intrusions.

The secondary quartz exhibits a speckled texture when compared to the primary core of quartz. This texture results from inclusions of clay minerals in the quartz rims.

Microscopic examination of the Hawkesbury Sandstone exhibiting columnar jointing shows that the secondary quartz has grown in optical continuity with the primary quartz which acts as a core. However, the original quartz does not lose its original properties as is evident by the retention of undulose extinction in some of the quartz cores. The presence of well-defined bedding in outcrops of columnar-jointed sandstone at Bulli, further indicates that the rock has not been totally melted.

The results obtained from this investigation suggest that the mode of origin of the columnar jointing in Hawkesbury Sandstone, at the outcrops studied near Bulli, is caused by hydrothermal solutions which emanate from, or are associated with, dykes in the area. Dykes also occur near, but not adjacent to, the outcrops of columnar-jointed sandstone at Bondi and West Pymble. If the quartz had been recrystallized by thermal metamorphism, one would expect the columns to form adjacent to the dykes at all outcrops and this is clearly not so.

The variation in the degree of uniformity between sites is related to the degree of mobilisation of the quartz. During cooling, the sandstone developed polygonal contraction joints. The greater the mobilisation of the quartz, the greater the heating and expansion of the rock.

The occurrence of isolated outcrops of the columnar-jointed Hawkesbury Sandstone is due to the inhomogeneous nature of the structure of the sandstone. The location of the sites is probably controlled by planes of weakness, such as joints, along which the hydrothermal solutions were able to pass.

A probable increase in total quartz in some outcrops can be explained by the addition of silica carried by the hydrothermal solutions. This free silica is unlikely to be derived from the igneous material; it is more probably derived from the dissolution of quartz by hydrothermal solutions, at depth, as these pass through the Hawkesbury Sandstone and other quartz-rich units.

COALFIELD GEOLOGY

Observations of columnar-jointed sandstone at Bondi and West Pymble indicate a close relationship between dykes and the jointed sandstone. In addition to this, the magnetic data derived from this study, suggests a close relationship between non-outcropping dykes and columnar-jointed Hawkesbury Sandstone at Bulli. As a consequence, we suggest that any outcrop of columnar-jointed sandstone in a known coal mining area should be investigated as a potential dyke or dyke zone.

As a preliminary study, a magnetic survey should be undertaken to test the area for dykes.

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QEM*SEM: A NEW TOOL FOR THE INVESTIGATION AND CHARACTERIZATION OF THE MINERAL MATTER IN COAL AND THE PRODUCTS OF COAL COMBUSTION

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QEM*SEM, an acronym of Quantitative Evaluation of Materials by Scanning Electron Microscope, is an automated mineral recognition system employing dispersive spectrometry (EDS) and back scatter electron responses (BSE) to make phase identifications. The machine is controlled, and data collected, by a high performance mini computer which is interfaced through data bus oriented electronics.

The major components of QEM*SEM are a scanning electron microscope (SEM) fitted with dual twin energy X-Ray spectrometers, a custom chamber and stage, a specially chosen back scatter electron detector fitted in the chamber, and the mini computer.

The base SEM is the International Scientific Instruments SX series which meets all resolution and beam stability criteria for QEM*SEM applications. The chamber was designed and built by CSIRO especially for QEM*SEM. The stage is a proprietary brand with stepping motor drive of X, Y & Z axes, capable of resolution of 2.5 micrometers per step. The chamber and stage are matched and allow 100 mm of stage movement in both X & Y axes. Computer control of the stage can be direct by software commands, interactive to a terminal, or by tracker ball.

The special EDS units are high performance spectrometers manufactured commercially to a CSIRO design. Each unit consists of twin silicon diode X-Ray detectors coupled to a single liquid nitrogen dewar, with separate preamplifiers for each detector. The units are supplied as matched pairs of twin detectors set up so that they view the QEM*SEM sample with an angle of 90° to the incident X-Ray cone at a working distance of 30 mm. Matching amplifiers are supplied specifically set up to handle high count rates with minimum spectral broadening or background from pulse pile up. The back scatter electron detector is a silicon surface barrier device operated in current mode, and its characteristics are chosen to compromise between speed of response and DC signal linearity. A standard secondary electron detector is fitted through the rear wall of the chamber.

The computer system chosen for QEM*SEM is the Digital Equipment Corporation VAX11 series with the VMS operating system software. Peripherals are a 9 track/1600 bpi tape drive, a Tektronics 4106 colour terminal and a HP 7550 graphics plotter. Data and control communicate with the VAX through a specially developed "bus window" which is plugged into the UNIBUS card frame. This computing system was chosen because the CPU speed is sufficient to allow processing of an X-Ray spectrum in the time that the next spectrum is being collected (16 msec).

Mineral grains for QEM*SEM are prepared in standard 25 or 30 mm epoxy mounts with special regard for representativeness and to ensure that individual grains don't touch. The instrument system has been designed to operate at point scanning rates in excess of 100,000 points per hour, with unique mineral species identification produced and stored for every point scanned on the specimen. The information contained in the X-Ray spectrum, and the measured intensity of the back scattered electrons, are collected at each point, and complex software is applied to this data to produce the mineral species identification. The species data is the basis of a "mineral map" which can be displayed as a colour graphics image or be stored on disc or tape for further analysis.

The "mineral map" data can be stereologically and statistically analysed and tables of mineralogy, shape, association etc produced or presented as plotted graphics. The stereological capability of QEM*SEM is not fully realized at this stage of its development and more work is being done along these lines.

It is possible for the operating mineralogist to input sample scan parameters in advance of analysis creating the sample processing schedule. The analysis process proper is completely automatic, and the schedule can include up to nine samples in succession that will be performed without operation intervention.

QEM*SEM was originally developed for sulphide orebodies in Australia, but is now being applied to measurements on other materials such as iron ores, precious metal ores, beach sands, coal fly ash and pyrometallurgical products.

Investigations into the characterization of fly ash began in July 1985. QEM*SEM is well suited to the problem because the material is particular and composite minerals are either spectrally directly related, or analogous, to gangue, in base metal ores.

Part of the QEM*SEM identification process is to group the minerals into a 32 item table known as the 'condensed mineral list'. In the early stages of the fly ash investigations the characterization of fly ash phases was possible from pre-existing mineral spectral data, the work guided by a detailed electron microprobe study of fly ash (Shibaoka & Ramsden, 1982) and EDS data accumulated by the Division of Fossil Fuels. Later versions required extensive rearrangement, but few additions. A simplified representation of the version now in use is shown in table 1.

Shibaoka & Ramsden (1982) demonstrated a relationship between fly ash particle composition and morphology. The operators of large pulverized coal fired furnaces have attempted to specifically identify particles that are causing boiler erosion and other operational problems with limited success, but QEM*SEM data now offers the opportunity to examine a large number of different fly ashes rapidly and thoroughly. To this end the stereological functions of aspect ratio, the ratio of the long and short axes of particles, and $(\text{perimeter})^2/\text{Area}$ have been correlated and a graphics routine written to present the functions. As this work progresses it will be possible to add particle type to the graphic representation, thus producing a useful characterization of all the important parameters on one diagram.

At present the technique shows distinct promise for a rapid and definitive characterization of fly ash material. A cooperative agreement between the QEM*SEM unit in Mineral Engineering and Fossil Fuels has been reached, and it is hoped that electricity generating authorities will also become involved. The opportunity offered here is a rapid means of determining the characteristics of 'problem' ashes, and to obtain feedback on changes in ash character as combustion conditions are changed. The next part of the project will be to accumulate data using the techniques developed to date.

Parallel to the fly ash investigations has been the characterization of mineral matter in coal. Standard SEM imaging of coal has long been fraught with problems, foremost being the low atomic number of the material which results in a low BSE response. The standard epoxy used for specimen mounting for most coal petrological work, and QEM*SEM, has a BSE response approximately equal to coal. This is true for the whole range of coal types. Consequently, although the mineral matter in coal- clays, quartz, carbonates, sulphides - is easily recognised, a modal analysis is not possible unless coal and setting medium can be distinguished.

Straley (1983) successfully distinguished coal from setting medium by using a brominated epoxy instead of the standard chlorinated material. CIBA-GEIGY provided a brominated epoxy, but used in undiluted form the material had a BSE response that interfered with the lower response minerals eg. clays. After extensive experimentation a mixed brominated/chlorinated epoxy product yielded the correct BSE response that has to lie between that of coal and the lowest of the contained minerals. Good images are now produced, and work is proceeding on software changes that will distinguish the coal - now the lowest response - as part of the modal count rather than background.

The joint project between the Division of Fossil Fuels and the QEM*SEM unit at Mineral Engineering has as a longer term aim relating the mineral matter in specific coals to their fly ashes produced under specified combustion conditions. This has the potential of allowing operators in general terms to predict the effect of various combustion conditions on coal types, and hence influence the design of combustion systems.

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SCHEMATIC DIAGRAM of QEM*SEM
DATA ACQUISITION & CONTROL

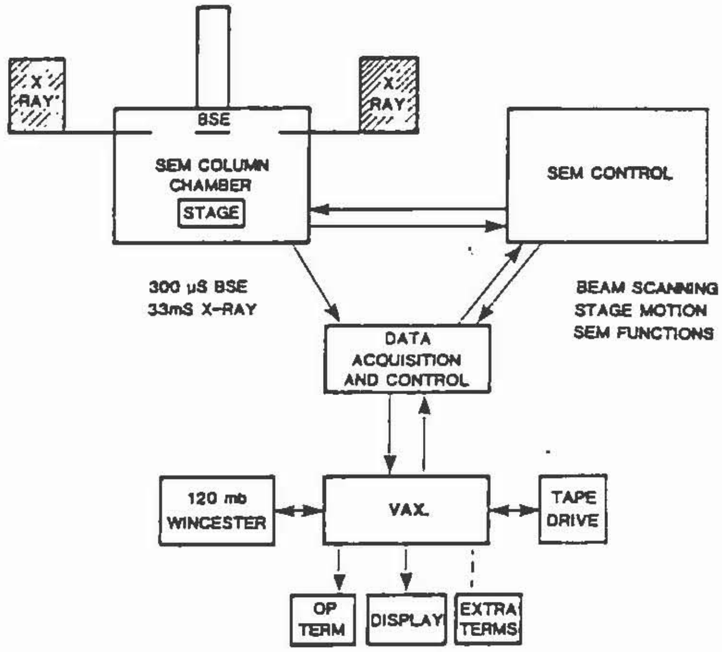

TABLE 1

QEM*SEM COMPRESSED MINERAL LIST: FLY ASH

	Group	Selected Mineral Species Present
1.	Background	Epoxy
2.	Burnt clay	Aluminium, silicate, potassium silicate, (would include mullite)
3.	Fe glasses	Iron & silicon
4.	Ca glasses	Calcium & silicon
5.	Mg glasses	Magnesium & silicon
6.	Ti glasses	Titanium & silicon
7.	Calciums	Calcium with minor silicon
8.	Irons	Iron Oxides
9.	Detrital quartz	Quartz
10.	Rutile/Ilmenite	Titanium/Iron oxides
11.	U/Ce Minerals	Various high atomic number U/Ce compounds
12.	Sulphides	Sulphides, e.g. pyrite, sphalerite, galena

THE INFLUENCE OF OXIDATION ON THE FLUORESCENCE PROPERTIES OF COKING COALS

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Fluorometric analysis, considered to be a potentially valid means of predicting coking behaviour, has a further application based on its ability to detect even subtle degrees of oxidation. Blue light excitation has been used in accordance with the method described by Diessel (1985) and Diessel and McHugh (1986).

In an attempt to monitor fluorescence response over time, freshly mined coal of differing rank was allowed to oxidise under constant temperature and humidity conditions. Five coals, all of Permian age and varying in rank from high-volatile bituminous to medium-volatile bituminous, were selected for the present investigations.

Only absolutely fresh coal was used so as to establish maximum fluorescence intensity levels prior to the commencement of controlled oxidation. Hence, samples were usually received within 24 hours of mining.

After crushing to -1 mm, one subsample of each coal was immediately set in epoxy resin to act as a reference sample, as the mounting medium acts to 'preserve' the inherent fluorescence properties of the coal. The remaining samples were kept in open Petri dishes in an environment of constant temperature and humidity. Fluorescence intensity measurements were then conducted on successive samples, at pre-determined intervals over a period of up to 9 months. On each respective testing day, samples were set in epoxy resin, cut, polished and analysed. Similarly, the reference sample was also re-ground and polished in order to expose a fresh surface, and subsequently re-examined.

Carbonisation tests were carried out concurrently with the fluorescence analysis to assess the relationship between variations in fluorescence intensity and carbonisation properties. These tests comprised Gray-King coke type, crucible swelling number, Gieseler plastometer and Audibert-Arnu dilatometer.

Results obtained for two of the five studied coals, representing a high-volatile and medium-volatile coal respectively, are shown in Figures 1 and 2. However, in all cases, fluorescence intensity is seen to decrease with time for both telocollinite and desmocollinite.

The corresponding trend for inertinite is less marked, particularly for the higher rank coals and, generally speaking, the lower rank coals display a far more sensitive response to oxidation than the former. The response of the reference sample for each of the five coals is essentially constant, i.e. unaffected by oxidation.

In general, each of the five coals reacts in a different and characteristic manner to oxidation. The effect of oxidation on the high-volatile bituminous samples is both more pronounced and more immediate compared to the higher rank material, with the latter samples generally maintaining initial intensity levels for a greater period of time. This is in keeping with the changes in the coal structure produced during coalification which in turn influences fluorescence properties.

Results obtained from fluorescence intensity determinations are consistent with those indicated by laboratory carbonisation tests, especially in the case of fluidity which is recognised as a particularly sensitive indicator of oxidation. There is general agreement between the commencement of the decline in fluidity and dilatation values and that shown by fluorescence intensity levels of telocollinite and desmocollinite for each sample. Inertinite varies in its response to oxidation, being less affected in the higher rank samples. CSN and GKCT also do not display a strong relationship although both values decline when oxidation is more pronounced. Reflectance levels were also noted during the course of the project but were not found to vary significantly.

Following determinations of both vitrinite and inertinite fluorescence intensities for a variety of coals of different rank, it became apparent that the fluorescence properties of coal in general follow a systematic pattern, as shown in Figure 3. Hence, in the prime coking coal range, fluorescence intensity reaches a maximum and drops markedly outside this optimum region. However, it was noted that some coals did not plot in a position consistent with their rank and therefore oxidation may have been influential in the apparent lowering of fluorescence intensity. Examples of such coals are delineated (☆) in Figure 3. All of these samples originate from areas of shallow overburden. Based on the results of oxidation studies, it seems obvious that oxidation does indeed play an important role in the suppression of measured values.

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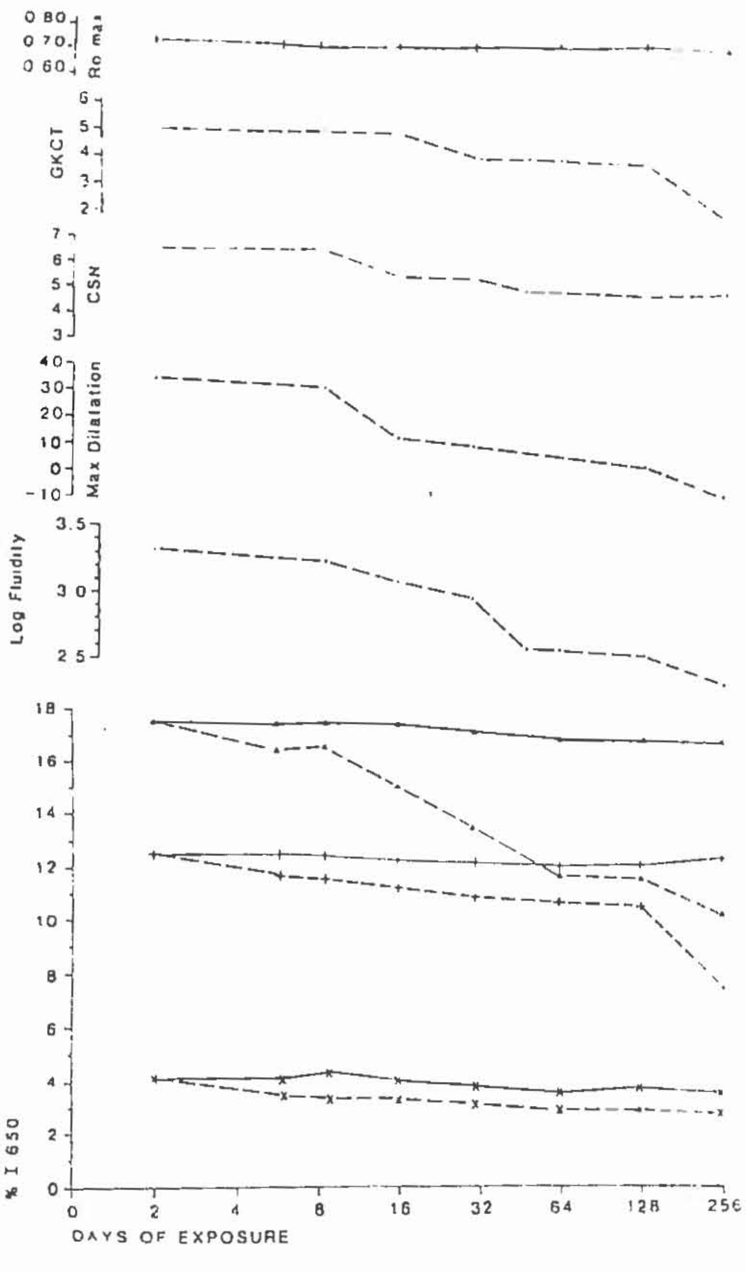

Figure 1 Comparison of the changes in various properties in relation to exposure time for a high volatile bituminous coal. Triangles = desmocollinite, vertical crosses = telocollinite, oblique crosses = inertinite, dots = bulk coal. Dashed lines = exposed sample, solid lines = reference sample (not exposed)

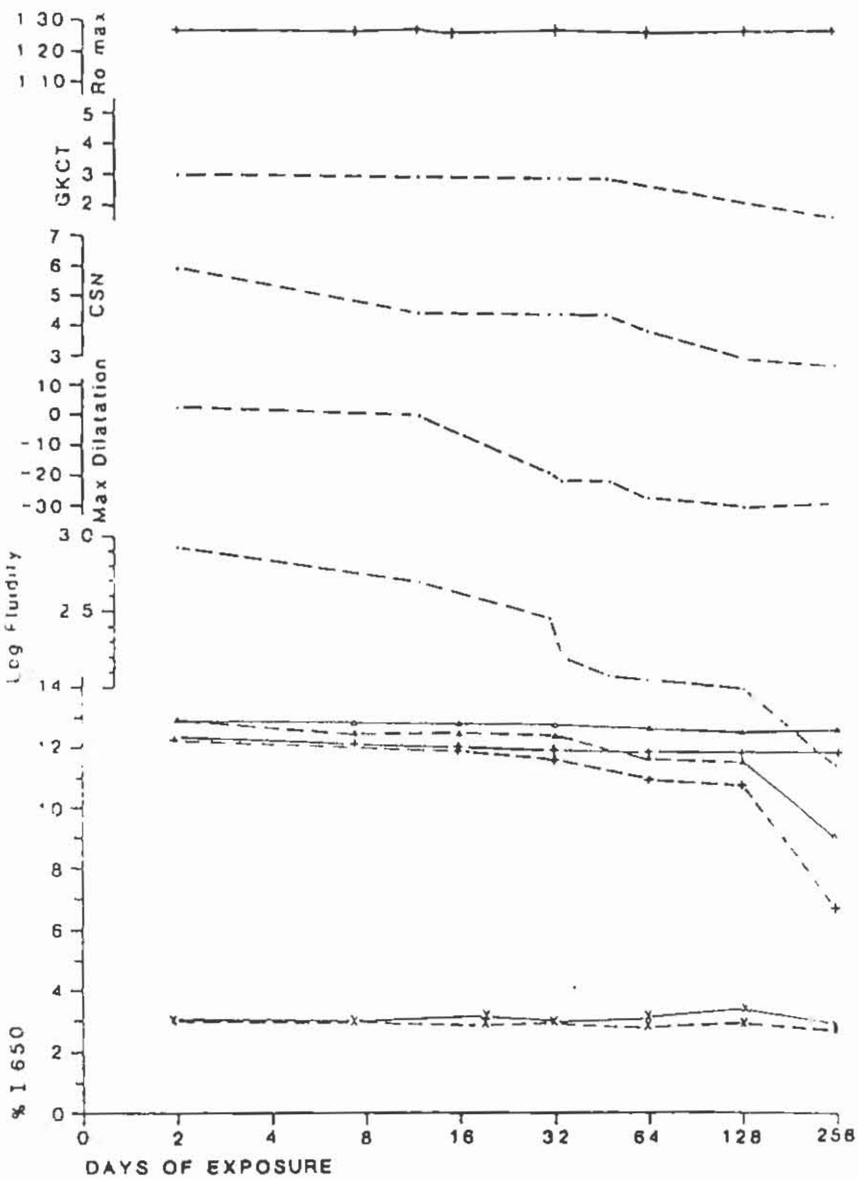

Figure 2. Comparison in the changes of various properties in relation to exposure time for a medium volatile bituminous coal. Legend as in Figure 1

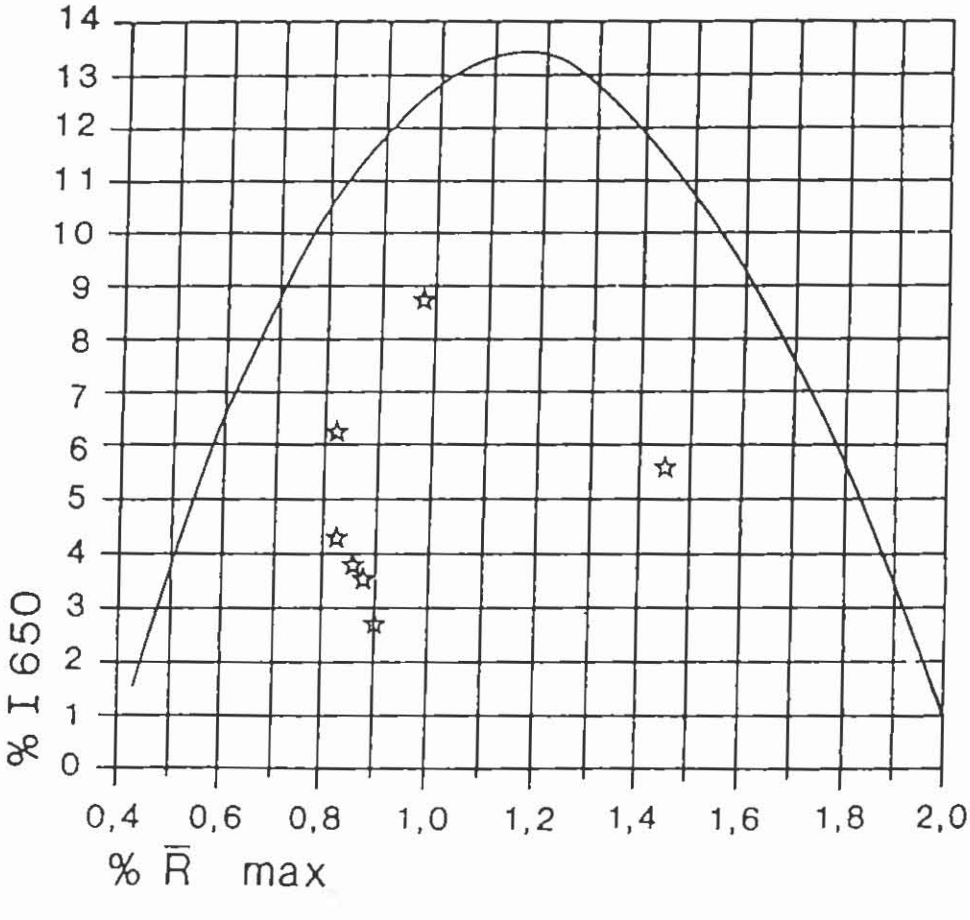

Figure 3

THE CORRELATION BETWEEN MICROFLUORESCENCE AND CARBONISATION PROPERTIES OF COALS

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Several Australian export coking coals contain a high proportion of coal macerals which because of their alleged failure to fuse during carbonisation have been grouped under the term INERTINITE. Notwithstanding the fact that these coals are capable of producing good quality metallurgical cokes both on their own and in blends, their high inertinite content is regarded as detrimental by overseas buyers. Indeed, the proposed ECE coal classification uses the inertinite content as one of its commercial parameters which will discriminate against Australian coals. On the other hand, coking experiments carried out by Diessel (1983) demonstrated that a substantial proportion of inertinite is, in fact, not inert but softens and becomes integrated with the coke matrix during carbonisation. It is therefore necessary to develop a method by which it is possible to make a reliable distinction between "inertinite by name" only and the smaller amount of truly non-fusible material. This has been subject of NERDDP - Project No. 84/4057 and a current project, No. 85/5141. The following remarks have been compiled from the completion report of the first mentioned project.

The main fluorometric procedure used is the determination of relative fluorescence intensities of telocollinite, desmocollinite and inertinite. The advantage of intensity determinations compared with more complicated analysis procedures is their relatively low cost in terms of equipment and high sample throughput.

Polished blocks of crushed coal are microscopically analysed in both white light and fluorescent mode. This work is supplemented by laboratory carbonisation tests and a limited amount of chemical analyses. The white light microscopy, i.e. maceral analyses and vitrinite reflectance determinations, is carried out in accordance with standard procedures. Fluorescence microscopy has been concentrated on a modified kind of maceral group analysis and measurements of relative fluorescence intensities in vitrinite and inertinite. The respective methods have been described by Diessel (1985), Brown et al. (1985a and 1985b), Diessel and McHugh (1986).

A total of 35 Australian and 30 overseas coals have been tested for fluorescence and a variety of other properties. The results demonstrate that vitrinite contained in bituminous coals fluoresces with differing intensities. These vary with vitrinite type (desmocollinite fluoresces more strongly than telocollinite) and the rank of the host coal, i.e. intensities are low at both ends of the coalification range but reach a peak in high to medium volatile bituminous coal. This relationship is illustrated in Figure 1 which also demonstrates that with the technique used, a portion of inertinite content of all coals tested shows a measurable degree of fluorescence. It too, waxes and wanes with increasing coalification and so does the proportion of fluorescing inertinite in coal.

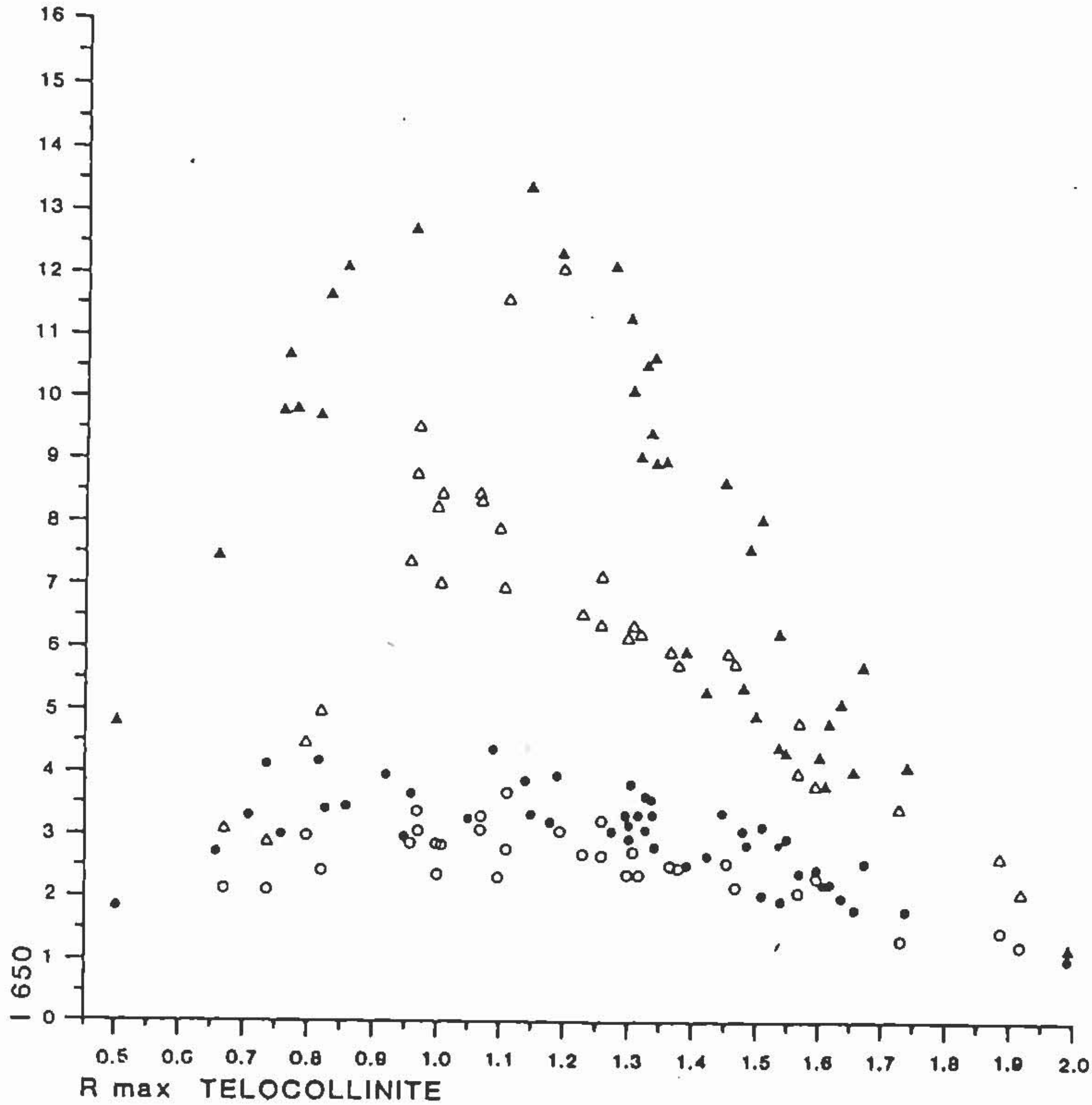

Figure 1. The relationship between mean values for relative fluorescence intensity and telocollinite reflectance. Open and closed triangles = Carboniferous and Permian telocollinite, respectively; open and closed circles = Carboniferous and Permian inertinite.

It is suggested that the fluorescence pattern shown in Figure 1 is due to the generation of secondary bitumens from the thermal cracking of macromolecules during coalification and, even without knowing the exact nature of the process and its products, the analysis results suggest that the substances which cause the coal to melt in the coke oven are identical to those which cause the coal to fluoresce when irradiated with a high energy beam. It should therefore be possible to assess the coking potential of a coal by a quantitative assessment of the fluorescence properties of its vitrinite and inertinite macerals.

The overseas coals tested have been all of Carboniferous age. In their fluorescence pattern they follow a similar trend to that observed in Australian coals but their fluorescence intensities are mostly lower than those of the local coals (Figure 1), even when fresh samples are compared. It appears therefore that Australian coals contain a higher proportion of the fluorescence generating secondary bitumens than their Carboniferous counterparts. Floral differences and variations in climate at the time of peat formation are probably responsible for the diverging properties.

Fluorescence analyses can be taken as a measure of inertinite reactivity only if their results agree with the actual behaviour of inertinite in the coke oven.

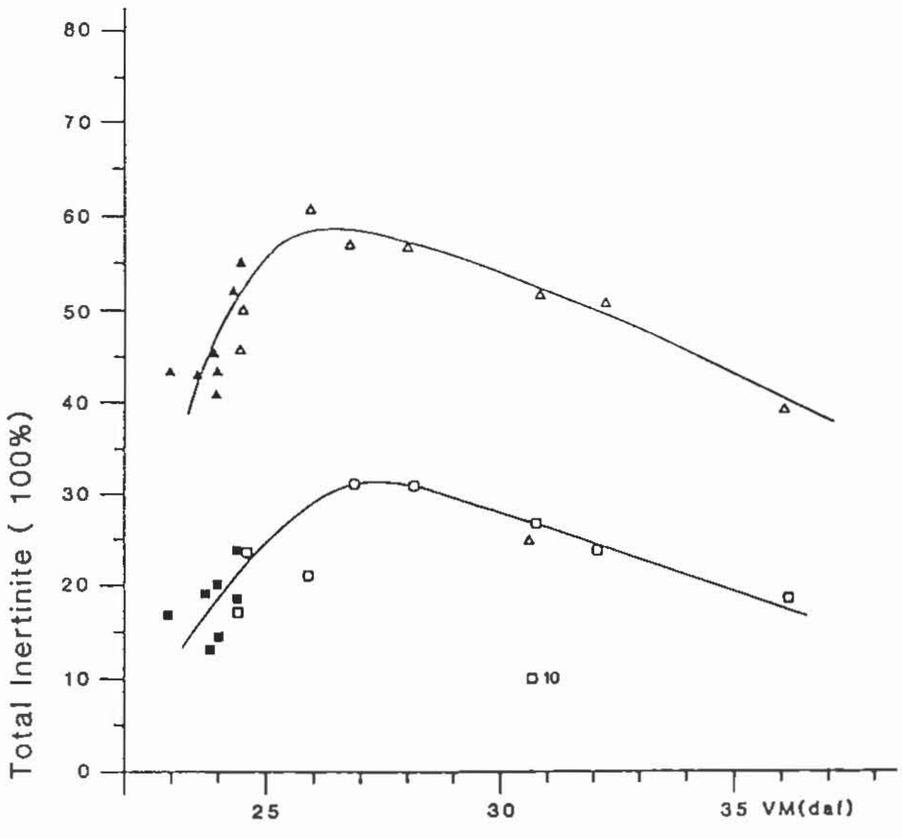

Figure 2. Comparison between the proportion of fluorescent inertinite (triangles) and the proportion of inertinite-derived coke matrix (squares) in relation to the volatile matter content of the feed coal. Open triangles and squares represent Carboniferous overseas coals, closed triangles and squares refer to Australian Permian coals.

In order to investigate the response of inertinite to carbonisation, mass balance calculations were carried out on 16 coke samples and their respective feed coals. Eight of the samples were of German origin whereas the others came from Australian sources.

The feed coals were subjected to the usual maceral and vitrinite reflectance analyses and the fluorometric tests mentioned above. The cokes which were produced in both pilot-type (ACIRL and Bergbau-Forschung GmbH) and industrial (Ruhrkohle A.G.) coke ovens were divided into four lump samples spaced evenly between the cauliflower and the tar seam across one half of an oven width. In each sample an area of approximately 20 x 20 mm was polished and microscopically assessed by using reflected polarised light in oil immersion at a magnification of 500X. Contrast enhancement was achieved by rotating both polariser and analyser into a 45 degree position which causes isotropic material to appear brown.

The essential components of the coke fabric were divided into three groups referred to as:

* COKE MATRIX (CM) consisting of reactive components,
* COKE INCLUSIONS (CI) consisting of non-reactive components,

and * PORES AND FISSURES (PF)

In each of the four measuring areas 500 fabric elements were determined by point count method so that the composition of each coke used in the study is based on a total of 2000 points.

The mass balance calculations have been described by Diessel and Wolff-Fischer (1986). An example is given in Table 1. Apart from the coke analysis, both maceral composition (1000 points have been counted) and the rank of the feed coal are required. If the coal charge consists of a blend it is necessary to establish the proportion of the contributing seam coals and their rank.

A comparison of the results of the calculations suggests that in all cokes analysed more fused matrix has been formed than could be expected on the basis of the proportion of vitrinite and liptinite analysed in the feed coal. On the other hand, all coke samples contain fewer unmolten inclusions of inertinite than should be present had all the inertinite contained in the feed coal been truly inert. This discrepancy in inertinite inclusions can only be explained by a complete fusion of a portion of the inertinite, such that it becomes part of the coke matrix.

The organic inclusions in the coke which can be recognised as having originated from inertinite can be divided into two groups, one which is unfused and optically mostly isotropic and another which is partly fused and appears optically anisotropic.

A comparison between the amounts of fused inertinite in the coke samples, estimated from mass balance calculations, and the proportions of fluorescent inertinite in the feed coals is illustrated in Figure 2 as a function of the volatile matter content of the feed coal. Both curves display a striking similarity (the only misfit in the diagram contains 20% petroleum coke) but systematic differences exist in the

Table 1 COAL/COKE MASS BALANCE FOR SAMPLE C7

Composition (expressed in grams) of 100 g of coal	Estimated density	Estimated weight loss during coking (%)	Expected yield and composition of coke (g)
8.8 g Vitrinite hv	1.27	33	5.9 g CM
16.4 g Vitrinite mv	1.28	29	11.6 g CM
3.6 g Vitrinite lv	1.31	23	2.8 g CM
26.4 g Vitrinite mv	1.30	25	19.8 g CM
4.3 g Vitrinite lv	1.34	16	3.6 g CM
2.1 g Liptinite hv	1.20	52	1.0 g CM
2.1 g Liptinite mv	1.25	42	1.2 g CM
0.5 g Liptinite lv	1.30	25	0.4 g CM
2.1 g Liptinite mv	1.25	31	1.4 g CM
0.2 g Micrinite hv	1.35	20	0.6 g "CM"
0.6 g Micrinite mv	1.37	19	0.5 g "CM"
0.1 g Micrinite lv	1.39	16	0.1 g "CM"
1.7 g Micrinite mv	1.38	17	1.4 g "CM"
0.3 g Micrinite lv	1.42	13	0.3 g "CM"
69.2 g "Reactive" Macerals			50.6 g CM + "CM"
0.9 g Fusinite + 43% Inertodet hv	1.50	14	0.8 g CI
1.6 g Fusinite + 24% Inertodet mv	1.50	13	1.4 g CI
0.3 g Fusinite + 24% Inertodet lv	1.51	11	0.3 g CI
1.9 g Fusinite + 23% Inertodet mv	1.50	11	1.7 g CI
0.3 g Fusinite + 23% Inetodet lv	1.51	9	0.3 g CI
1.4 g Semifusinite + 57% Inerto+Mac hv	1.35	20	1.1 g CI
5.7 g Semifusinite + 76% Inerto+Mac mv	1.38	19	4.6 g CI
1.2 g Semifusinite + 76% Inerto+Mac lv	1.39	16	1.0 g CI
8.5 g Semifusinite + 77% Inerto+Mac mv	1.38	17	7.1 g CI
1.4 g Semifusinite + 77% Inerto+Mac lv	1.47	13	1.2 g CI
23.2 g "Inert" Macerals			19.5 g CI
92.4 g Coal			70.1 g Coke
7.6 g Minerals			6.8 g Ash
100.0 g Coal + Minerals			76.9 g Coke + Ash

Analysed Coke Yield and Composition (in grams)		Difference to Expected Composition
58.5 g CM	=	+7.9 g
2.6 g CI, partly fused 9.7 g CI, unfused	} =	-7.2 g
6.9 g Ash	=	+0.1 g
77.7 g Coke + Ash	=	+0.8 g

actual percentages such that the proportion of fluorescent inertinite is on average 2.4 times the amount of completely fusible, i.e. coke matrix producing inertinite. If, on the other hand, the proportion of fluorescent inertinite is compared with the amount of totally unfused inertinite in coke the two add up to 100% after allowing for some shrinkage due to about 10% degassing from the otherwise non-reactive inertinite. This suggests that the difference between the respective amounts of fused and fluorescent inertinite would be taken up by partly fused inertinite.

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FUSIBLE SEMI-INERTINITE IN AUSTRALIAN COKING COALS

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One of the most widespread uses of coal petrography has been in the field of cokemaking for blast furnace use. Using the results from petrographic point count analyses and measurement of coal rank by reflectance of vitrinite, schemes for the prediction of the cold tumble strength of cokes produced from single coals or from blends have been constructed[Ammosov, 1957; Schapiro et al., 1961,1964 etc.]. These schemes of prediction required that assumptions be made as to the fusibility characteristics of the recognisable coal macerals e.g. vitrinite and liptinites fuse, inertinite macerals are largely infusible. Another necessary assumption was that vitrinites of the same reflectance[R°max] had the same fusibility characteristics. Each incremental increase in rank had its own optimum ratio of fusibles to "inerts" [non-fusibles] and deviation from that optimum was measured by the Composition Balance Index. The assumption made by Schapiro et al. was that 1/3 of the semi-inertinite was considered to be fusible, 2/3 inert [non-fusible].

However others found, when they extracted grains of individual semi-inertinite macerals that the whole of the inertinite group including the semi-inertinite was infusible[Taylor et al., 1967; Bennett, 1968; Mackowsky, 1973; Kosina et al., 1984].

Another way to tackle and resolve the enigma of fusible semi-inertinite is to look at all the macerals in the coal and attempt a material balance between the precursor coal and the carbonized product. This paper outlines that approach.

The enigma of fusible semi-inertinite is but one of many reasons why classic methods of coke strength prediction have often failed to provide the right answers on many coals. As a consequence various modifications have been made to standard prediction schemes such as that of Schapiro et al. to enable the 'right' answers to be predicted. Steyn and Smith[1977], to account for much better coke tumble strength than the Schapiro et al. method predicted, postulated that 60% of the semi-fusinite in South African coals was fusible. Similar statements have been made for some Australian coals.

The research in this paper is based on the examination of a number of Australian coking coals and the cokes made from them. Also included are two South African coking coals which are being used in the ICCP reactive inertinite sub-committee's investigation. The aim was to correlate the maceral analyses with the coke microtextural analysis and by means of a material balance determine the amount of fused semi-inertinite. Although not covered in this paper, the consideration of standard errors derived from the maceral analyses and the coke point count analyses are vital to a proper appreciation of the results[Coin & Hall, 1986].

From the coal maceral analysis, the percentage [by volume] of the coked product from each maceral can be calculated from the equation

$$K_i = \frac{C_i . P_i [1-V_i]/d_i}{\sum^n [C_i . P_i [1-V_i]/d}$$

where, $n=$ the number of macerals[mineral matter free]

$K_i=$ fraction by volume of the product of the i'th maceral in the coke.

$C_i=$ fraction by volume[mmf] of the i'th maceral in the coal.

$P_i=$ density of the i'th maceral

$V_i=$ fractional volatile matter by weight of the i'th maceral.

$d_i=$ density of the product of the i'th maceral in the coke.

$d=$ density of the total pore wall material of the coke.

The relationships of maceral densities were taken from the ICCP Handbook for Coal Petrology and the volatile matters were determined according to published regression equations[Mackowsky & Simonis, 1969].

Comparison with the coke microtextural analysis enables the proportion of fusible semi-inertinite to be calculated within confidence limits determined by the amount of semi-inertinite and the number of points counted in the coal and in the coke.

Figure 1 illustrates the fused semi-inertinite as a percentage of the total semi-inertinite versus rank as R^omax. The percentage of fusible semi-inertinite ranges from being almost totally fusible to being totally infusible. The two South African coals, although having a high proportion of fusible semi-inertinite, are not exceptional. There is no trend of semi-inertinite fusibility with rank although there are few coals with less than zero fused semi-inertinite in the mid rank range.

It can be seen from Figure 1., that the Schapiro et al. estimation of 1/3 semi-inertinite fusible is not inappropriate as an average. If then this value is used and the results recalculated to compare predicted infusible in the coke and actual infusible in the coke then it can be seen from Figure 2 that most coals fit the 1:1 line but some are quite discrepant and the practice of using an arbitrary percentage is questionable.

Diessel[1983a,1983b] found that the pre-carbonization reflectance [PCR] of the inertinite appears to be a good predictor of fusibility or "inertness" and that the 'anisotropy jump rarely exceeds 1.8% PCR'. For the two South African coals and their reflectance profile, the 'anisotropy jump' appears to occur at 1.95% and 1.96% respectively.

The Coke Mosaic Size Index[CMSI] is a measure of the 'rank' of the mosaic in the coke and there is a good correlation between vitrinite R°max and CMSI [Figure 3]. However the relationship also shows some coals of the same or similar rank which have produced distinguishably different mosaic in the fused component of the coke. It can be argued that the mosaic size is a good reflection of the viscosity of the mesophase during carbonization and Ihnatowicz[1966] has pointed out that there is a good relationship between rheological properties and microtexture. Kosina[1985] has shown that vitrinites of the same rank are quite variable in their physico-chemical properties during pyrolysis. Also Mackowsky et al.[1966] have noted that variation in heating rate can lead to parallel changes in viscosity and mosaic grainsize. The mosaic grainsize is also a function of the fusion of the other fusible macerals including liptinites and semi-inertinite. Therefore it can be argued that for cokemaking purposes the mean coke mosaic size may be a better measure of 'rank' or viscous characteristics of the mesophase than the vitrinite RoMax.

For comparison, in Figures 4 and 5 are plotted the coal rank/type data and the coke rank/type data for the coals in this study. Overall there is general correspondence, but there are also some coals/cokes that have poor correspondence. LSG and Gregory when compared on coal petrography are distinguishably different but when compared on coke microscopy are very similar. Peak Downs and Saraji coals although practically identical petrographically have quite different coke microscopy. The two South African coals, DNC and VC also show significant 'shifts', having significantly less inert material than coal petrology would predict.

Therefore to compare coals petrographically for metallurgical use may in many cases be invalid as the correspondence between rank/type in the coal and coke is not adequate. It would seem far more appropriate to remove the 'step of uncertainty' and routinely characterise coking coals by their carbonized product rather than by coal maceral analysis. Such carbonization can be achieved both quickly and cheaply on a laboratory scale.

Future work will establish whether the characteristics of the carbonized products provide a better means of predicting relevant physical properties of metallurgical cokes.

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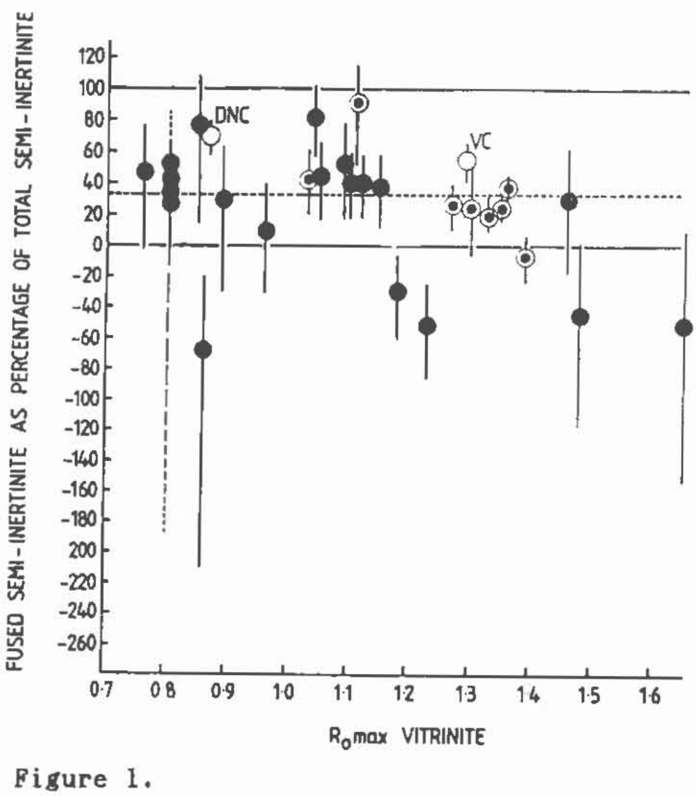

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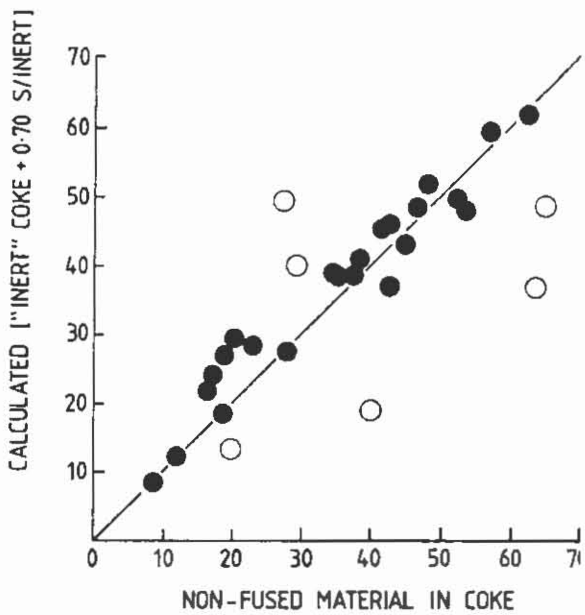

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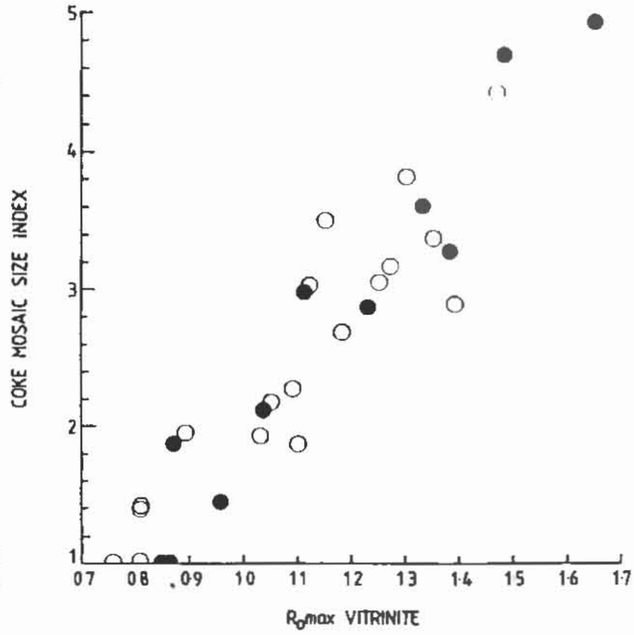

Figure 3.

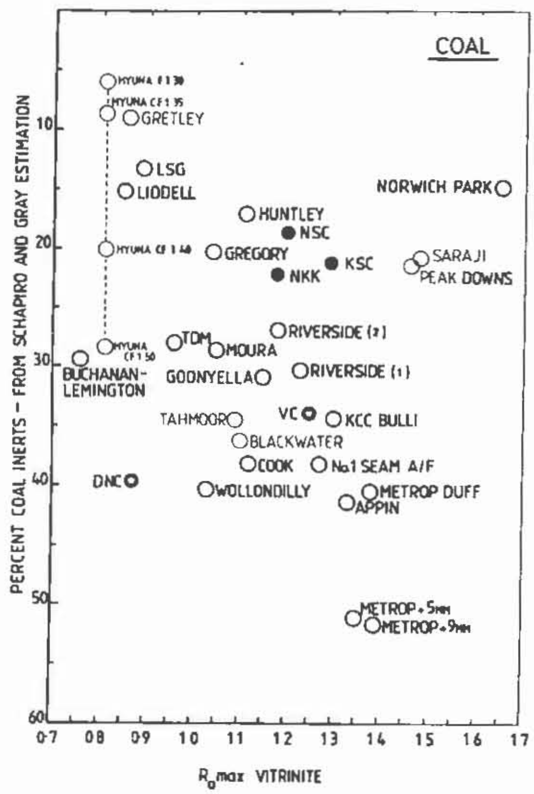

Figure 4.

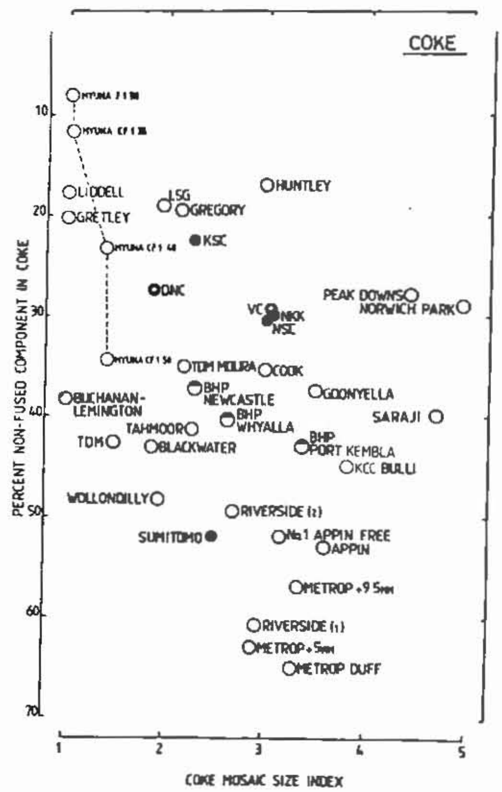

Figure 5.

CONTROL OF METHANE EMISSIONS FROM STRATA ABOVE OPERATING LONGWALLS AT APPIN COLLIERY

S. Battino and J. Doyle   B.H.P. Illawarra Collieries

BHP Collieries Illawarra is currently undertaking a NERDCC sponsored project with the objectives of:

(1) identifying the sources of gas emission supplementing those normally encountered during the longwall mining process at Appin Colliery, and

(2) removing these supplementary gas sources in order to maximise safety and productivity in the underground workings.

This project has involved the undertaking of a literature survey and a review of historical mining data relating to the gas emissions during longwall extractions. Two surface boreholes were then drilled into the Bulgo Sandstone some 120 m above the No. 11 longwall block, prior to extraction. Investigations were conducted to monitor the water and gas emissions and compositions prior, during and after mining.

Natural gas flow rates up to 70 000 cu. m/day were recorded from each of the holes shortly following mining. These flows were accompanied by significant volumes of saline water which created problems to the degassification system. Two major benefits were drawn from this study:

(a) During the extraction of the No. 11 longwall block, the frequency of gas "surges" has markedly decreased and permitted its extraction to proceed at a safer and more acceptable rate of advance, and

(b) The very high volumes of natural gas emitted from the two experimental boreholes have confirmed the early suspicions that there exists an extensive gas field in the Appin district. The extent of this gas field is now the subject of further investigations.

THE MT. KEMBLA OIL SHALE — A REAPPRAISAL

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The Pioneer Kerosene Works at America Creek, Mt Kembla had a short but turbulent life after shale oil, Australia's first, reportedly flowed from the retorts in December 1865. Operations temporarily ceased in 1875-1876, began again in 1877 and finally ceased in 1880. A new adit was driven into the seam by locals in 1943 but little shale was produced. Total production was 8640 tonnes of shale with a peak production of about 3000 tonnes in 1873-1874.

Many aspects of the Mt Kembla works have been a source of controversy. Even the discovery of oil shale itself is apparently open to question. Fleming (1976) quoted the Rev. W.B. Clarke as saying "There are oil-bearing shales or carbonaceous deposits behind Mt Kembla in the Illawarra, from which I selected specimens in the year 1849 ..." although Lishmund attributes discovery of the seam to a Mr R.J. Want in the same year as the works were built - 1865. It has even been rumoured that shale was brought to the works from deposits further to the west.

This paper looks at the geology of the deposit and outlines the history of operations of one of Australia's early pioneering, geologically-based industries in an attempt to clarify some of the clouded issues associated with the deposit.

GEOLOGY OF THE DEPOSIT

The oil shale is reported to have been mined from the American Creek seam which is a coaly interval, up to 9m thick, within the Allans Creek Formation. Lishmund (1974) and Raphael and Saxby (1980) reported that the torbanite was 46 to 140 cm thick and Carne (1903) gave a measured section showing a thickness, for the oil shale, of 142 cms. The torbanite has been variously described as "generally massive with faint laminations, dark grey to black" (Raphael and Saxby 1980), "... schistose beds are arenaceous in appearance and when taken from the retort, after distillation, are found as lumps of charcoal, not coked, but with a ligneous character' (Moody, reported in Carne, 1903) or "dull, very dark grey-black and coarse in appearance ... somewhat rubbery and fairly sectile and gives a shiny very dark brown to brownish black streak" (Kenny, 1954).

The abridged descriptions above hardly fit the description of torbanite as given by Lishmund (1974) - "In hand-specimen typical torbanite is light (specified gravity 1 to 1.35), homogeneous and compact, and black or dark in colour with a silky sheen and a greasy feel. Fracture is conchoidal across bedding ...".

In fact the dissimilar nature of Mt Kembla oil shale to torbanite caused Kenny (1954) to state "No other deposit of similar material has yet been recorded from New South Wales." The question arises - is the Mt Kembla oil shale a true torbanite?

Samples from a Mt Kembla Mine dump fit the descriptions given by Raphael and Saxby, Moody and Kenny. However, the samples are most unlike those of torbanite.

Petrographic studies of samples from the mine dump and a sample of "Wollongongite" collected from the Mt Kembla mine (housed in the Geological and Mining Museum collection) also show that Mt Kembla oil shale is, petrographically, most unlike the torbanites from other NSW deposits. Mt Kembla oil shale contains large stringers and lenses of bitumen (mean maximum reflectance, $R_o$max, of 0.02 to 0.32%), vitrinite

Table 1 Comparison of Properties of Mt Kembla Oil Shale and Selected Torbanite Samples

Sample	Composition: Major Components	Composition: Minor Components	Vitrinite Reflectance ($R_v$max)
Wollongongite Mt Kembla (Reference No. 10929)	bitumen (10%)	vitrinite (4%), inertinite (11%) bitumen-impregnated groundmass (75%)	-
Dump Sample Mt Kembla	bitumen (41%)	vitrinite (2%), inertinite (9%) bitumen-impregnated groundmass (48%)	1.23%
Torbanite Joadja	alginite (74%0	vitrinite (9%) sporinite (9%), inertinite (1%) mineral-organic groundmass (7%)	0.34%
Torbanite Glen Davis	alginite (89%)	vitrinite (2%), sporinite (1%) inertinite (1%) mineral-organic groundmass (7%)	0.23%
Torbanite Temi	alginite (60%)	alginite (13%), vitrinite (13%), inertinite (1%) mineral-organic groundmass (13%)	0.33%
Torbanite Alpha	alginite (82%)	vitrinite (5%), inertinite (2%) sporinite (2%) mineral-organic groundmass (9%)	0.23%

and inertinite with an orange fluorescing bitumen - clay-sized mineral mixture interstitial to these macerals. All torbanites (Table 1) from Australia contain abundant algal bodies within a groundmass of vitrinite, inertinite, sporinite and mineral matter. No algal matter was observed in the Mt Keira oil shale samples.

If the Mt Kembla samples are representative, and all evidence suggests this, they are bitumen-impregnated, carbonaceous shales which may have formed when hydrocarbons condensed after being released from coaly intervals that were heated by one or more intrusions. A number of dykes and at least one sill are known within the environs of Mt Kembla.

STRATIGRAPHY

Carne (1903) published a section reportedly measured by Moody in 1875. This section is reproduced next to the sections for two drill holes near Mt Kembla (Fig. 2). Reconciliation of the stratigraphic thickness suggests that the American Creek Formation, in Carne's section, is an improbable stratigraphic location for the oil shale seam. The American Creek Seam has been intersected by a number of drill holes and mine workings in the vicinity of the old Mt Kembla mine with no hint of oil shale. Moody's section suggests that the oil shale interval occurs in the Appin Formation at or near the top of the Bargo Claystone.

HISTORICAL ASPECTS

On March 21, 1865, a public meeting was held at the Queen's Hotel, Wollongong, to ask for subscriptions to test the commercial value of the oil shale. Subsequently, a local businessman, Mr John Graham, paid for the cost of the testing himself and a three to four feet square sample was sent to the government analyst. The analysis indicated that the shale should yield approximately 50 gallons of oil to the tonne.

A refining plant was built during mid 1865 and in December of the same year oil was produced with John Graham as manager of the works. Capacity of the plant was 1500 gallons per week but generally the output was much less. Approximately 12 tons of coal per week were required to heat the shale.

The company changed names in 1872 from the Pioneer Kerosene Oil Works to the Sun Kerosene Shale and Oil Company with an issued capital of twenty five thousand £1 shares. In 1870 or thereabouts, John Graham's younger brother took over as manager and in 1874, John Graham sold his interest in the company for £10 000 ($20 000).

After a short closure in 1876, the mine reopened in 1877 with Mr J.M. Fell as manager. Fire, at least the second or third, raised the horse stable in August, 1877 - this was the beginning of the end. Little more appears to have been done and on June 28, 1878, the "kerosene team" of horses was sold; the heart of the shale works was gone. A diagram of the mine plan (Fig. 1) during the middle stages of production shows that it was never a very large mine.

In the same year capital was raised in England to form a new company, The Mount Kembla Coal and Oil Co. Ltd, which was to mine coal. The company opened a rail link from the mine to Port Kembla, in February 1883. Production reached 1000 tons per week by November of the same year. Disaster struck on July 31, 1902, when an explosion resulted in Australia's biggest colliery disaster with the loss of 96 men and boys. A new company, Mount Kembla Collieries Ltd was formed.

In 1943, the oil shale mine was reopened by the firm of Madden and Madden, Timber Merchants of Port Kembla. A new adit was driven near a previous adit to test the suitability of the oil shale for the production of vaporiser fuel for vehicles used in transport. Kenny (1950) reported that the adit had been driven 40 ft (13m) and at the face 2 ft 1 in (0.63m) of oil shale was exposed. The shale was of very low grade with three samples averaging 16.3% (range of 9.6 to 29.4%) volatile matter and an average of 66.1% (range of 51.8 to 75.8%) ash. Assays indicated an average of 22.6 gallons/ton (approximately 100 L/tonne) shale oil yield with the highest grade sample giving 51.8 gallons/ton (235 L/tonne).

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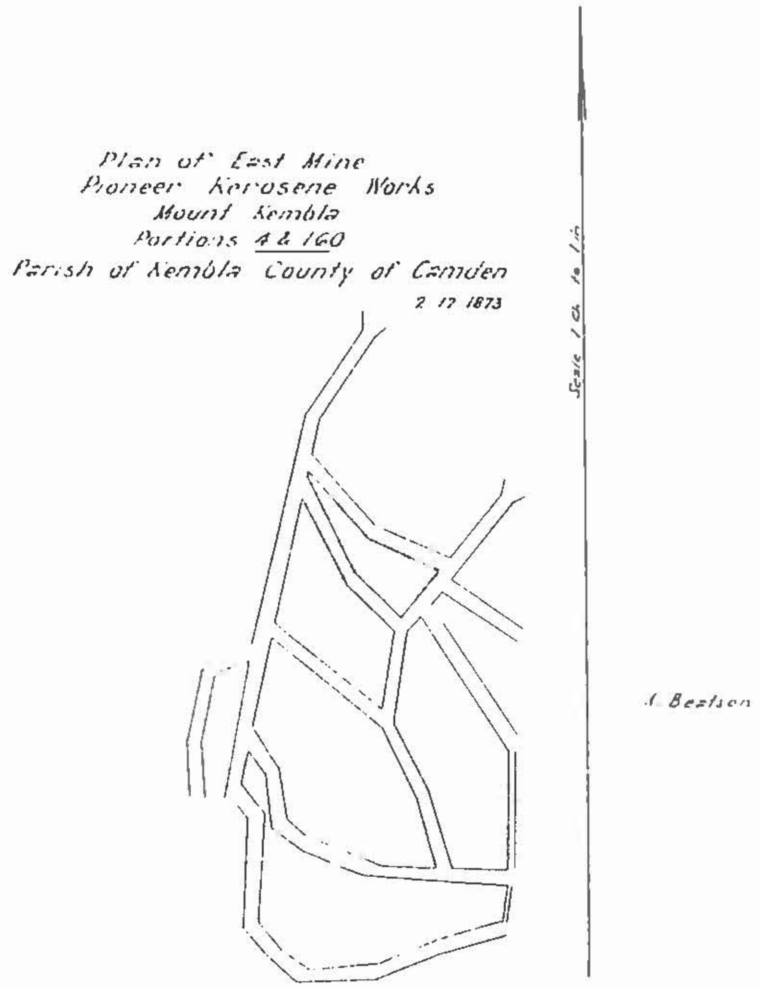
Figure 1.



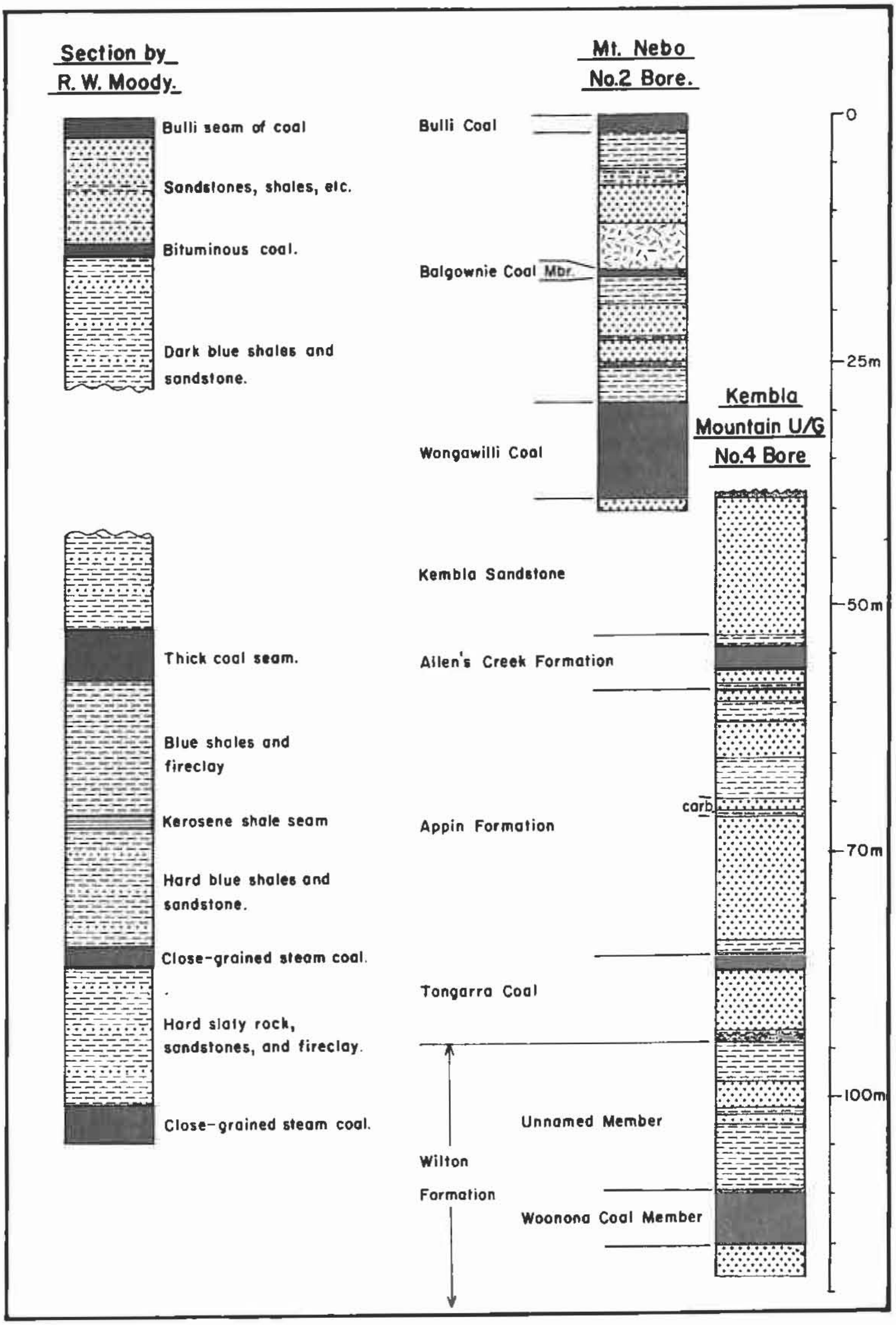


Figure 2 Mt. Kembla Area - Reconciliation of R. W. Moody's Section with later drilling

SYNDAX 3 — A NEW FORM OF POLYCRYSTALLINE DIAMOND TO REVOLUTIONISE CORE DRILLING

G.R. Shafto De Beers Industrial Diamond Division Pty. Ltd.

SYNDAX 3 is a relatively new synthetic diamond material which has made possible the design of many novel types of diamond drill bit having enhanced performance.

The principal advantages of SYNDAX 3 bits lie in the very high penetration rates which can be achieved - not only in soft sedimentary rocks but also in the hardest rocks, such as quartzitic granites.

The influence of bit design on performance is discussed and the requirements for bit designs, suitable for drilling both medium/soft and hard formations, are presented.

NEW DEVELOPMENTS IN SYNDRILL POLYCRYSTALLINE DIAMOND DRILLS FOR THE PETROLEUM AND MINING INDUSTRIES

P.N. Tomlinson De Beers Industrial Diamond Division Pty. Ltd.

SYNDRILL is polycrystalline diamond with a tungsten carbide backing and is widely used in drill bits for the petroleum industry. SYNDRILL has also been used for smaller diameter mining bits because of its remarkable abrasion resistance.

Large pieces of SYNDRILL, up to 50 mm in diameter, are now available and have made possible a novel design of an oil well bit. The results of a field trial with this bit are presented.

SYNDRILL bits have also enjoyed considerable success in mining applications. Designs of bits for methane drainage, roof bolting and blast hole drilling are presented and some results given.

COMPARATIVE MINERALOGY OF METAMORPHIC INCLUSIONS IN BASALTIC CYKES FROM BLACK JACK AND NEWCASTLE COAL MEASURES

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D. French C.S.I.R.O.

Introduction

A variety of basic and ultrabasic inclusions are described in basaltic dykes from two locations: the Macquarie Dyke intruding the Newcastle Coal Measures at the Macquarie Mine, and the Gunnedah Intrusive Complex cutting the Black Jack Coal Measures. Textural, mineralogical and mineral chemical studies have been applied to clarify the origin of these inclusions.

Inclusions of the Macquarie Dyke, Newcastle Coal Measures

The Macquarie Dyke, up to several metres wide, has been mapped over a length of several hundred metres in the Macquarie Mine (BHP mine geologists, pers. comm.). Although part of a regionally extensive dyke swarm, it appears to be atypical in containing abundant peridotitic inclusions which in places may constitute up to 40 volume percent of the rock. The inclusions are of two types: spinel lherzolite of the Cr-diopside suite, and spinel lherzolite of the Al-Ti augite suite. Both types of inclusions display disequilibrium textures indicative of partial recrystallisation. In particular, those of the Cr-diopside suite display prominent protoclastic deformation.

Although the principal phases are similar in the inclusions, their compositions differ significantly. Olivines, orthopyroxenes, and clinopyroxenes are more magnesian, and both pyroxenes are less aluminous and less titaniferous, in the Cr-diopside suite inclusions. Chromian spinel in the Cr-diopside suite inclusions contrasts with pleonaste in the Al-Ti augite suite inclusions.

Geothermometry produces non-unique results owing to disequilibrium recrystallisation as evidenced by their textures. Pyroxene compositions, projected into Wo-En-Fs at an assumed pressure of 10kb, give the following ranges for the Cr-diopside and Al-Ti augite suite inclusions respectively: orthopyroxene, 600-800 (°C), 680-870; clinopyroxene, 850-1050, 970-1060. Multi-phase geothermometers, at an assumed pressure of 16kb, give temperatures 800-1000, and 960-1450 for the two suites.

The results are consistent with the interpretation that the Cr-diopside suite inclusions represent deformed residual upper mantle material which originated in the spinel peridotite facies (8-24kb) and may have last equilibrated at temperatures in the range 800-1000°C. The Al-Ti augite suite inclusions represent material solidified from basaltic magma in a similar pressure range, but retain evidence of previous equilibration to higher temperatures (900->1000°C).

Inclusions of the Gunnedah Intrusive Complex, Black Jack Coal Measures

Cr-diopside and Al-Ti augite suite inclusions are also present in the Gunnedah Intrusive Complex, but a much wider variety of rocktypes is evident. Rocktypes belonging to the Cr-diopside suite include protogranular spinel lherzolite and protoclastic spinel lherzolite; those of the Al-Ti augite suite include feldspathic lherzolite, orthopyroxenite, clinopyroxenite, leucogabbro, and anorthoclasite.

Olivine in the spinel lherzolites ($Fo_{89.6 \pm 0.1}$) is much more magnesian than that in the feldspathic lherzolite ($Fo_{76.5}$). Orthopyroxene displays a similar relationship, and also increases in alumina content from 3% in the protoclastic spinel lherzolite, through protogranular lherzolite, feldspathic lherzolite, and orthopyroxenite, to almost 7% in the leucogabbro. Clinopyroxene is of restricted composition in the Cr-diopside suite, but ranges more widely through the augite and salite fields in the Al-Ti augite suite (TiO_2 up to 2.23 wt%, Al_2O_3 up to 8.4%). Amongst spinel phases, chromian spinel occurs in the spinel lherzolites, pleonaste or exsolved Al-magnetite in the leucogabbros. Restricted compositional ranges are present in plagioclase of feldspathic lherzolite (andesine), in leucogabbro (andesine or labradorite), and in anorthoclasite (anorthoclase). Additional phases in the Al-Ti augite suite include pargasite, pargasitic hornblende, kaersutite, and titan-phlogopite. Chalcopyrite and members of the Fe-Ni-S system are present in the inclusion suites.

Geobarometry and geothermometry suggest that the Cr-diopside suite last equilibrated at pressures of 14± 5kb (n=20) and temperatures of 1040 ± 130°C (n=50). Estimates for the Al-Ti augite suite are 10 ± 4kb (n=22), and 1070 ± ±40°C (n=55).

These results are consistent with derivation of the Cr-diopside suite by scavenging of residual upper mantle material by uprising basaltic magma. The Al-Ti augite suite represents various rocktypes formed by crystallisation and fractionation of basaltic magma at somewhat shallower depths broadly equivalent to the crust/mantle boundary.

GEOLOGICAL INVESTIGATIONS AT DUNCAN COLLIERY, TASMANIA

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Duncan Colliery is located near the town of Fingal in north-eastern Tasmania. Mining of the Duncan seam occurs from outcrop to a depth of 420 m. The seam is of Triassic age. It is one of up to eight coal seams occurring in a 250 m thick, fluvial sequence of dominantly lithic sandstone with minor interbedded mudstone, claystone and siltstone. The coal measures have been intruded by, and are now capped, with up to 340 m of Jurassic dolerite.

The geological investigations arose out of a need to determine improved methods of minimising severe floor heave and increasing percentage extraction under poorly caving strata.

The depth of cover and the sedimentology of the roof, seam and floor strata are particularly variable. An important objective for the geological investigations was to define the nature and extent of this variability. Associated rock mechanics, geomechanical testing and mathematical modelling investigations could then be designed and evaluated in the context of the range of conditions to be encountered over the mining lease.

Emphasis was therefore given to an assessment of the regional controls on mining conditions. The basic approach was to assess the nature, distribution and degree of variability of sedimentological and structural geological elements that affect mining from underground observation and mapping. Surrounding boreholes were relogged and evaluated in the light of empirical knowledge of how the strata react to mining.

The Duncan seam undergoes wide variations in seam thickness (2 to 5 m) due to two distinct geological processes. The first relates to the conditions of peat accretion. The second process involves erosion of the seam by sandstone channels.

Peat accretion was least in the south west corner of the lease (Figure 1), where the full seam is preserved (approximately 2 m thick, MS 2, Figure 2). To the north, the seam rapidly thickens.

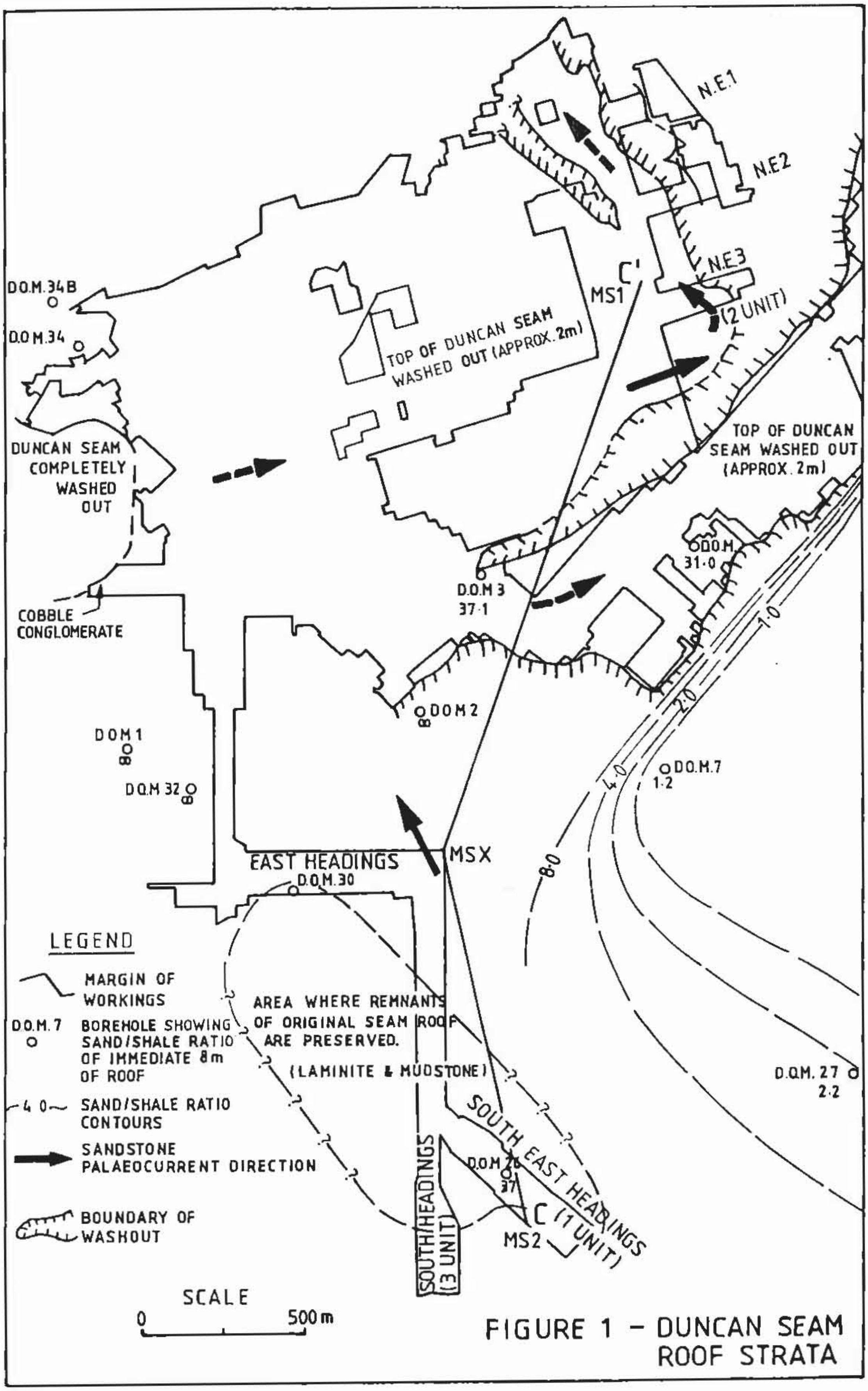

FIGURE 1 - DUNCAN SEAM ROOF STRATA

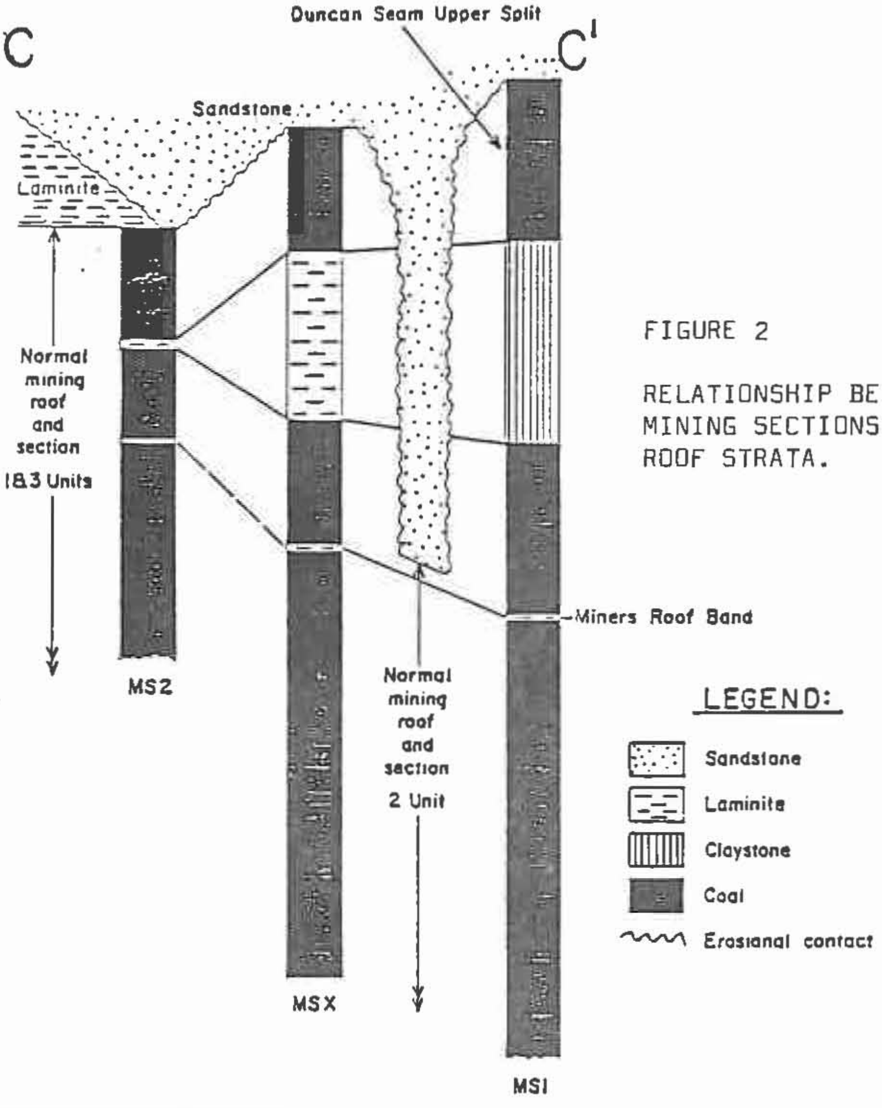

FIGURE 2

RELATIONSHIP BETWEEN MINING SECTIONS AND ROOF STRATA.

At the East Headings/South Headings junction (Figure 1), the seam thickness is 4.3 m (MSX, Figure 2). The increase in thickness is accompanied by splitting of the seam. East and south-east of the workings, the seam split increases in thickness.

Sandstone channels have almost completely eroded and replaced the original sediments overlying the Duncan seam. To the north west of the workings, the seam has been completely washed out and replaced by sandstone and cobble conglomerate. In general, the erosional sandstone is confined to the north west half of the lease, where it has uniformly eroded the upper two metres of the seam. The erosional sandstone forms an even, stable roof. Long, elongate remnants of the original seam are also preserved (Figure 1). Mining of these areas is avoided due to the difficulty in supporting this "top" coal which contains a thick band of very weak claystone (M.S. 1 - Figure 2).

The eroding sandstone has been deposited from a general south westerly direction. Palaeocurrent indicators are the channel margin geometries, cross bedding, flute casts, tool marks and the alignment of fossil detritus.

Differential compaction faults occur along the wash out margins. They form the most extensive type of faulting and result in displacements to the mining section of up to 6 m.

Remnants of the original roof strata are confined to the south west corner of the lease. The primary laminite roof has been irregularly eroded by a sandy siltstone unit which has in turn been eroded by the main, overlying sandstone unit. This has resulted in a complex distribution of immediate roof strata. These variations, their mode of failure and their effect on mining in terms of support type and density have been defined.

The immediate floor strata undergo wide variations from predominantly sandstone to completely claystone and clayey mudstone.

With the variation and contrast in roof and floor strata types, mining can take place in any one of the following situations.

Strong roof (sandstone) - weak floor (claystone)
Weak immediate roof (claystone) - weak floor (claystone)
Strong roof (sandstone) - strong floor (sandstone)
Weak immediate roof (claystone/laminite) - strong floor (sandstone).

The actual response to mining is further complicated by the large and rapid variations in surface topography.

The majority of mining in recent years has taken place in the region of strong sandstone roof and weak claystone floor. Extraction areas are typically limited to 3 to 4 hectares due to the intensity of abutment load induced and time dependent floor heave in the access roadways.

Irrespective of the immediate roof strata types, the problem of inadequate caving of the "main roof" is present throughout the colliery holding. The basis of the research program which is continuing, is to define optimum panel geometries and pillar dimensions to permit the maximum possible percentage extraction. The stability of the immediate roof and floor is a critical factor in the design which must take into account, the wide variations that are present.

In summary, the geological investigations have in broad terms, provided an understanding of the processes controlling the distribution of roof and floor strata. Variations in seam development and immediate roof strata are the result of a sequence of deposition followed by erosion and deposition. The erosion process removed up to 30 m of peat and clay from the top of the Duncan seam over an area in excess of two square kilometres.

Underground mapping, relogging of borecore and lithofacies maps have enabled the areal delineation of roof and floor strata over the colliery holding. An empirical index of competency has been applied to borecore in the areas yet to be mined, to provide an indication of likely roof and floor stability.

The geological studies have proven to be an essential basis for the optimum design and interpretation of rock mechanics monitoring, sampling for physical property testing, and mathematical modelling. These studies will collectively result in significantly improved percentage extraction and productivity.

Acknowledgements

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EXCURSION 1

ENGINEERING GEOLOGICAL ASPECTS OF THE NEWCASTLE COAL MEASURES

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INTRODUCTION

The aim of the excursion is to study engineering geological aspects of the lower, middle and upper portions of the Newcastle Coal Measures at four locations.

The box-cut at Gretley Colliery (Wallsend) will be the first stop to examine outcrops of an ancient land- and rockslide recently re-activated in rocks of the Lambton Sub-Group.

Geotechnically interesting areas along the north-eastern shores of Lake Macquarie provide insight into the behaviour of rockmasses in the Boolaroo and Moon Island Beach Sub-Groups. The second and third stops will be made there.

The instability problems at Carnley Avenue in rocks of the Adamstown Sub-Group will be examined on the fourth and last stop.

Engineering geological problems in Newcastle Coal Measure Rocks can often be related to the diversity of rock-types that occurs in rapid vertical succession. The lithological changes in the coal measure sequence are a reflection of the palaeoenvironments that have progressed from alluvial plain to piedmont-type sedimentation through Newcastle Coal Measure time. A significant attribute of engineering geological consequence is the frequent occurrence of volcanigenic deposits.

The Macquarie Syncline controls the structural setting of the Greater Newcastle and Lake Macquarie District. The axis of the syncline has a north and north-easterly trend and plunges to the south.

The venue for the excursion has been designed to include as many rock-types and formations of the coal measure sequence as possible as well as a range of engineering problems that can be related to geological causes.

The geological development and setting of the Macquarie Syncline during Newcastle Coal Measure time have led to the deposition of terrestrial sediments of great variety. The New England Fold Belt has acted as the source area; palaeocurrent directions have been reconstructed from numerous measurements of cross-beds and other indicative sedimentary structures. The centripetal tendency of the palaeocurrent directions indicates a depositional centre of Permian deposition in the north-eastern fringe area of the Sydney Basin, imparting strong directional anisotropies on the rockmasses.

Claystone layers above and below the coal seams, extensive developments of conglomerates and coarse sandstones, interbedded mudstones and laminites as well as siltstones and tuffaceous rocks characterise the sedimentary sequences to be studied.

Uplift movements and an NE-SW directed extensional stress system occurred during the Tertiary period, resulting in the formation of faults as well as in the emplacement of dykes predominantly in a NW-SE attitude. A strongly developed joint system has been measured in all units of the Newcastle Coal Measures with the following spatial attitudes:

N55° - 70°W - near vertical
and N35° - 20°E - near vertical

There are several minor joint sets with different attitudes.

BOX CUT AT N.W.C.C. GRETLEY COLLIERY, WALLSEND

STOP 1

A box cut has been prepared at Gretley Colliery to test the feasibility of mining the Young Wallsend Seam in an open-cut operation.

Excavations in the last quarter of 1985 exposed an ancient landslip and rockslide feature which has recently been re-activated by the construction of the box-cut.

Heavy rainfall in late 1985 has led to the failure of a highwall in the box cut. The original slide movement has involved the uppermost layer of the Nobbys Tuff and the overlying Shepherds Hill Formation, the Victoria Tunnel Seam as well as units of the Kotara Formation.

The rockmass affected by the movement has a volume of at least 300 000m^3 and can be traced for 350m along the southeastern flank of a NE-SW trending ridge.

The glide horizons, debris accumulations and toe section can be examined in detail.

The induced fracture pattern on the highwall and the developing fractures on the flank of the ridge attest to the continuing activity of the reactivated slide.

The toe section is very steeply bent upward and has a "stacked" appearance.

The cause for the original slide is not known. The linearity of the movement horizon and several other features would suggest a rather slow distortion process.

INSTABILITY PATTERNS AT THE NORTH-EASTERN FRINGE OF LAKE MACQUARIE

STOPS 2 AND 3

Residential areas with a history of superficial slope failure are situated in a Permain proximal-braidplain sequence consisting of interbedded claystone, tuffs and coal seams, overlain by a thick conglomerate lithosome. The eastern limb of the Macquarie Syncline is the controlling tectonic feature.

Structural elements show preferred orientations that are genetically related to sedimentation, diagenesis and regional deformation patterns.

Residual stress relief across discontinuities has increased rockmass permeability and has resulted in the translation and rotation of conglomerate blocks on a lubricated, plastically deforming argillaceous and tuffaceous substratum.

Slope development is controlled by a dynamic block morphology that strongly influences superficial slope processes such as weathering, erosion and mass transportation. Slope failures can be related to the presence of Permian debris flows and NW-SE trending fracture sets.

Appropriately designed drainage systems can achieve effective stabilization.

The prevailing joint system in the Teralba Conglomerate has the following attitudes:

N28°E - near vertical
and N60°W - near vertical

The failure patterns are superficial and there is no evidence for a deep-seated circular failure plane. The instability at Chelston Street can probably be related to block movement.

It has not been possible to establish a direct relationship between very heavy rainfalls and slope instability.

The manifestations of the instability will be studied in the Thompson Road and Chelston Street areas.

An area of considerable instability with significant movements in May 1974 and in the May/June 1983 period will be inspected further south involving rocks of the Croudace Bay and

Eleebana Formations.

High plasticity claystone layers are responsible for the instability observed.

The landsliding is evidenced by wide tension cracks and scarps shown in the accompanying figure. Their effects on the houses in the area consist of horizontal and vertical (>0.6m) movements as well as in rotational action which is causing the houses to tilt. Subsidence into the tension crack areas is also occurring on some blocks. Before recent stabilization measures were carried out jetties along the foreshore demonstrated movements which had occurred, by varying angles of their piers. Damage to houses in the area has been extensive but not catastrophic.

The most commonly suggested cause for the sliding process is pore pressure increasing in rocks on the up-slope side (ESE) forcing individual blocks, defined by joint planes, to move along a lubricated movement horizon, resulting in a progressive failure of the hillside.

Other possible mechanisms will be discussed at the site. It should be noted that the installed piezometers show very little response to rainfall and yet movements continue.

Stabilization Measures

The stabilizing berm constructed by Lake Macquarie City Council was designed by a firm of consulting geotechnical engineers using design parameters of $C = 0$ and $\phi = 10°$ for the slide plane in conjunction with a water table 1m below the surface.

The berm was located at the toe of the slide. Material was excavated from the foreshore and lake bottom to a depth of approximately 2m by an excavator which used the developing berm as a working platform. Once the material was removed it was replaced by a black slag obtained from the Sulphide Corporation Plant at Cockle Creek. The slag is an inert glassy material with a high specific gravity and is gap graded between a coarse to fine sand.

The dimensions of the berm are shown in the accompanying figure. The height is 4.5m above AHD and it is sloped at 1 in 5 down to a 5m wide bench located 1m above AHD. Beyond this benched area the slope is increased to 1 in 3 to the lake bottom.

The quantity of slag used is approximately 30 000m^3. Partial compaction was achieved by track machines working on the berm, however, no rollers were used.

Permanent marks have been installed at various locations to monitor and to determine the extent of further movement, if it occurs.

INSTABILITY PATTERNS AT THE WIMBLEDON GROVE AREA, CARNELY AVENUE, CARRISBROOK AVENUE

STOP 4

The instability of this area manifests itself in several forms, ranging from landslides, rockfalls, to episodic "creep"-type movements affecting several engineering structures.

The rocks involved here belong to Adamstown Sub-Group succession. The Charlestown Conglomerate has become affected by movements along the underlying Stockrington Tuff.

The Charlestown Conglomerate is a massive unit with very pronounced imbrication structures. The clasts are of pebble size, generally well rounded and show varying sphericity. The majority of the pebbles are metasediments, approximately 60%, components of volcanic origin make up approximately 30%, the remaining pebbles consist of reworked sediments. All the components have a northerly provenance. The Charlestown Conglomerate contains many sandstone lenses with strong fluvial fabric arrangement. Fossil wood including many treetrunks is usually associated with the sandstone lenses.

The conglomerate has an argillaceous cement, consisting predominantly of illite and kaolinite.

The Montrose Seam consists mainly of dull coal plies, durain and fusain being the most common macerals. The roof of the Montrose Seam is normally formed by a thin layer of claystone/siltstone laminate; this layer is in places eroded by the Charlestown Conglomerate which then forms the immediate roof. The clay in the laminate can vary from illite, kaolinite to montmorillonite, with illite and kaolinite being the more frequently occurring clay minerals. The Montrose Seam contains very few thin bands in this area. At the base of the Montrose Seam occurs a thin clayband made up chiefly of illite and vermicular kaolinite, but also containing montmorillonite in places in small quantities.

Below the immediate Floor of the Montrose Seam follows a siltstone bed with several cherty bands. The siltstone/chert sequence is approximately 5.5m thick with the cherty bands reaching up to 7 cm in thickness.

This is underlain by approximately 1.6m of a claystone/siltstone laminite unit.

The laminite is underlain by 3.2m of medium to coarse sandstone with strong fluvial aspects; it has an argillaceous cement and weathers readily. The top 80 cm of this unit consist of a block heavily jointed medium grained standstone, much more resistant to weathering.

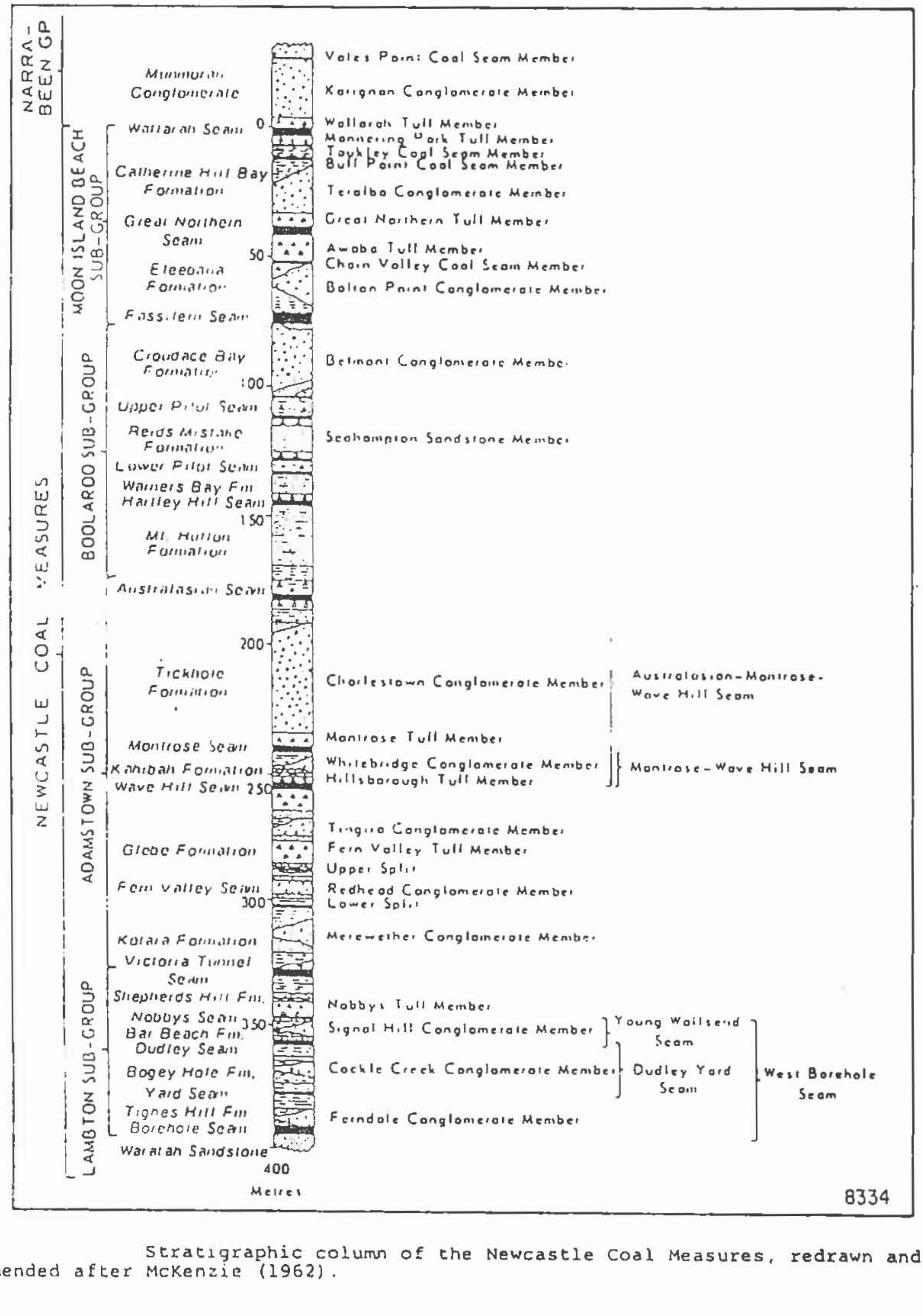
The base of the exposed section at Carnley Avenue consists of two chert bands separated by a very friable claystone up to 30 cm thick.

The Charlestown Conglomerate contains very steeply dipping foreset beds.

The sequence below the Montrose Seam is characterized by medium scale slump structures. It would appear that initially unconsolidated material slumped; the resulting primary non-diastrophic structures were later modified by differential compaction. Wash-outs do occur in this sequence with a mean current direction of approximately 200°. This datum correlates well with palaeocurrent data obtained from the overlying Charlestown Conglomerate which show a mean direction of 205° for sedimentary "a".

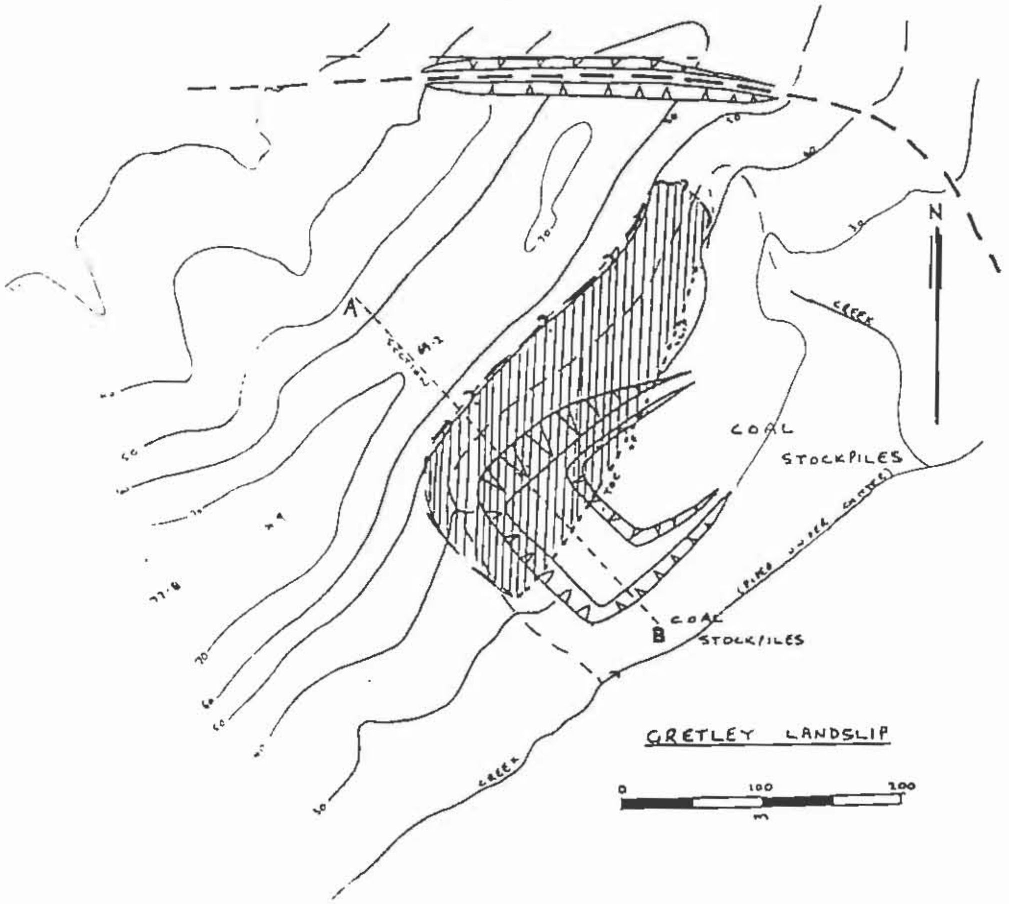
The effect of lateral movements, involving the lower portion of the Charlestown Conglomerate and the underlying sequence of the Montrose Seam and its associated clay layers, can be directly observed on "offsets" in the support cradles for a water pipeline as well as on distortions of supports for guide rails at Carrisbrook Avenue.

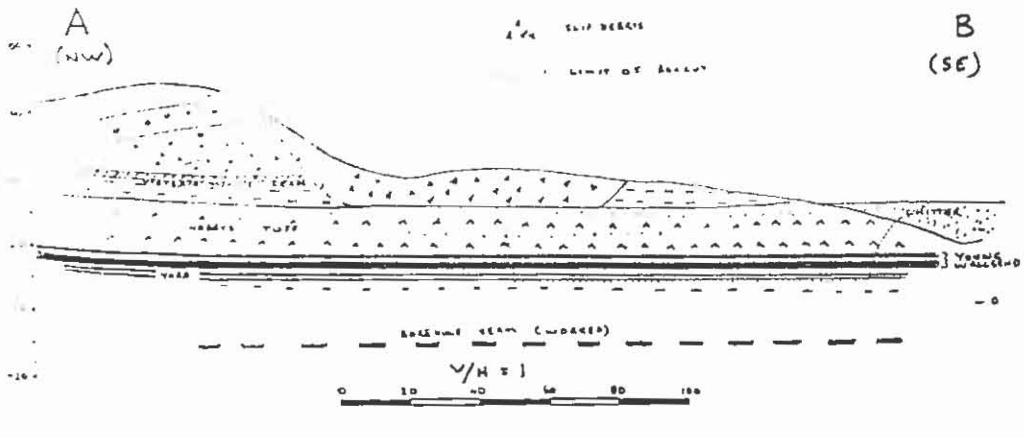
The evidence, as gathered by many measurements of the water pipeline's movements, suggests an overall trend of subsidence at its top end and heave at the lower end. This could be interpreted as translational failure, possibly at Montrose Seam level, although this does not agree with fluctuations that appear over apparently short time periods.



Stratigraphic column of the Newcastle Coal Measures, redrawn and amended after McKenzie (1962).

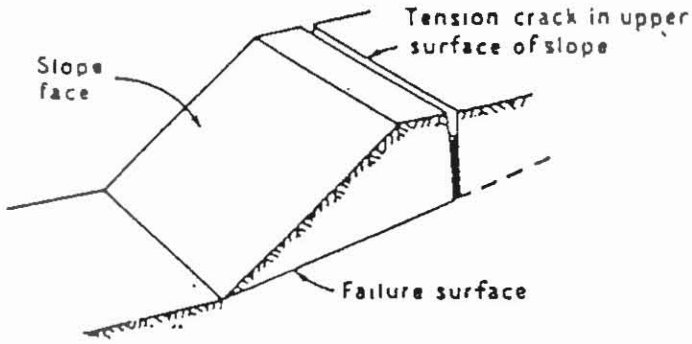
STOP 1


N
CREEK
COAL
STOCKPILES
COAL
STOCKPILES
GRETLEY LANDSLIP
0
100
200
m
CREEK
A
B

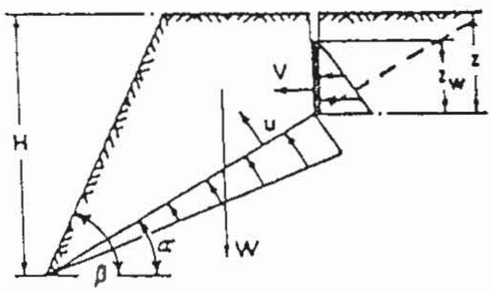

A
(NW)
B
(SE)
V/H = 1

STABILITY ANALYSIS MODEL

STOP 2



Geometry of a rock slope with tension cracks in the upper part of a planar sliding wedge.



Factor of safety $F = \dfrac{cA + (W\cos\alpha - u - V\sin\alpha)\tan\phi}{W\sin\alpha + V\cos\alpha}$

Length of block base $A = (H - z)\operatorname{cosec}\alpha$

Pore water uplift $u = \frac{1}{2}\gamma_w . z_w(H - z)\operatorname{cosec}\alpha$

Cleft water pressure force $V = \frac{1}{2}\gamma_w . z^2_w$

Constants:

$\alpha = 9°$

$\beta = 40°$

$H = 8.6$ metres

$\gamma = 17.7$ kN/m³

$\gamma_w = 9.8$ kN/m³

$z = 6.2$ metres

Variables:

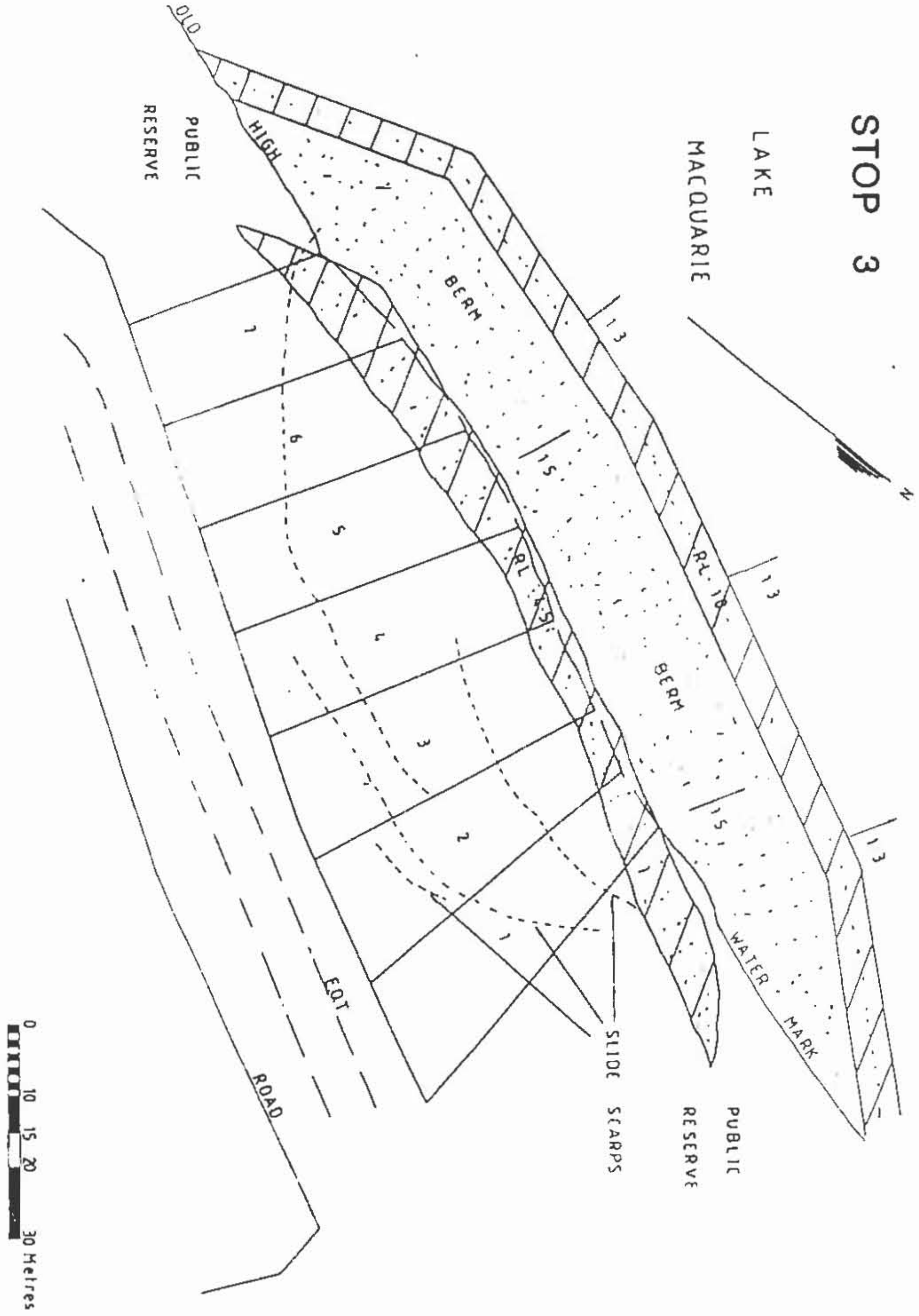
$z = 2.8$ metres

$z = 3.7$ metres

$z = 6.2$ metres

cohesion

angle of internal friction



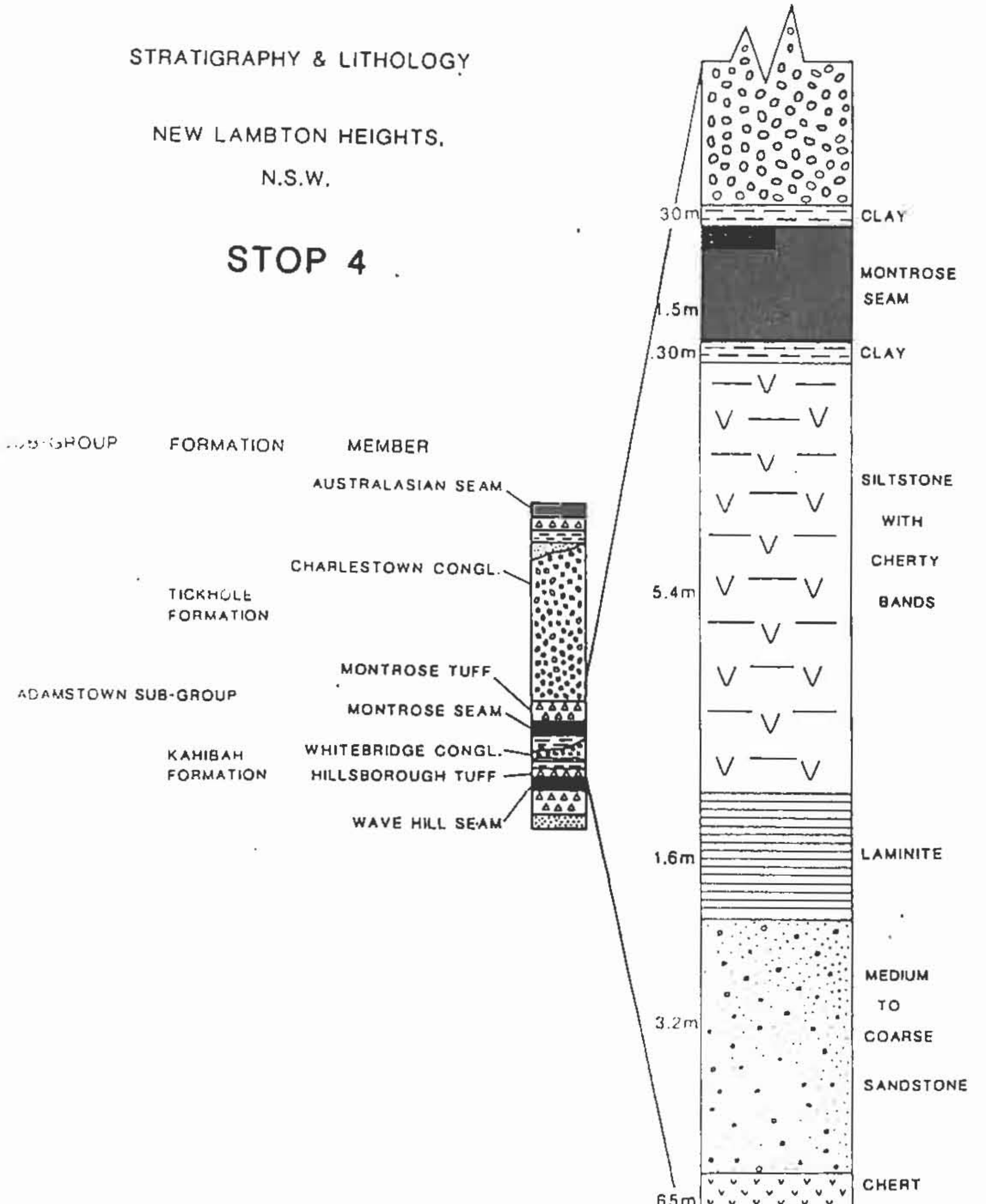
STOP 3
LAKE
MACQUARIE
N
OLD
HIGH
WATER
MARK
BERM
BERM
RL 18
RL 4.5
13
13
13
15
15
PUBLIC
RESERVE
PUBLIC
RESERVE
SLIDE SCARPS
ROAD
0
10
15
20
30 Metres

STRATIGRAPHY & LITHOLOGY

NEW LAMBTON HEIGHTS,

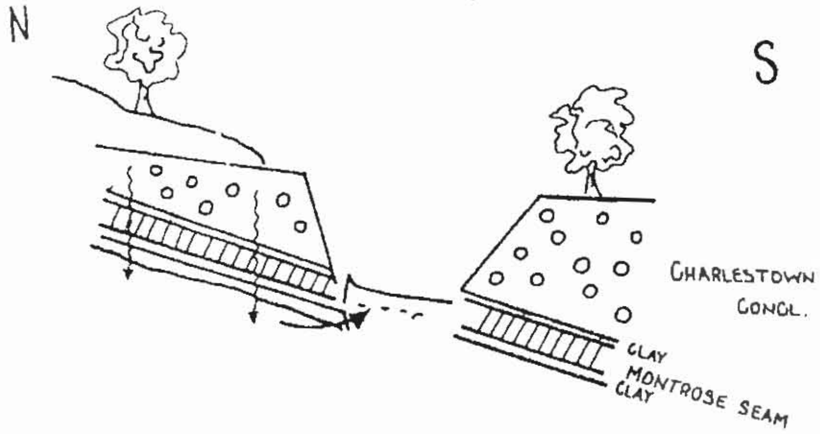
N.S.W.

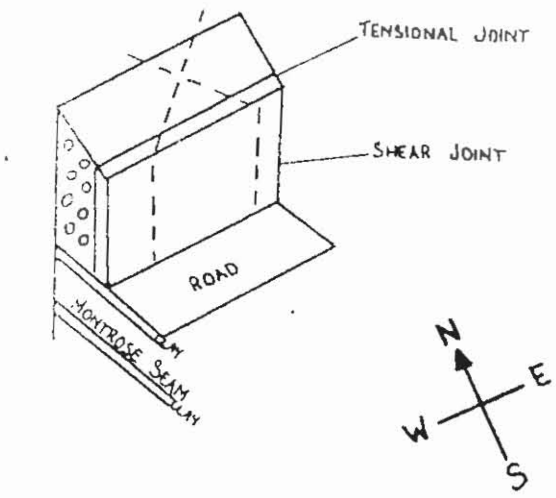
STOP 4

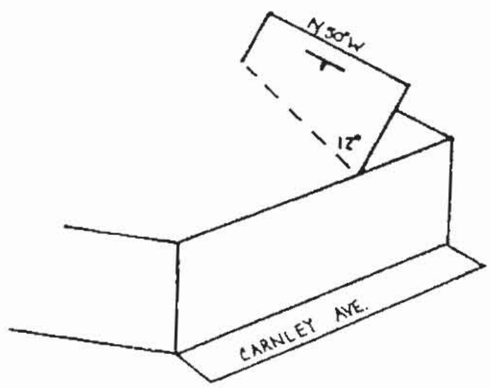


Note. All measurements given are approximate only. The stratigraphic column is not based on bore core.

STOP 5


N
S
CHARLESTOWN
CONGL.
CLAY
MONTROSE SEAM
CLAY


TENSIONAL JOINT
SHEAR JOINT
ROAD
MONTROSE SEAM
N
E
W
S


N 30° W
12°
CARNLEY AVE.

EXCURSION NO.2

GEOLOGICAL GUIDE TO BHP SAXONVALE MINE

by

Claus F.K. Diessel, The University of Newcastle, and
Frank G. Stoddart, Principal Development Geologist,
BHP Collieries Division

1. LOCATION

The Saxonvale mine is located in the central western region of the Hunter Valley, NSW. It is approximately 15km south of the town of Singleton, 37km north-west from the town of Cessnock and some 100 rail km from the coal export facilities at the Port of Newcastle.

In 1972 BHP was authorised to prospect for coal in an 44 sq. km area between Singleton and Broke in the Hunter Valley of New South Wales, referred to as the BHP Broke Area (Figure 1). After a number of renewals and extensions the original Authorisation No. 3 was replaced by Authorisation No. 213 for an area of 20.6 sq. km known as the BHP Saxonvale Area. The mining lease, Coal Lease No. 224, was formally granted to BHP on December 23rd, 1981, and was extended to 25.8 sq. km to cover infrastructure and overburden dumping areas outside of the coal mining area.

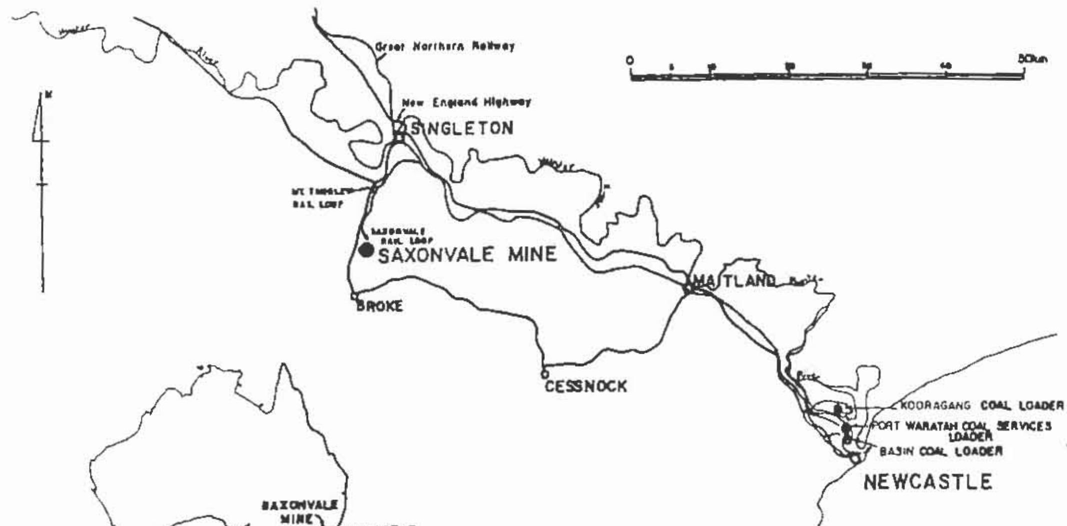


Figure 1. Locality map and transport links of Saxonvale Mine to the part of Newcastle.

The Saxonvale Lease includes 24 named coal seams and a substantial number of splits, all of which subcrop in the north-east quarter and contain a total of more than 1,000 million tonnes of coal. The mine project is based on extracting the top 9 seams to a depth of more than 300 metres by means of a large open pit mine (Figures 2 and 3).

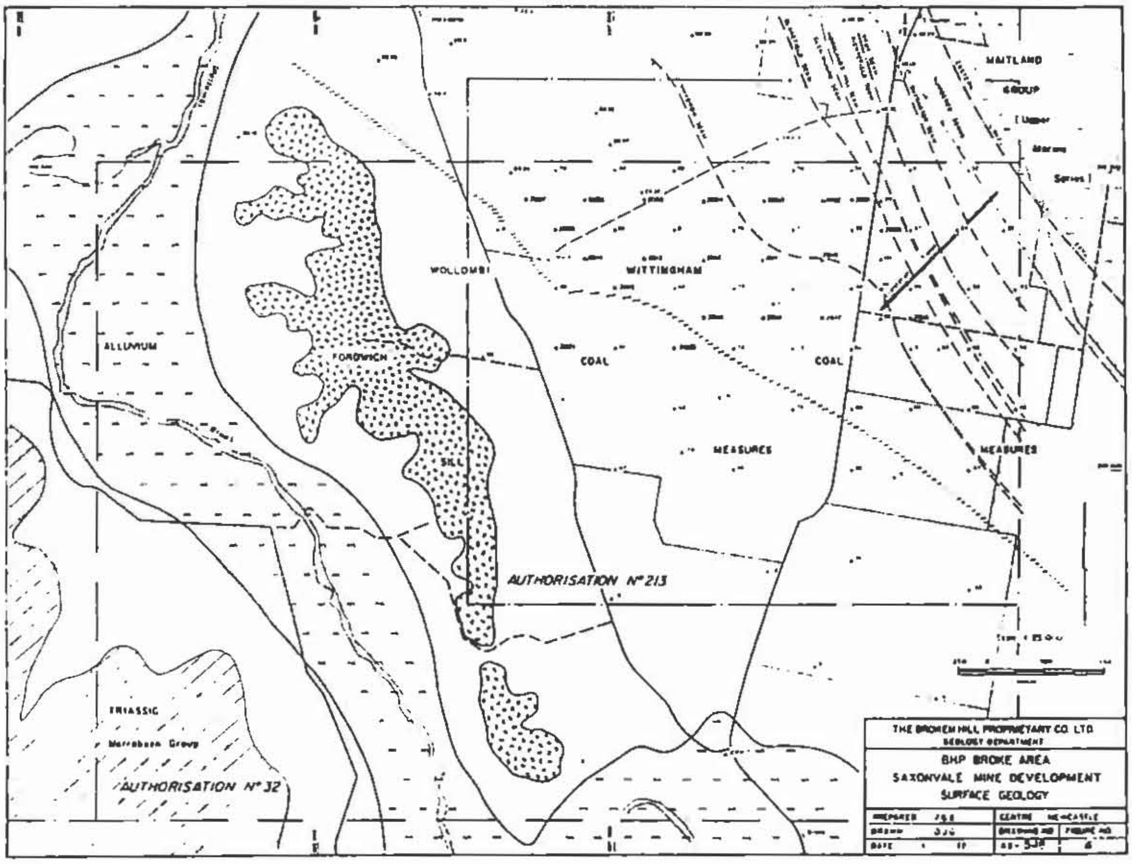


Figure 2. Surface geology of BHP Saxonvale Mine.

2. MINING OPERATIONS

Saxonvale mine is a truck and shovel multi-bench mining operation. The use of draglines for the removal of overburden was precluded, because of the structure of the coal deposit with its number and proximity of seams and steepness of dip in the subcrop area and other geotechnical and mining factors.

Major items of mining equipment in operation at the end of 1984 are shown in Table 1.

Ultimately up to eight primary and secondary drills, seventy overburden trucks, twenty-three coal and reject trucks, nine overburden shovels, three coal shovels and seven front-end loaders will be required. Planning for a small dragline operation on the Whybrow Seam, west of the Broke Road, is currently being undertaken.

Development of the pit commenced in the subcrop regions between the Glen Munro and Vaux seams because of the lower stripping ratio in this area. Development is continuing in a down dip direction, following the base of the Vaux seam, while at the same time widening the pit to the west and south, exposing all the coal seams for maximum flexibility in the raw coal blending. Once the pit reaches a depth of approximately 200m the major working axis of the pit will change and further extension will progress north-west along the line of the strike. The pit will ultimately reach a depth of 300m and a capacity of 7.0 Mtpa raw coal.

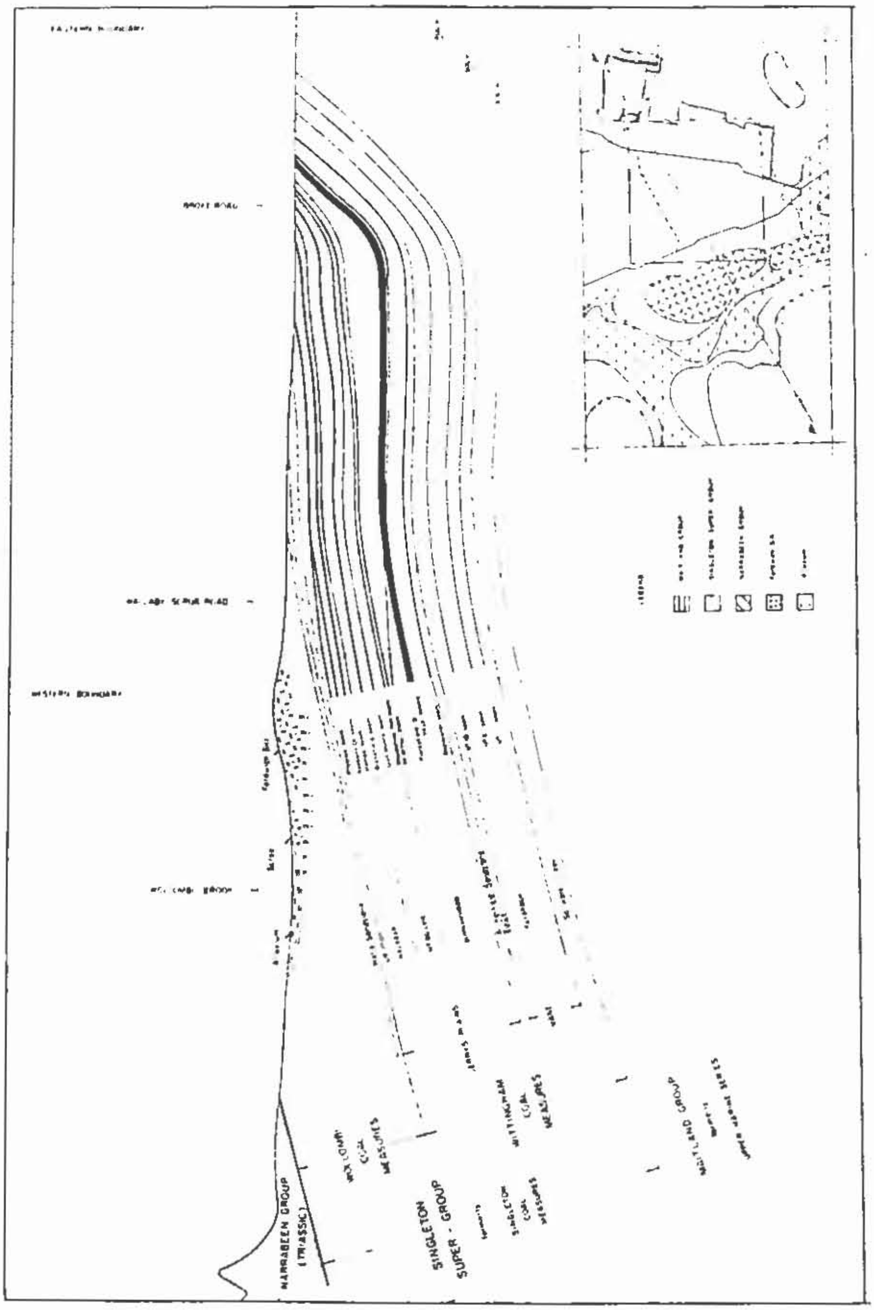


Figure 3. Geological cross-section (NE-SW) through Saxonvale Mine and adjacent area.

Electric shovel combine with overburden trucks to remove the overburden in 10 metre lifts. The overburden is hauled a distance of up to 4km to the external dump in the south-east corner of the lease area. The dump is being formed against a rising ridge in 10m - 20m lifts and will be progressively rehabilitated to blend with the topography of this feature. After seven years of operation the pit will have extended sufficiently along strike for in-pit dumping to commence, allowing the external dump area to be rehabilitated to its final contours.

Wedges of overburden above the inclined coal seams are pushed off by tracker dozers and loaded by front-end loaders into overburden trucks. After the exposed coal seams are finally cleaned of overlying interburden, tracked dozers then push the coal to the bench floor.

TABLE 1 MAJOR MINING EQUIPMENT - STAGE I

TYPE	MODEL	CAPACITY	NO. OF UNITS
Drills - Primary	BE 55R-II	270mm hole dia	2
Drills - Secondary	GD 25C	150mm hole dia	1
Shovels	P & H 2300	19.1 cubic metres	1
		17.6 cubic metres	2
Haulage Trucks	Titan 33-15C	172 tonnes	3
	Titan 33-15B	154 tonnes	12
	Wabco 85D	77 tonnes	6
Front-end Loaders	Caterpillar 992C	14.0 cubic metres	1
	Caterpillar 992C	9.6 cubic metres	3

AUXILIARY MINING EQUIPMENT - STAGE I

TYPE	MODEL	CAPACITY	NO. OF UNITS
Tracked Bulldozers	Komatsu 455	520 kW	3
	Komatsu 355-III	306 kW	5
	Caterpillar D9L	343 kW	1
Wheeled Bulldozers	Caterpillar 988B	300 kW	2
Motorscrapers	Caterpillar 657B	25 cubic metres	2
Motorgraders	Caterpillar 16G	186 kW	2
Water Trucks	Wabco 85D	60,000 litres	3

Front-end loaders load the coal into coal trucks for the 2.5km haul to the raw coal dump station. The generalised sequence of mining operations is shown in Figure 4.

Figure 5 shows the mine layout and surface facilities. The mine service area is located off mineable coal reserves, north-east of the mining area and consists of administration office, amenities, workshop and stores. The main workshop provides major maintenance of mobile equipment and plant. The general store is housed in the annexe.

In order to minimise truck movements from the mine area to the main workshop area, an area station has been located close to the mine, consisting of a fuelling and service station; wash down pad; mine office and bathhouse for up to 240 mine workers.

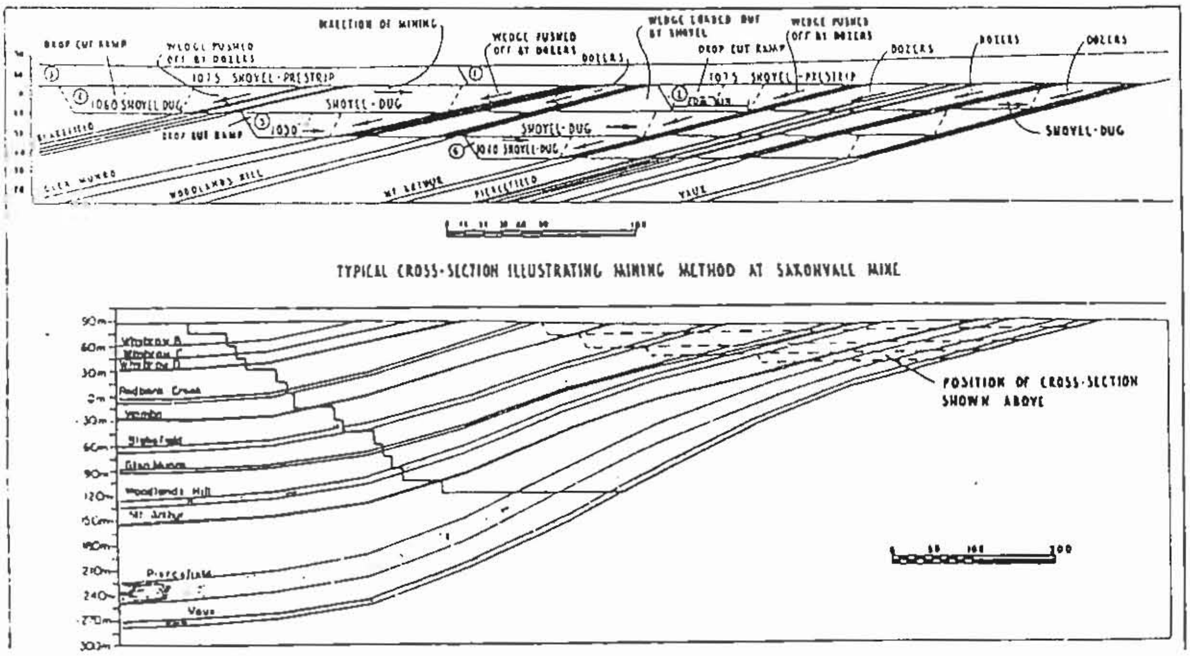


Figure 4. Open pit mining of inclined seams.

3. COAL HANDLING AND PREPARATION

3.1 Raw Coal Handling

At the current level of operations, coal is delivered from the mine to raw coal dump hopper in 77 tonne rear dump trucks. From the hopper coal is fed by conveyor at rates up to 1,500 tonnes per hour to the rotary breaker which reduces the topsize of the coal to 125mm and discards large rocks and other material. From the breaker the coal is fed to the 500 tonne coal preparation plant feed bin located to the washery.

3.2 Coal Preparation

The present coal prepartation plant was completed and commissioned in April 1982. It consists of a single module capable of treating 400 tonnes per hour or raw coal by dense medium processes.

Raw coal (-125mm) from the rotary breaker is received in a 500 tonne bin, located adjacent to the plant. The bin discharges via feeders and weighers to two primary wet screens separation at 20 - 30mm. The oversize is washed in a dense medium drum, the products are rinsed to recover magnetite and pass to the product and reject belts respectively.

Undersize from the primary screen is fed onto four sets of sieve bends and desliming screens for removal of -0.5mm material. The -30 + 0.5mm screen product is mixed with magnetite slurry and pumped to four 600mm diameter dense medium cyclones. Products from the cyclones are rinsed to recover magnetite and dewatered on screens. The rejects pass directly to the reject belt and clean coal is further dewatered by means of centrifuges before discharge onto the product belt.

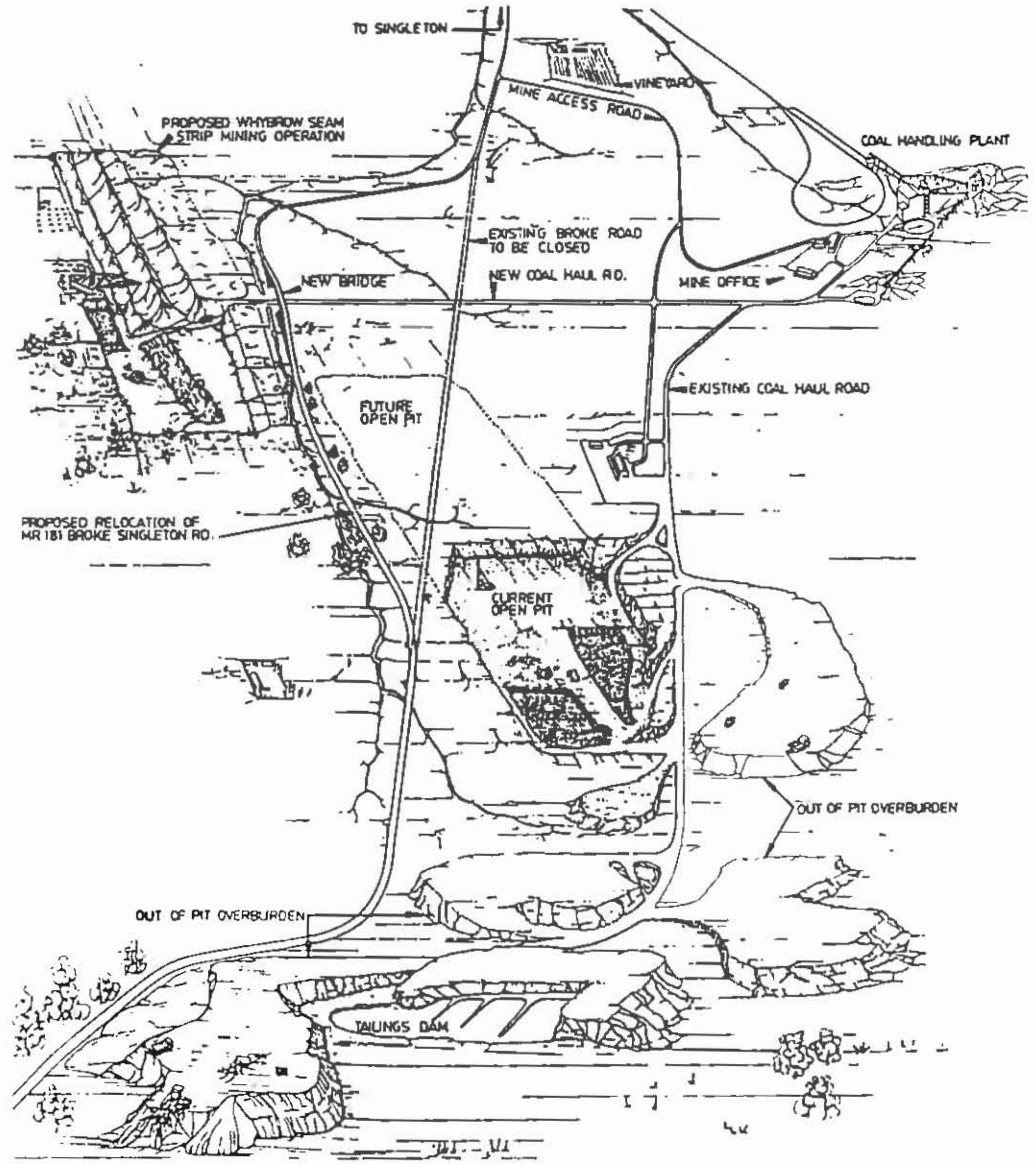


Figure 5. Artist's impression of proposed diversion of Broke road and proposed mining of Whybrow Seam.

The -0.5mm screen underflow is deslimed by cyclones separating at about 0.125mm and the slimes gravitate to a 60 metre diameter thickener. The thickened underflow is pumped to tailings dams located in the overburden dump area. Water is recovered from the thickener overflow and tailings dam for recycling to the plant. The coarse product from the desliming cyclones is dewatered on screens and directed to product or reject. Installation of fine coal benefication by spiral concentrators has been completed. The fine coal concentrates are recovered on dewatering screens and the tailings will be discharged with the solid reject.

The clean coal leaving the plant is conveyed to a transfer house containing an automatic sampler after which it is directed to the clean coal stockpile. Plant rejects are conveyed to a 300 tonne bin then removed by truck for dumping with the overburden from the mine.

4. CLEAN COAL HANDLING

Clean coal from the coal preparation plant is sampled and discharged onto a 20,000 tonne capacity conical stockpile. From here it is pushed by bulldozers so that total stockpile capacity is up to 300,000 tonnes. Coal is recovered by bulldozing into three discharge hoppers which feed onto an underground belt of capacity 3,000 tonnes per hour.

The recovery system carries coal from the stockpile through an automatic sampler to the 1500 tonne train loading bin. Coal is loaded from the bin into 42 wagon until trains of total capacity 31,250 tonnes. The system is designed to load trains in less than one hour by utilisation of the capacity of the bin. Coal is then railed the 90 kilometres to the port of Newcastle for export.

5. ENVIRONMENTAL ASPECTS

Most of the land is currently used for grazing purposes, and a pasture improvement programme is being implemented on land which is not to be mined in the short term. In some of these areas natural regeneration is being allowed to take place.

Erosion control works have been facilitated by the stabilisation and revegetation of civil works on site. The office, bathhouse and laboratory areas have been landscaped with native trees and shrubs.

Some 8,000 native tree seedlings were planted in October 1981 to form visual buffer zones around the mine which will also assist in dust and noise mitigation.

To ensure the effectiveness of pollution control measures implemented at the Saxonvale Mine, regular air, water and noise monitoring programmes are undertaken.

5. COAL QUALITY & RESOURCES

5.2 Geological Evaluation

A comprehensive geological exploration programme was carried out at Saxonvale prior to the development of the mine. The programme commenced in 1972 and when completed included 115 fully cored holes, 76 partially cored holes and 274 open holes. Cored drilling was carried out on a 500 metre grid which was subsequently infilled to a 250 metre grid over most of the lease by open hole drilling. Within the subcrop zone the bore spacing was reducing to 100 metres and within the initial mine area further reduced to 70 metres.

Geophysical investigations undertaken include extensive downhole logging, high resolution seismic, conventional seismic, resistivity, magnetometer, mini-sosie, gravity and piezometric surveys.

Numerous bulk samples were obtained for coal quality analysis including those from large diameter bores, a shaft, trial cut and a 1.5km long exploration trench. These bulk samples were subjected to detailed physical, analytical and petrographic analyses. This work formed the basis for the design of the coal preparation plant.

Development drilling is undertaken ahead of the mine working to provide more detail on seam structure and coal quality. Strip sampling is carried out in the pit and routine sampling of the preparation plant feed is also undertaken. This information is used in the design of the short term mine planes and production planning.

5.3 Coal Seams and Resources

All the coal seams comprising the Wittingham Coal Measures have been intersected in the drilling programme and the relative positions of these seams subcropping near the northern boundary of the Authorisation Area are illustrated in the cross section view of Figure 3.

True dip averages 15 degrees at the eastern seam subcrops and flattens 0 - 5 degrees at depth and to the west.

The Saxonvale Mine has been developed on the nine upper seams of the Wittingham Coal Measures. Many of the seams contain a number of splits which are often thick enough to be mined separately hence reducing potential seam contamination. The major seams vary in thickness from two to three metres for the Glen Munro, Woodlands Hill and Vaux seams to 20 metres for the Piercefield seam.

The upper coal seams Whybrow, Redbank, Creek and Wambo are suitable quality for energy coal production whilst the Blakefield, Glen Munro, Woodland Hill, Mt. Arthur, Piercefield and Vaux seams could be washed to produce not only energy coal but also coking coal as the mine proceeds to depth. A summary of coal specifications is included on Table 2.

The measured in-situ resources to the base of the Vaux seam may be summarised as follows:

0 - 300m	700 million tonnes
below 300m	320 million tonnes
Total	1020 million tonnes

TABLE 2 SOME QUALITY PARAMETERS OF SAXONVALE COAL

Saxonvale Energy Coal is a medium high volatile coal with medium ash, low sulphur and a high specific energy content.

Specification

Proximate Analysis	(% Air Dried)	Ash Analysis	(% Ash Dry)
Total Moisture (ar)	9	SiO_2	72-77
Inherent Moisture	2.5	Al_2O_3	17-21
Ash	16 0	Fe_2O_3	2.3-3.0
Volatile Matter	29 0	TiO_2	0.8
Fixed Carbon	52.5	P_2O_5	0.06
Total Sulphur	0.5	CaO	0.2
		MgO	0 3
Calorific Value	6600 Kcal/kg	K_2O	1.5
Hardgrove Index	50-55	Na_2O	0 2
Swell	1-3	Mn_3O_4	0 03
Size (mm)	50 x 0	SO_3	0 04
		Ash Fusion	
Ultimate Analysis	(% Dry Ash Free)	Temperature	(°C Reducing)
Carbon	84.9	Initial	1470
Hydrogen	5.2	Spherical	+ 1540
Nitrogen	1.8	Hemispherical	+ 1540
Oxygen	7.7	Flow	+ 1540
Sulphur	0.4		

6. TECTONIC SETTING OF THE MINE

The Saxonvale mine is located on a portion of the northern limb of the Sydney Basin which outcrops in the Hunter Valley. This basin forms part of the much larger depositional basin sequence which was active during Permian and Triassic time and extended through NSW and QLD.

Regional structural controls resulted in asymmetrical depositional conditions. Along the western and southern margins (in NSW) subsidence was relatively slow and steady which resulted in deposition of relatively few seams which were subject to little or no splitting. Deposition in the northern and eastern portion was much faster and greater and was also influenced by more slowly subsiding local "highs" e.g. Lochinvar Anticline and Loder Dome.

This greater but yet somewhat uneven depositional pattern resulted in a far more varied sequence of coal seams which is characterised by significant splitting, recombination and lensing out of coal seams over relatively short distances. There is at least at Saxonvale, a marked thinning of the sequence as the coal measures onlap of the western flank of the Loder Dome. This reduction in coal seam thickness is reflected in increasing raw coal ash and decreasing proportion of the bright coal onto the Dome. Examples of this are given in Table 3.

TABLE 3 VARIATIONS IN PIERCEFIELD & VAUX SEAM DEPOSITION

		DISTANCE DOWN DIP			
Interval		**Subcrop**	**1/2km down**	**1km**	**2km**
Interval Mt. Arthur/Piercfield		12m	62m	81m	85m
"Piercefield"	overall	12m	16m	24m	23m
	coal only	10m	13m	18m	16m
Piercefield to Vaux		9m	7m	10m	11m
Vaux	overall	3.5m	5.4m	10.6m	8.4m
	coal only	3.2m	4.6m	7.5m	5.6m
Piercefield	A raw coal ash	32.1	43	22.8	35.5
	B raw coal ash	36.9	28.9	23.2	18.3
	C raw coal ash	49.0	51.0	36.0	34.0
	D raw coal ash	32.8	38.0	23.3	25.0
Vaux	raw coal ash	30.4	32.	22.2	15.6

This "differential" subsidence is also reflected in seam dip with the Vaux having inclination of approx. 15^{o} at subcrop. This steepens to a maximum of almost 30^{o} at 350m depth of cover from which point the dip flattens again to less than 5^{o}.

7. STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

The sedimentary sequence seen at Saxonvale Mine belongs to the Wittingham Coal Measures from the upper portion of the Vane Subgroup to the top of Jerrys Plains Subgroup. Genetically, this sequence covers the transition from lower to upper delta plain environments (Vane to Jerrys Plains Subgroups), as well as, a short-lived marine transgression-regression reversal (Archerfield-Bulga Formation) followed by coal deposition in a back barrier to lagoonal setting (Bayswater Seam).

The palaeoenvironmental interpretation is based on both coal composition and the character of the interseam sediments. In the first case use is made of the degree of preservation of plant cell tissue (= Tissue Preservation Index, TPI) and the degree of gelification (= Gelification Index, GI). As shown elsewhere in this volume, these two properties bear strong links with the geological setting of peat formation. In Figure 6 the 25 coal seams (except No's 15 and 19) encountered in the excursion area have been plotted on the basis of their respective TPI and GI values. The numbers correspond to those used in the stratigraphic columns displayed in Figure 7A to D. The boomerang-shaped enclosure in the diagram indicates the area occupied by coals formed on the lower delta plain (the circle gives the mean of 16 readings) the upper delta and alluvial plain (the triangle gives the mean of 36 readings) and the alluvial fan to braid plain (the

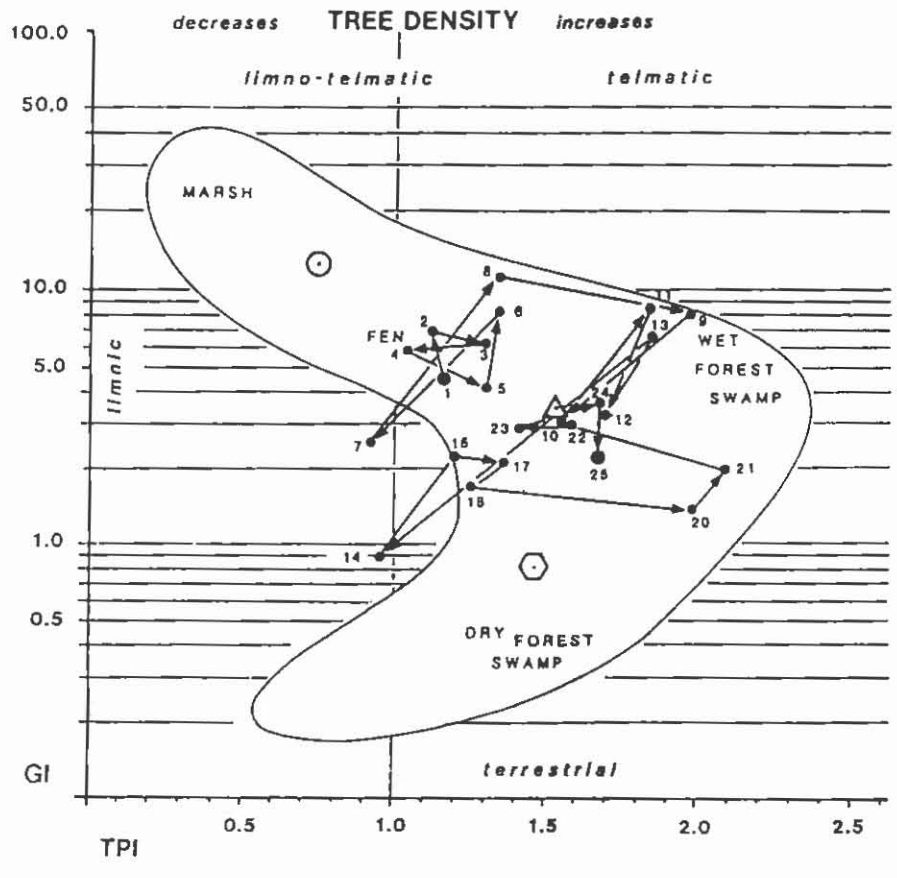


Figure 6. The position of the Saxonvale coals in the GI/TPI diagram. The numbers refer to the coal seams illustrated in Figure 7A to D.

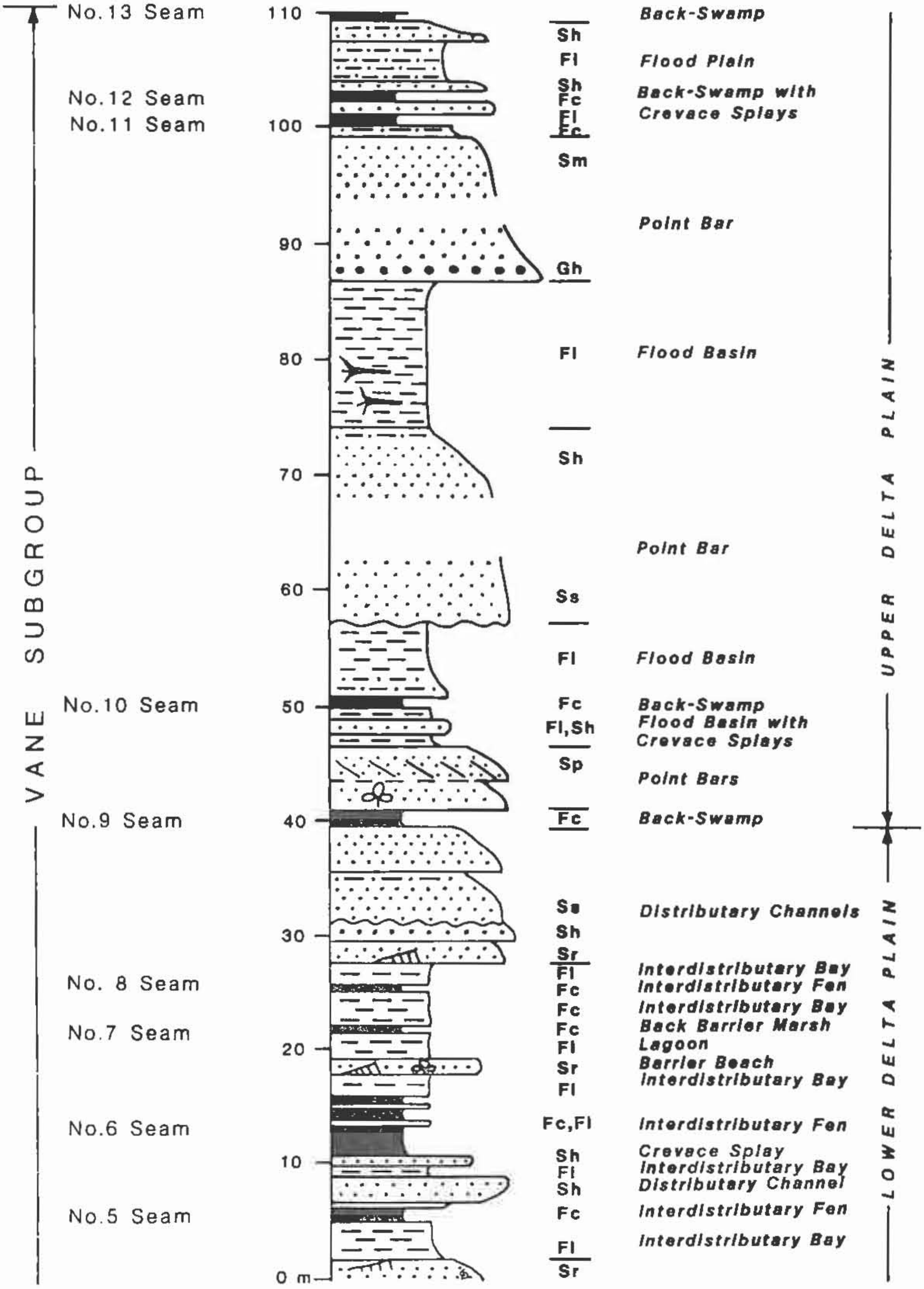


Figure 7A. Stratigraphic column measured in the exploration trench of BHP Saxonvale Mine. Modified and supplemented after Cameron (1979) and Bailey (1981).

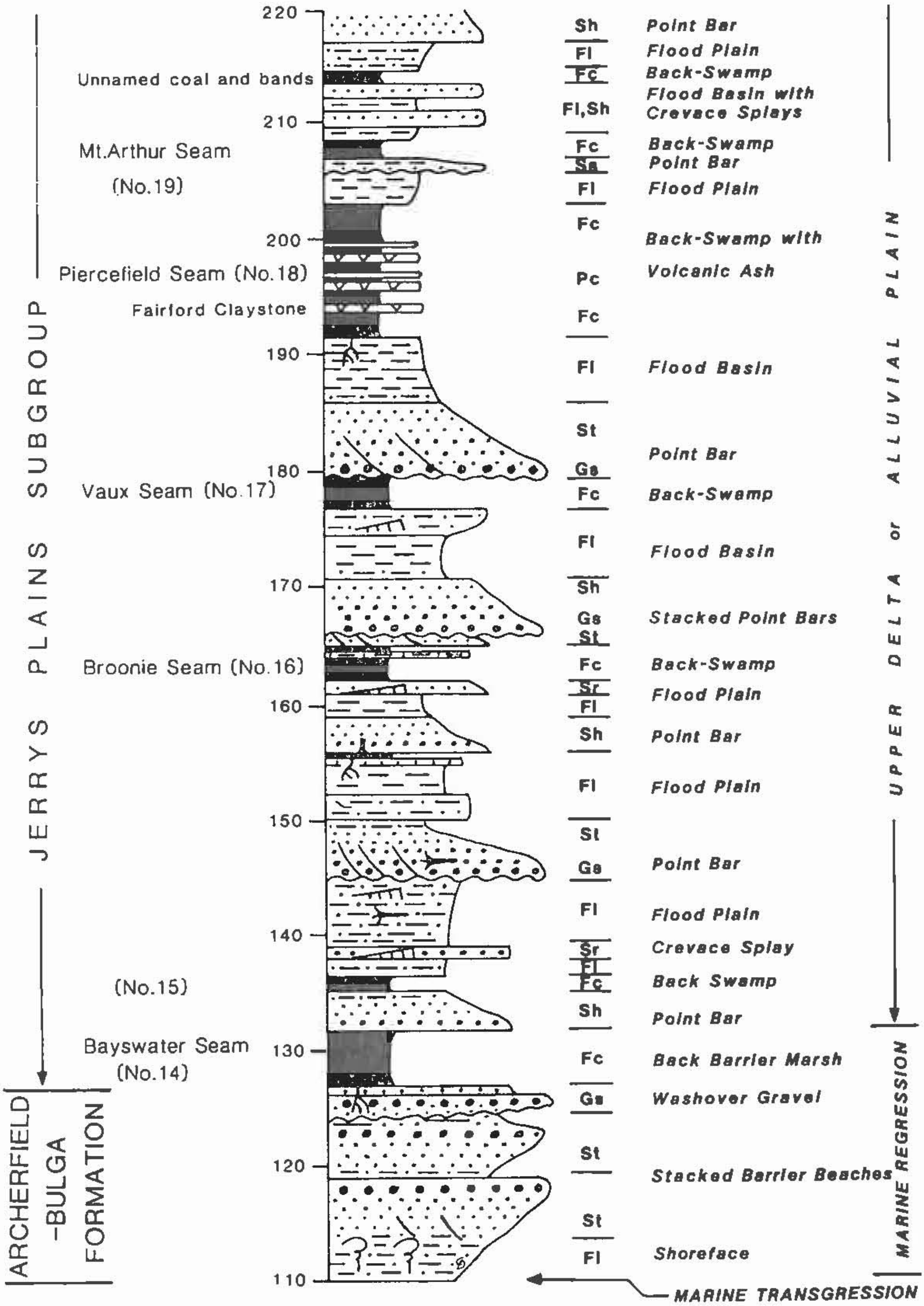


Figure 7B. Continued.

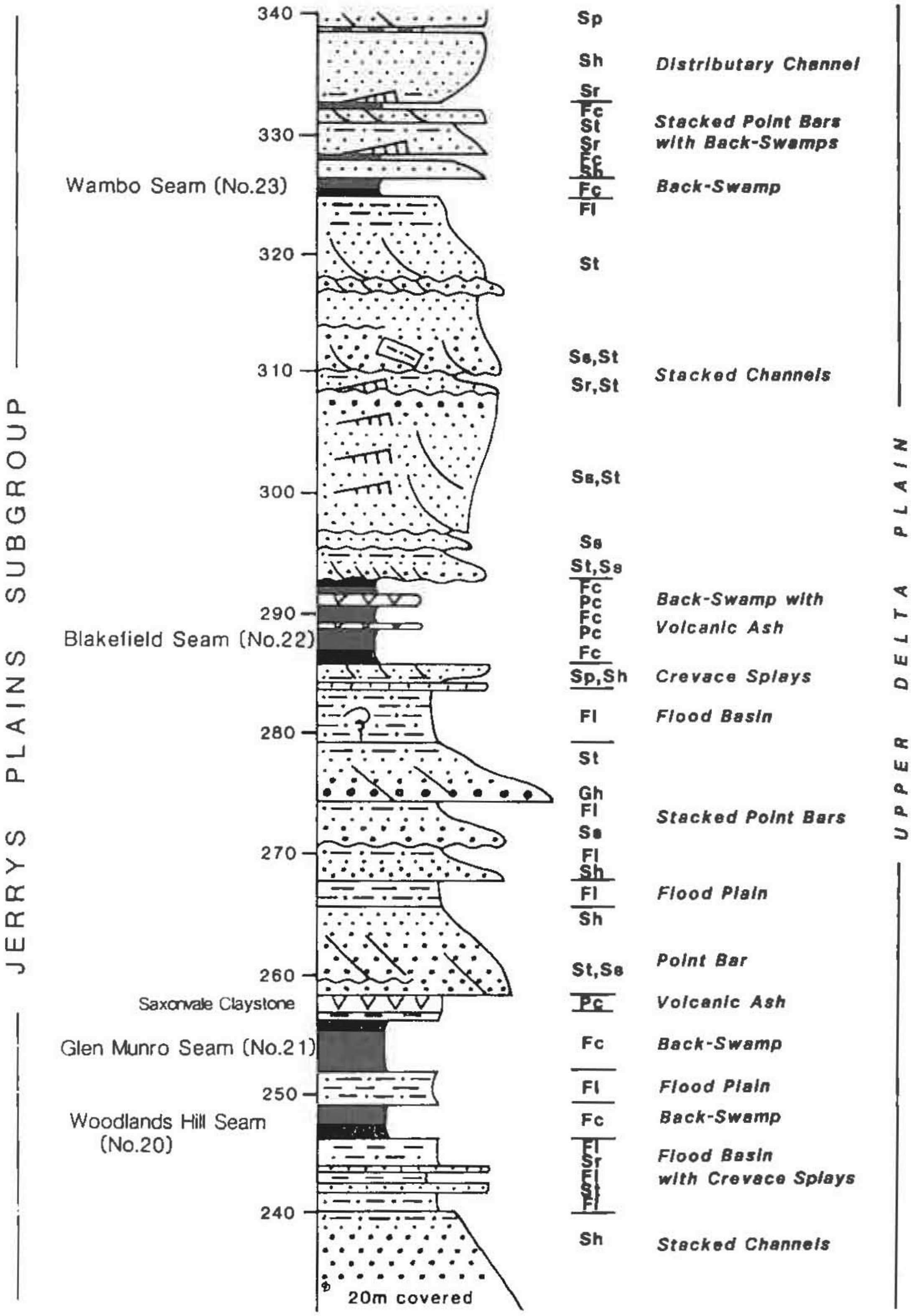


Figure 7C. Continued.

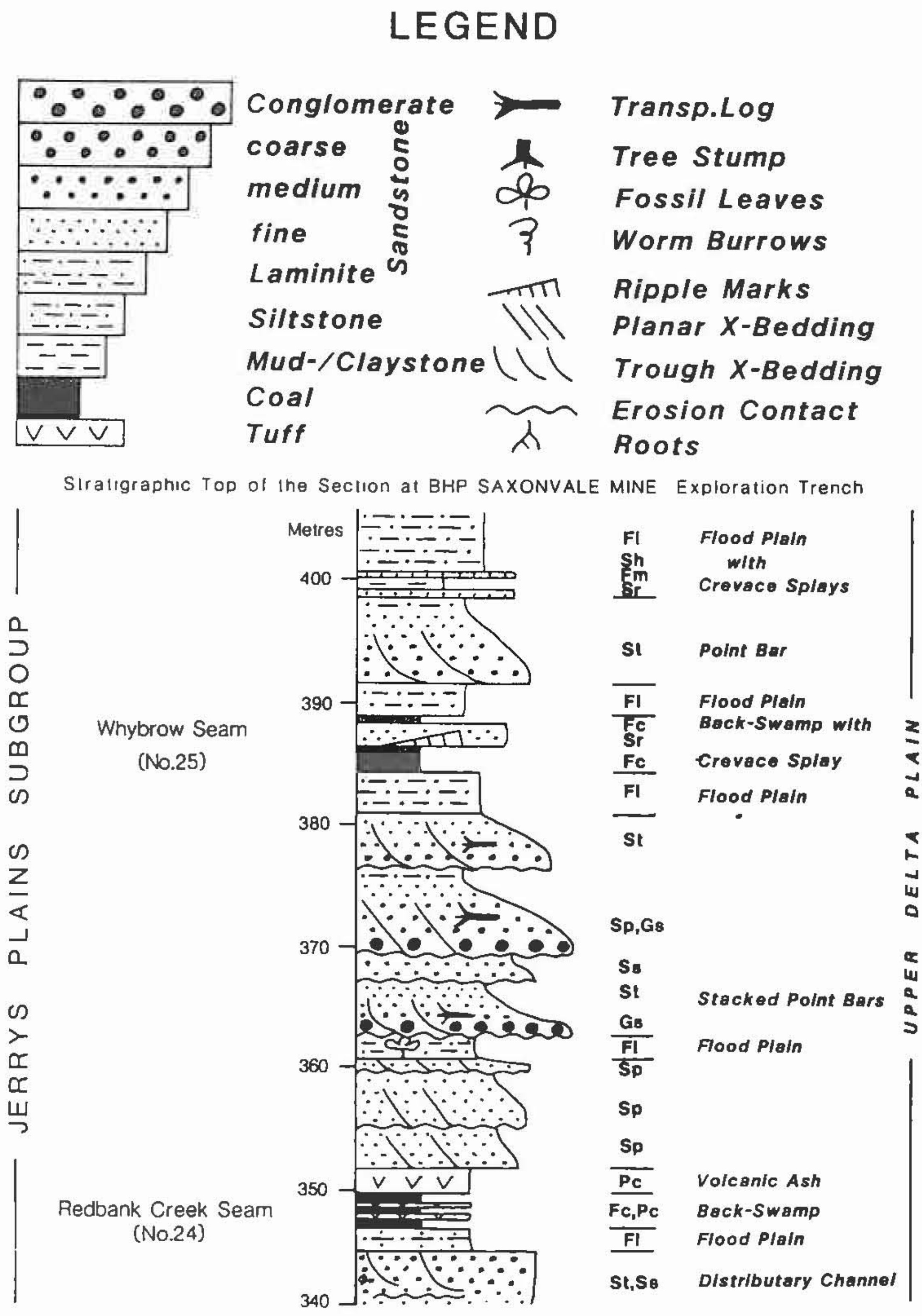


Figure 7D. Continued.

hexagon gives the mean of 18 readings). The Saxonvale coals form two clusters within the diagram plus two misfits. Seams No's 1 to 8 (except No. 7) occupy a position within the lower delta plain but not far from its boundary with the upper delta plain. The other seams are well within the upper delta to alluvial plain and several of the seams cluster closely around its mean. Seam No. 14 which is the Bayswater Seam, is different beacause it has been formed at the end of a basinwide marine transgression as will be discussed below.

The palaeoenvironmental interpretation of the interseam sediments is based on the usual combination of depositional textures and structures, fossils, and order of superposition.

7.1 The Saltwater Creek Formation

The stratigraphic setting of the excursion area within the Permian System is indicated in Table 4 which shows that the basal unit of the Wittingham Coal Measures, the Saltwater Creek Formation, is still

TABLE 4 THE STRATIGRAPHIC SUBDIVISIONS OF THE PERMIAN SYSTEM IN THE HUNTER VALLEY

Moon Island Beach S.-Gr.	NEWCASTLE COAL M.	Glen Gallic S.-Gr.	WOLLOMBI COAL M.
Boolaroo S.-Gr.		Doyles Creek S.-Gr.	
Adamstown S.-Gr.		Horseshoe Cr. S.-Gr.	
Lambton S.-Gr.		Apple Tree Flat S.-Gr.	
Waratah Sandstone		Watts Sandstone	
Hexham S.-Gr.	TOMAGO C.M.	Jerrys Plains S.-Gr.	WITTINGHAM C.M.
Four Mile Creek S.-Gr.		Archerfield-Bulga F.	
		Foybrook F.	
Wallis Creek S.-Gr.		Saltwater Creek F.	
MAITLAND GROUP	Mulbring Siltstone Muree Sandstone Branxton Formation		
GRETA COAL M.	Paxton F. Kitchener F. Kurri Kurri Cgl. Neath Sandst.	Rowan F. Skeletar F.	
DALWOOD GROUP	Farley F. Rutherford F. Allandale F. Lochinvar F	Gyarran Volcanics	

marine influenced and represents a delta slope environment. It consists mainly of laminated shale and sandstone including frontal splay sands. Its lower boundary is gradational with the underlying Mulbring Siltstone of the marine Maitland Group and, although body fossils seem to be missing in the Saltwater Creek Formation it is characterised by widespread bioturbation. Near the top the formation it becomes sandy and displays irregular bands of pebble conglomerate.

7.2 The Vane Subgroup

This stratigraphic unit is partly exposed in the old exploration trench at Saxonvale Mine. The sequence is equivalent to the Foybrook Formation, east of the Muswellbrook Anticline, but its coal seams are thinner and even more prone to splitting and deterioration. A total of 13 coal seams has been discovered in the excursion area which cannot be individually correlated with either the seams named by Robinson (1963) in the Foybrook Formation or the coal seams defined by Britten (1972) for the Vane Subgroup. The reason for the reduced thickness of both coal and interseam sediments may be related to the position of the Broke-Saxonvale area, near the axis of the Loder Dome, which as discussed above, might have constituted a platform of reduced subsidence during the formation of the Wittingham Coal Measures.

The coals of the Vane Subgroup display a high degree of similarity to those found in the Wallis Creek Formation of the Tomago Coal Measures. They consist mainly of bright coal and banded bright coal rich in vitrinite. The similarity is greatest in the high degree of gelification, although the basal seams of the Vane Subgroup display a preference for telinite and telocollinite compared with basal Wallis Creek coals which contain more desmocollinite. The tissue preservation index is thus higher which probably means that the coals were formed in wood bearing fens or swamps rather than in the tree-less marshes which produced the lower delta plain coals of the Wallis Creek Formation.

The coal facies indices of the upper five seams plot well within a region of Figure 6 usually occupied by coals of the upper delta plain.

During the excursion the lower part of the Vane Subgroup can be seen in the old exploration trench only from Seam No. 5 upward which also forms the basal portion of the stratigraphic column displayed in Figure 7A to D.

7.3 The Archerfield-Bulga Formation

This stratigraphic unit constitutes a particularly interesting interval in the exploration trench and, indeed, in the lower portion of the Wittingham Coal Measures at large because it represents a brief but very widespread episode of marine transgression and regression. As shown in the stratigraphic column of Figure 7A and B the formation is underlain by Seam No. 13 in the BHP numbering system which is probably equivalent to No. 24A in R.W. Miller's Mt. Thorley area and to one of the Lemington seams, as well as possibly, the Upper Wynn

Seam further north. This seam is particularly sulphur-rich, containing small pyrite concretions disseminated within the coal. Also the overlying siltstone and silty sandstone of the Archerfield-Bulga Formation contain much pyrite in the basal portion plus considerable bioturbation. This combination and the subsequent upward increase in particle size suggest that the formation of Seam No. 13 was genetically linked to a rapid marine transgression which subsequently inundated the peat as far as north of Muswellbrook. The transgression was halted near Kayuga (Uren, 1985) where the Archerfield-Bulga Formation wedges out such that the underlying Wynn Seam and the overlying Bayswater Seam coalesce. Figure 8 represents a section across the zone of coalescence. Attention is drawn to the erosion of the upper tuff band in the Wynn Seam and "the occurrence" of patches of basal conglomerate on top of the partly eroded coal surface both of which suggest that the Archerfield-Bulga Formation was formed during the marine regression. Its lower fine-grained and heavily bioturbated portion represents an offshore to lower shoreface environment. Towards the top of the sequence the proportion of medium and coarse sand increases with the addition of bands of pebble lag. Also, stratiform concentrations of iron oxides and zircon, similar to the heavy mineral placers of beach sands have been found by Bailey (1981). Cementing minerals quoted by the same author are illite, monmorillonite, dawsonite, calcite and jarrosite.

It seems reasonable to assume that the upper portion of the Archerfield-Bulga Formation represents a beach environment including elements of the swash zone. Its configuration in the excursion area is that of a 15 to 20m thick blanket deposit which resulted from the progradation of the shoreline as the shallow sea retreated to the south-east of the Sydney Basin.

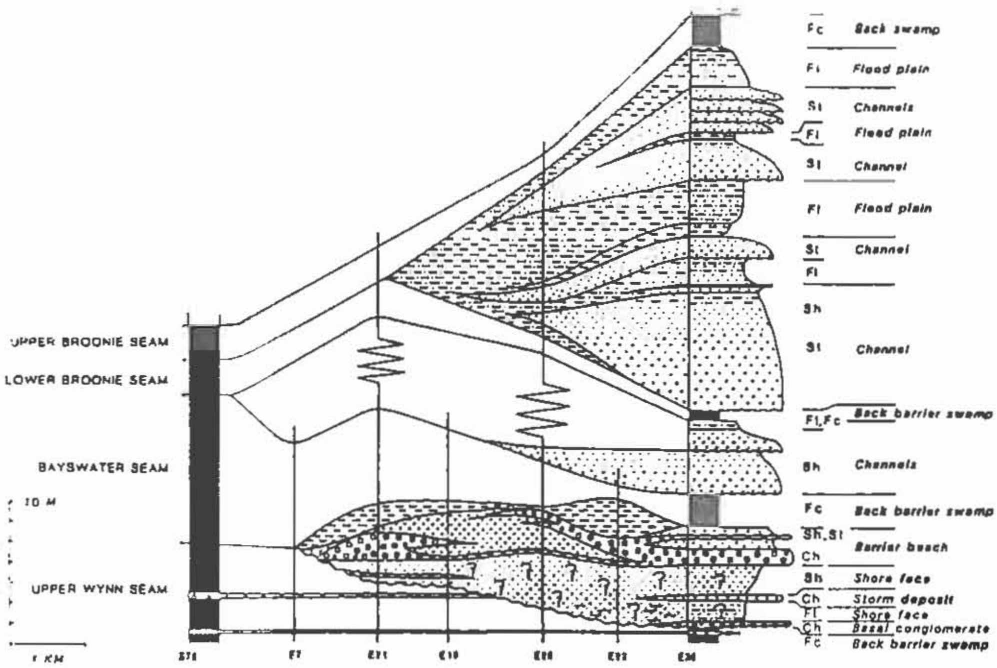


Figure 8. The termination of the Archerfield-Bulga Formation between the Upper Wynn and the Bayswater Seam near Kayuga, north of Muswellbrook. After Uren and Diessel (1986).

7.4 The Jerrys Plains Subgroup

Since the upper portion of the Archerfield-Bulga Formation has been formed as a south-eastward migrating barrier beach any immediately overlying conformable deposit is likely to have occupied a back-barrier environment. In the excursion areas this applies to the Bayswater Seam which is the basal unit in the Jerrys Plains Subgroup. However, whilst in the exploration trench the seam can be seen to rest directly on the Archerfield-Bulga Formation, there are other areas in the Hunter Valley where a shale horizon occurs between the latter and the overlying Bayswater Seam. This suggests that landwards of the barrier beach a sequence of lagoons developed which were surrounded and separated by peatlands. As the barrier prograded, its sands were covered either by lagoonal muds or back-barrier peats as indicated in Figure 9 from the Kayuga area. Lateral shifts between open lagoons and peatland are shown by the occurrence of splits in the Bayswater Seam of which one can be seen in the old exploration trench.

The coal of the Bayswater Seam (No. 14) is mostly dull which is due to the high concentration of inertinite, particularly, in the form of inertodetrinite. For this reason, both TPI and GI are quite low and suggest that the seam has been formed from a marsh peat which intermittently fell dry and was flooded, the latter being indicated by the occasional observation of concentrations of inertodetrinite of micro-crosslamination and graded bedding.

The stratigraphic interval between the Bayswater and Broonie seams is characterised by the re-establishment of upper delta or alluvial plain conditions which remain dominant for the remainder of the Vane Subgroup. The main charateristic is the repeated change from laminated overbank shales, interspersed with thin sheets of splay sands to point bar sands showing a distinct upward reduction in particle size. In the lower portion of the Jerrys Plains Subgroup, i.e. from the Bayswater to the Glen Munro seams, the fluvial events represented by the point bar sands are well separated by overbank deposits. Naturally, the latter have been subjected to some erosion at the bases of the fluvial sandstones but the rate of subsidence was

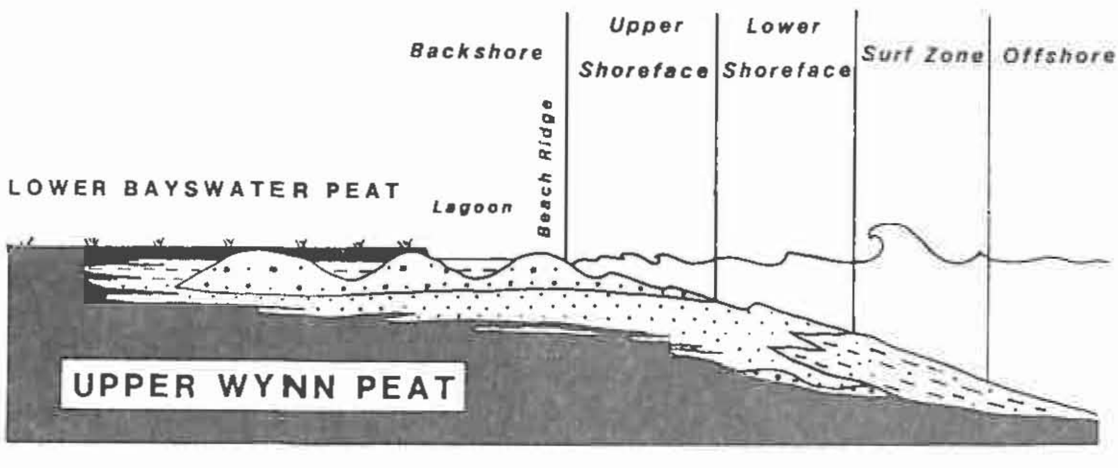


Figure 9. Cartoon illustrating the transgression-regression reversal at the beginning of Bayswater peat formation. Modified after Uren (1985).

evidently sufficient to protect the previously deposited point bar blankets underneath a thick column of overbank deposits before it could be eroded into by the next fluvial event passing through the area. The only exception occurs above the Broonie Seam where two point bars appear to be telescoped into each other.

Both trough and planar cross-bedding are common in the megaripple zones of the sandstones which in the Bayswater-Broonie interval, above the Broonie Seam and the Vaux Seam, contain a conglomeratic bedload zone. Ripple marks are common in both point bar and flood deposits.

Whilst the sequence up the the Vaux Seam will be seen in the old exploration trench only, the remainder of the Jerrys Plains Subgroup will be inspected twice, before lunch along the exploration trench and after lunch in the mine itself. The stratigraphic column of the latter is displayed in Figure 10. In spite of the short distance between the two localities, their depositional history was by no means identical in all detail.

The Vaux Seam is in average 2.5m thick but its top is quite irregular due to the erosion it has suffered before the overlying point bar was emplaced. In the exploration trench this is represented by a 7m thick sandstone with a basal conglomerate grading first into a laminite (flood plain) and then into several metres of shale/mudstone (flood basin) to the base of the Piercefield Seam. In contrast, the same sequence in the open-cut is considerably thinner but the stratigraphic distance of 12m between the Vaux Seam and the Piercefield Seam is retained by the addition of another 3m of coarse fluvial sandstone capped by 1m of laminated levee bank (?) sand. The latter forms the base of the Piercefield Seam and contains very large Vertebraria roots.

The Piercefield Seam consists of an alternation of coal plies and altered tuff bands of which the lowest, the Fairford Claystone between Piercefield D and C has been given member status. Although many of the thin ash-fall tuffs have been altered to claystones within the peat environment, the thicker pyroclastic surge deposits consist of crystal tuffs and are therefore quite sandy. Their violent emplacement is revealed by the contorted pinch and swell bedding and the frequency of tree trunks extending for a short distance from the coal roof into the tuff layers indicating that the trees were snapped off in the volcanic blast.

Another example of the lateral change in coal measure facies is evident above the Piercefield Seam. In the exploration trench the interval to the overlying Mt. Arthur Seam encompasses only 2m of shale and 1m of point bar sand. The same section in the mine is 9m thick, the point bar alone taking up 5m. The difference between the two localities is even more striking in the interval between the Mt. Arthur Seam and the so-called Unnamed Seam. In the trench the interval is composed of 5m of flood basin shales and two proximal splay sands indicating an overbank setting, possibly near a channel. The same interval in the open cut is 18m thick and consists primarily of braided conglomeratic channels. The reverse is the case in the next cyper interval between the Unnamed Seam and the Woodlands Hill Seam. It is approximately 30m thick in the trench but only 2m in the

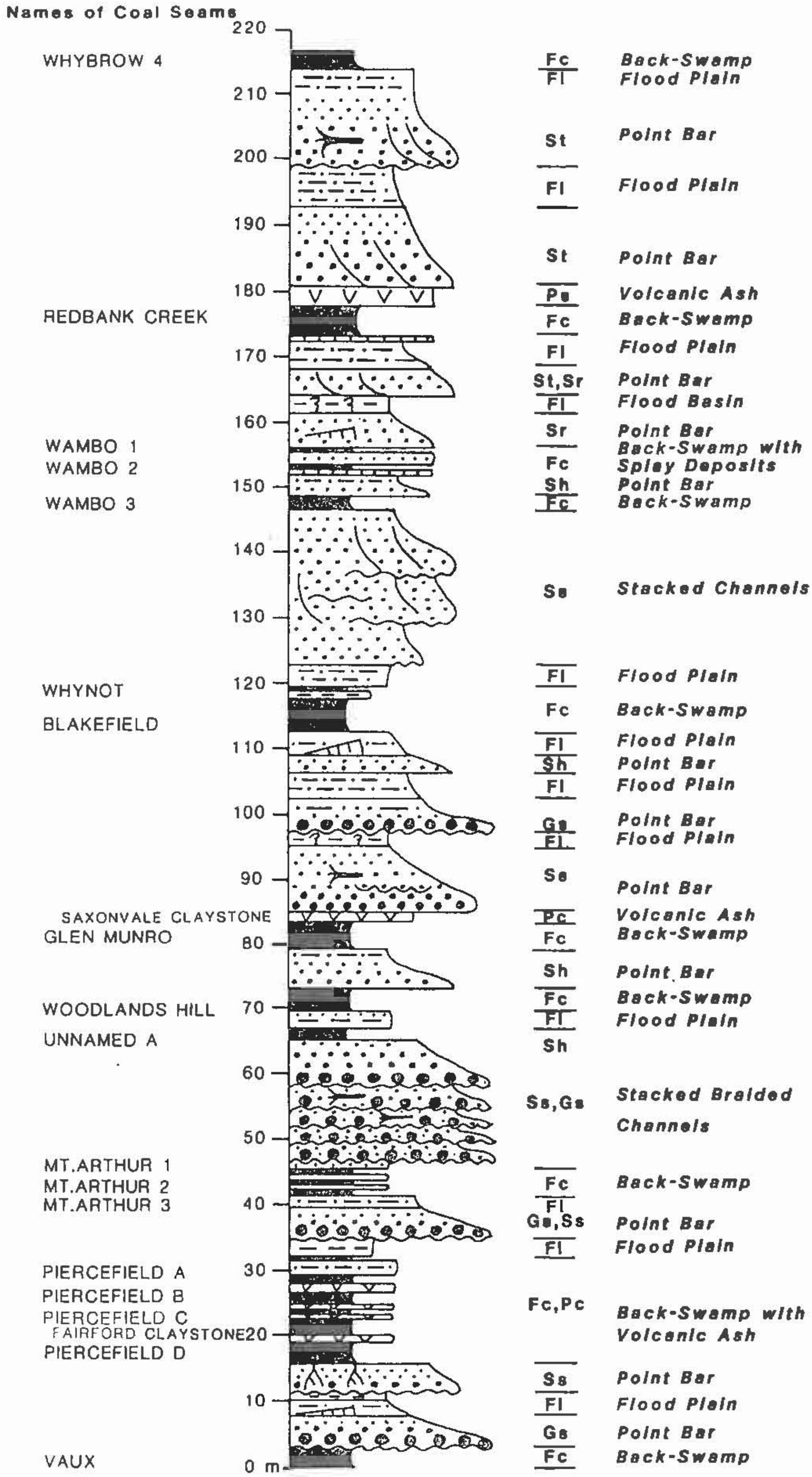


Figure 10. Stratigraphic column illustrating the sediments exposed at the northern end of Saxonvale Mine.

mine. Further differences will be noted when comparing Figures 7 and 10.

The Upper portion of the exposed portion of the Jerrys Plains Subgroup, i.e. from the Glen Munro Seam to the Whybrow Seam is characterised by multistorey sands in the form of multiple stacked channel deposits in the Blakefield-Wambo interval, as well as, stacked point bar sands in the Glen Munro-Blakefield and Redbank Creek-Whybrow intervals. The lenticularity of the Blakefield-Wambo interval is impressively exposed in a bc-section in the highwall of the open-cut were its maximum thickness of 20m is reduced to almost nothing over a lateral distance of only 80m, whereby the sandstone is replaced by overbank lutites.

Another interesting feature of the upper portion of the Jerrys Plains Subgroup is the occurrence of some bioturbation underneath the Blakefield Seam and in the Wambo-Redbank Creek interval. The latter consists of some upward coarsening sandstones in the exploration trench but in the mine the sandstone is split by 2.5m ripple-marked laminated shale which contains most of the worm burrows. In view of the fact that the respective coal seams are quite low in their sulphur content and display no other characteristics of a lower delta plain setting, it is assumed that the worm burrows have been formed at the bottom of fresh water flood basins emplaced on the upper delta plain.

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