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ADVANCES IN THE STUDY OF THE SYDNEY BASIN

PROCEEDINGS OF THE TWENTY SECOND SYMPOSIUM

15TH-17TH APRIL, 1988

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

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TWENTY SECOND NEWCASTLE SYMPOSIUM

ON

"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

15th - 17th APRIL, 1988

NEWCASTLE N.S.W. AUSTRALIA

P.K.SECCOMBE
CONVENER

THE UNIVERSITY OF NEWCASTLE
New South Wales 2308
DEPARTMENT OF GEOLOGY
Publication No. 301
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PREFACE

To our long time supporters and to those who are discovering Newcastle for the first time this weekend, welcome to the 22nd Newcastle Symposium!

It has been pleasing in organising the Symposium to see the continuing good response among the geological community to our annual conference. Despite difficult times in the coal industry, the number of contributions have grown this year to a record 30, of which four are to be presented as poster papers. My thanks to these many authors for their ready response in supporting the Symposium and their general willingness to adhere to the requirements of printing schedules.

This year we are delighted to welcome back to Newcastle Mr Lauchlan McIntosh to present the Keynote Address. Mr McIntosh, a graduate of this University, is Executive Director of the Australian Mining Industry Council, a body that has as its brief, the representation and promotion of the Australian exploration, mining and metals industries. We look forward to a stimulating address on the role of geology and geologists in shaping the future of our country.

The theme of this year's Symposium Excursion is the Redhead Conglomerate. The trip will take in aspects of the sedimentology and engineering properties of this unit within the Newcastle Coal Measures. My thanks go to Claus Diessel and Konrad Moelle for their efforts in preparing for the excursion.

The Geology Graduates' Society has again kindly taken on the task of organising a spit roast for the welcoming function on Friday night. It is hoped that as many delegates as possible, in addition to the excursion participants, will renew old acquaintances and sample Newcastle hospitality at this function, to be held in the courtyard between the Geology Building and the Great Hall.

This year we have changed the venue of the Saturday night Symposium Dinner, to the Newcastle Building Centre, 165 Lambton Road, Broadmeadow, where Chef Meyer will be providing the fare.

Finally, I would like to thank my colleagues in the Department of Geology for their willingness to help in the many aspects of organising the scientific and social program for, what we hope, is another successful and enjoyable Newcastle Symposium.

P.K. Seccombe
Convenor

FOREWORD

Welcome to the 22nd Newcastle Symposium. Participants hardly need to be reminded that this is the longest running geological symposium in Australia. That 200-250 participate in the April weekend is tangible recognition that the Department of Geology at the University of Newcastle is foremost in the field of coal geology, has close and healthy relations with the coal industry and that the Symposium is a valuable contribution to the discipline.

In a climate of Green Papers and White Papers, rationalisation for irrational reasons and dynamic reorganised stability, the Department of Geology welcomes the opportunity for peer assessment. The Department covers the basic disciplines of the geosciences necessary for basic teaching and has strengths in resource geology.

Unlike other Science Departments in the University which are essentially service Departments to the large Engineering Faculty (e.g. Physics), the Geology Department produces career geoscientists for the resource industry. For example, the average student numbers over the last decade are :

	IIIA	Honours	Postgraduates	IIIA as a % of total EFTSUs
Geology	12.4	4.1	14.1	**17.1%**
Physics	6.0	1.8	6.3	**2.6%**

Participants need not be reminded that the resources sector of the economy contributes to 45% of export earnings and 12% of the G.N.P.

Graduates from this Department are highly regarded commodities for the resources sector. Higher degree graduates from this Department are not trained for academic positions — all of our higher degree graduates enter senior positions in the resources industry. Although the Department of Geology is small and relatively expensive on a per capita basis, few Departments in this University have had a greater effect on the economy. The fact that there have been 22 Newcastle Symposia, well attended by industry, is surely proof enough.

Although the Geology Department has a reputation for coal geology, has made fundamental contributions to the science, has made major technological advances and wins substantial research grants for this work, it has another string to its bow. Since coming here three years ago, I have been attempting to build up the ore deposit geology sector which is now nationally and internationally perceived as one of the strengths of the Department. We have numerous honours and PhD students in this area, have post-doctoral fellows from Europe funded by their governments to work here, have published numerous major contributions in economic geology and have received substantial support from industry and granting bodies for research. A survey of the 16 principal international refereed journals in the 8 principal geoscience disciplines shows that over the last 3 years, the Department of Geology has contributed to 0.33% of the literature. Therefore, on a world-wide basis, one in every 300 major geoscientific contributions is from Newcastle. The Department is justifiably proud of what is a significant research contribution when one considers the thousands of geoscience departments in North America, U.K., western Europe and Japan. This contribution is some 150% greater than the average for the 35 geoscience organisations in Australia.

The dual strengths of coal geology and ore deposit geology make Newcastle unique — it is the only Department in Australia which specifically caters for the resource industry. Because all of our honours and post-graduate students are partially financially supported by individual companies, the graduates and industry at large, it can only be concluded that the Department of Geology at the University of Newcastle fulfils national economic objectives admirably.

I.R. PLIMER
Head of Department

PROGRAM

THURSDAY, 14th APRIL, 1988

10:00 **MEETING** of the Working Group MN/1/1/1 (Petrography) of the Standards Association of Australia

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FRIDAY, 15th APRIL, 1988

13:30-17:30 **EXCURSION**

THE REDHEAD CONGLOMERATE

Leaders : Associate Professors C.F.K. Diessel and K.H.R. Moelle

Departure Point : Bus leaves from the University No. 1 car park (near the Great Hall) at 13:30

The excursion will examine sedimentological and engineering aspects of the Redhead Conglomerate in coastal and quarry exposures south of Newcastle. Included is participation in the Graduate Society's Sheep Roast.

18:30-23:00 UNIVERSITY OF NEWCASTLE GRADUATES' SOCIETY **SHEEP ROAST**

Great Hall Courtyard and Purdue Room

SATURDAY, 16th APRIL, 1988

08:30-09:00 **REGISTRATION** - Geology Department Foyer

LECTURE THEATRE E01

09:00-09:05 Welcome by the Head of the Geology Department,
Professor I.R. Plimer

09:05-09:10 OPENING of the 22nd NEWCASTLE SYMPOSIUM by the Vice-Chancellor of The University of Newcastle,
Professor K.J. Morgan

TECHNICAL SESSION 1:

CHAIR : Mr B.W. Vitnell
Consultant Geologist

09:10-09:40 THE IMPLICATIONS FOR THE SYDNEY BASIN OF UPPER CRUSTAL EXTENSION IN THE BOWEN BASIN
C.W. Mallett[1], R.L. Hammond[2] & T.D. Sullivan[1]
1 CSIRO, Division of Geomechanics
2 Hunter Resources

09:40-10:20 THE NATURE AND TECTONIC SIGNIFICANCE OF EARLY PERMIAN VOLCANIC ROCKS FROM THE GUNNEDAH BASIN AND THE SOUTHERN PART OF THE NEW ENGLAND FOLD BELT
E.C. Leitch[1], P.A. Morris[2] and D.S. Hamilton[3]
1 University of Technology, Sydney
2 Geological Survey of Western Australia
3 University of Sydney

.....

10:20-10:50 **MORNING TEA** in the foyer of the GREAT HALL

.....

10:50-11:20 A VERTICAL SEDIMENTOLOGICAL PROFILE THROUGH THE UPPER CARBONIFEROUS COAL MEASURES OF THE RUHR BASIN, GERMANY
C.F.K. Diessel
University of Newcastle

11:20-12:20 * * * * * **KEYNOTE ADDRESS** * * * * *
GEOLOGY, GEOLOGISTS AND THIS NATION'S FUTURE
Mr J.L. McIntosh
Executive Director
Australian Mining Industry Council

12:20-12:25 **CHAIR** : SUMMARY AND VOTE OF THANKS

.....

12:30-13.45 **LUNCH** in the UNIVERSITY UNION

.....

SATURDAY 16th APRIL, 1988

LECTURE THEATRE E01

TECHNICAL SESSION 2A:

CHAIR : Professor G.H. Taylor
Research School of Earth Sciences, ANU

13:45-14:15 COMPARISON OF THE STYLE OF IGNEOUS INTRUSIONS IN THE SYDNEY AND BOWEN BASINS
L. Hamilton and C. Pattison
Queensland Institute of Technology

14:15-14:45 PALAEOCHANNEL DEVELOPMENT IN THE MOON ISLAND BEACH SUB-GROUP OF THE NEWCASTLE COAL MEASURES
M. Bocking, M. Howes and C. Weber
Electricity Commission of NSW

14:45-15:15 DIAGENESIS OF THE SANDSTONES IN THE NARRABEEN GROUP
G.P. Bai
University of Sydney

15:15-15:45 **AFTERNOON TEA** in the foyer of the GREAT HALL

15:45-16:15 TRIASSIC DEPOSITIONAL SYSTEMS IN THE GUNNEDAH BASIN
F.X. Jian and C.R. Ward
University of NSW

16:15-16:45 THE LATE PERMIAN PALAEOGEOGRAPHY OF THE AUSTRALIAN CONTINENT
A.T. Brakel and J.M. Totterdell
Bureau of Mineral Resources

16:45-17:15 THE WORLD SIGNIFICANCE OF THE HUNTER-BOWEN (INDOSINIAN) OROGENIC PHASE
J.M. Dickins
Bureau of Mineral Resources

17:15-17:20 **CHAIR** : SUMMARY AND VOTE OF THANKS

19:00 **SYMPOSIUM DINNER** at the NEWCASTLE BUILDING CENTRE

SATURDAY 16th APRIL, 1988

LECTURE THEATRE B01

TECHNICAL SESSION 2B:

CHAIR : Professor D.F. Branagan
Department of Geology & Geophysics
University of Sydney

13:45-14:15 THRUST FAULTING AT FREEMAN'S WATERHOLES
K.H.R. Moelle, University of Newcastle
D.F. Branagan, University of Sydney

14:15-14:45 ROOF AND FLOOR INSTABILITY WITH THE AWABA TUFF
R. Seedsman
ACIRL

14:45-15:15 STRUCTURAL CHARACTERISTICS OF THE SEDAN COAL DEPOSIT : AN EXAMPLE OF TECTONIC ANALYSIS OF DRILL CORES FOR GEOTECHNICAL PURPOSES
W. Bogacz, Australian Groundwater Consultants, and
G.L. Boyd, CSR Coal

.....

15:15-15:45 **AFTERNOON TEA** in the foyer of the GREAT HALL

.....

15:45-16:15 THE GEOTECHNICAL INVESTIGATION FOR THE F3 FREEWAY NORTH OF PALMERS ROAD : SITE GEOLOGY AND INVESTIGATION TECHNIQUES
C.L. Francis and S.J. Summerell
Department of Main Roads

16:15-16:45 CRACK FORMATION AFTER CYCLIC LOADING OF ANISOTROPIC SEDIMENTARY ROCKS
G. Li and K.H.R. Moelle
University of Newcastle

16:45-17:15 STRUCTURE AND ENGINEERING IMPLICATIONS OF OFFSET DYKES OF THE SYDNEY BASIN
J.V. Smith
University of Technology, Sydney

17:15-17:20 **CHAIR** : SUMMARY AND VOTE OF THANKS

19:00 **SYMPOSIUM DINNER** at the NEWCASTLE BUILDING CENTRE

SUNDAY 17th APRIL, 1988

LECTURE THEATRE E01

TECHNICAL SESSION 3A:

CHAIR : Ms V. Smith
Geological Consultant

09:30-10:00 SYDNEY FAULTS : FACTS AND FANTASIES
D.F. Branagan[1], K.J. Mills[1] and A.R. Norman[2]
1 University of Sydney
2 Macquarie University

10:00-10:30 TALLAWANG MAGNETITE - A CASE HISTORY REVIEW
G. Lee
Peter Stitt and Associates

.....

10:30-11:00 **MORNING TEA** in the foyer of the GREAT HALL

.....

11:00-11:30 THE DISPERSION OF CONSERVATIVE AND NON-CONSERVATIVE POLLUTANTS IN A TIDAL ESTUARY
I.A. Mumme
CSIRO, Lucas Heights

11:30-12:00 ENVIRONMENTAL AND GEOLOGICAL CONSTRAINTS TO SAND AND GRAVEL EXTRACTION IN THE PEEL AND COCKBURN RIVERS, TAMWORTH REGION.
V. Smith
Resource Planning

12:00-12:30 SYDNEY REGIONAL ENVIRONMENTAL PLAN No. 9 - MANAGEMENT OF EXTRACTIVE RESOURCES IN THE SYDNEY REGION
I.B.L. Paterson
NSW Department of Mineral Resources

12:30-12:35 **CHAIR** : SUMMARY AND VOTE OF THANKS

.....

12:35-14:00 **LUNCH** IN THE UNIVERSITY UNION

SUNDAY 17th APRIL, 1988

LECTURE THEATRE B01

TECHNICAL SESSION 3B:

CHAIR : Dr M. Salehi
Australian Coal Industry Research Laboratories

09:30-10:00 TECTOGENETIC ASPECTS OF THE TELFORD BASIN, LEIGH CREEK COALFIELD, SOUTH AUSTRALIA
W. Bogacz, Geo-Mining Consultants
I. Kivior, Electricity Trust of South Australia

10:00-10:30 'JOINT FILLINGS' IN SOME PERMIAN AND TRIASSIC ROCKS OF THE SYDNEY BASIN
C. Adamson, Consultant
K.H.R. Moelle, University of Newcastle

.....

10:30-11:00 **MORNING TEA** in the foyer of the GREAT HALL

.....

11:00-11:30 AEROMAGNETICS OVER THE SOUTHERN COALFIELDS
W. Stasinowsky[1], G. Poole[2], C. Barto[3] and P. Lamb[4]
1 BHP Engineering
2 BHP Illawarra Collieries
3 Electricity Commission of NSW
4 Kembla Coal and Coke

11:30-12:00 A CHAR MORPHOLOGY CLASSIFICATION WITH APPLICATIONS TO COAL COMBUSTION
J. Bailey
University of Newcastle

12:00-12:30 PETROGRAPHY OF CERTAIN GONDWANA COALS OF AUSTRALIA AND INDIA
K.K. Sappal
Curtin University of Technology

12:30-12:35 **CHAIR** : SUMMARY AND VOTE OF THANKS

.....

12:35-14:00 **LUNCH** IN THE UNIVERSITY UNION

POSTER PAPERS

THE ROLE OF GEOLOGISTS IN ENVIRONMENTAL PLANNING IN NSW

V. Smith
Resource Planning

BMR - APIRA PHANEROZOIC PALAEOGEOGRAPHY OF AUSTRALIA PROJECT

A.T. Brakel and J.M. Totterdell
Bureau of Mineral Resources

THE QUEENSLAND DEPARTMENT OF MINES COMPUTERISED FIELD MAPPING SYSTEM

M. Thornton
Queensland Dept. of Mines

THE BELLATA DDH 1 PETROLEUM STRATIGRAPHIC WELL, NARRABRI-MOREE DISTRICT

I. Walsh
NSW Department of Mineral Resources

Poster papers and displays of material relating to some technical papers will be located in the morning/afternoon tea venue - the foyer of the Great Hall.

THE IMPLICATIONS FOR THE SYDNEY BASIN OF UPPER CRUSTAL EXTENSION IN THE BOWEN BASIN

C.W. Mallet[1], R.L. Hammond[2] & T.D. Sullivan[1]

CSIRO Division of Geomechanics, Indooroopilly[1]

Hunter Resources, Perth[2]

The Bowen Basin and Sydney Basin are part of a series of basins which developed close to Australia's eastern margin during the Permian and Triassic. They are connected by the Gunnedah Basin and concealed strata beneath the Surat Basin. There are many similarities in the basin's histories, and it is probable that tectonic processes controlling the formation of the Bowen Basin will also be significant for the Sydney Basin. Hammond (1987) proposed the application of a crustal extension model based on examples of Gibbs (1984) and Lister et al (1986). The basic features of this model will be outlined, and its application to the Sydney Basin assessed.

BOWEN BASIN

The basin consists of three NNW-SSE oriented depositional troughs lying between basement highs. In sequence from west to east they are the Springsure Shelf, Denison Trough, Comet Ridge / Collinsville Shelf, Taroom Trough, Connors Arch /Gogango Overfolded Zone / Auburn Arch, and an un-named trough composed of a series of grabens and half grabens along the coast from Mackay to Broad Sound.

The nature of these troughs and highs changes along their length. The Denison Trough cannot be traced as far north as can the Taroom Trough, and the easterly trough cannot be recognised south of the Gogango Overfolded Zone. In the Taroom Trough, very different structural elements are now found, from south to north, Mimosa Syncline, Folded Zone, and Nebo Synclinorium.

The geological history of the Bowen Basin is summarised as: (after Ziolkowski & Taylor, 1985; and Draper, 1985)

1. Early Permian - Rift phase with thick graben and half graben sediments (Denison Trough) and volcanics (Taroom and eastern Troughs).

2. Early to Late Permian - Basin sag with initial shallow marine followed by marginal marine sediments over most of the basin, with thicked deposition in the Denison and Taroon Troughs. Compression with some inversion of graben sequences was initiated.

IMPLICATION FOR SYDNEY BASIN OF BOWEN BASIN UPPER CRUSTAL EXTENSION

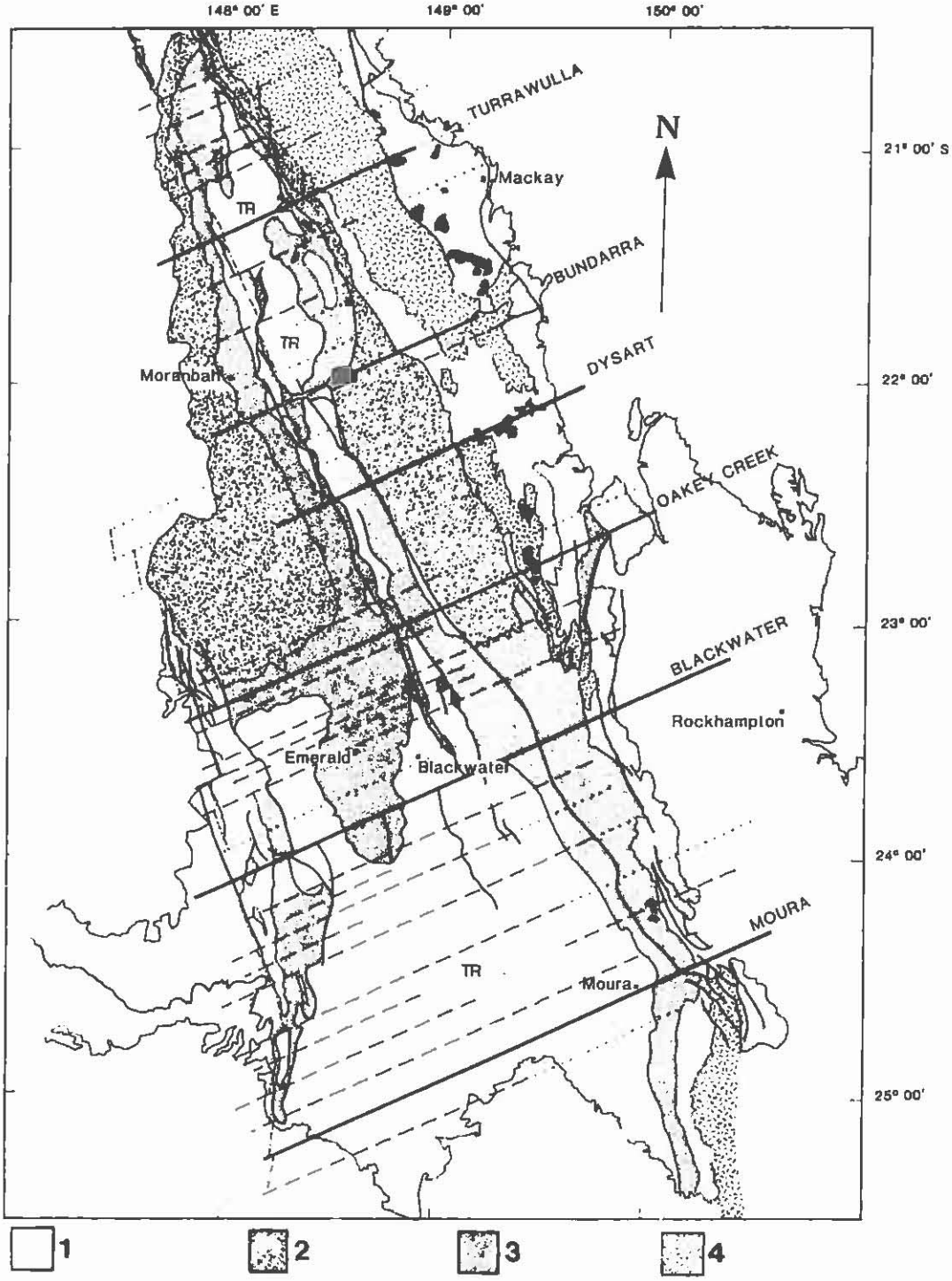

Figure 1. Bowen Basin with distribution of major stratigraphic units:

1. Early Permian rift phase 2. Middle to Late Permian sag phases 3. Late Permian Blackwater Group (mainly coal measures) 4.Devonian and Carboniferous basement, TR. Triassic (clear), Solid - Cretaceous intrusives. Bold lines are traces of major basement transfer faults, and broken and dotted lines are probable and possible minor transfer traces. (After Hammond in Mallett et al. 1988)

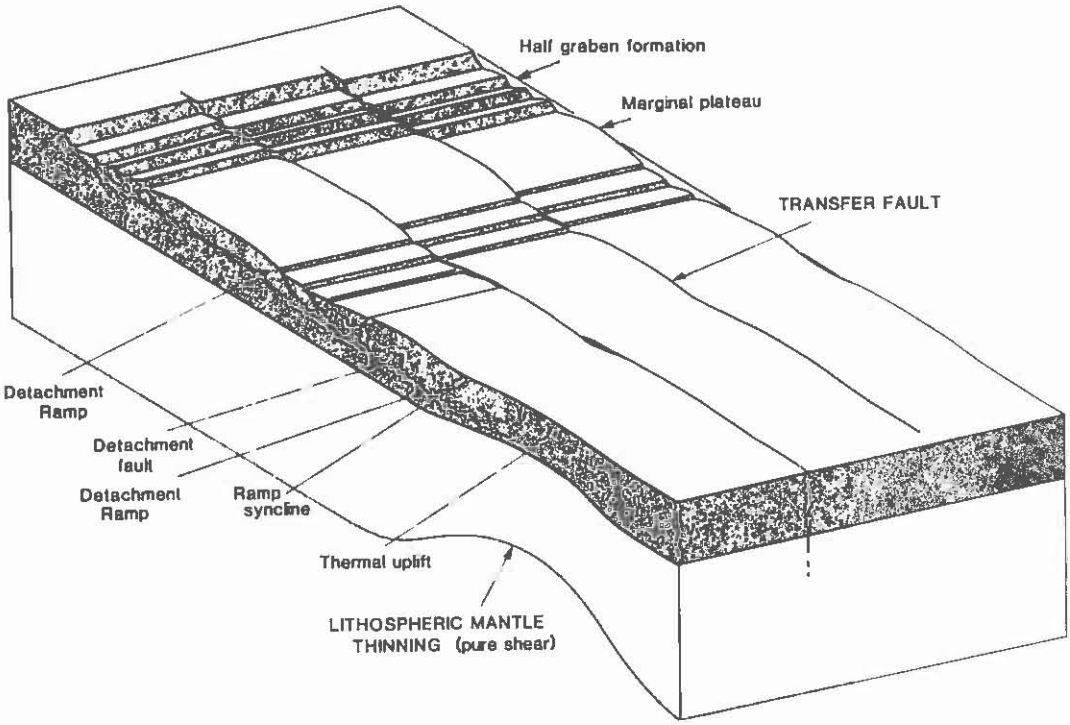

Figure 2. Generalised model for crustal extension, rifting and evolution of sedimentary basins (after Hammond in Mallett et al. 1988)

3. Late Permian and Triassic - Foreland basin sag phase, beginning with widespread marine trangression followed by coal measures, and finally fluvial and lacustrine beds. Deposition was concentrated in the Taroom Trough. Compression and reversal of half grabens continued and culminated in a major overthrusting event in the Middle Triassic.

The distribution of mapped stratigraphic units and faults is also controlled by NE-SW striking structures, that are transverse to the trend of troughs and basement highs. They break the basin into domains which are internally consistent with respect to the arrangement of NNW-SSE features, but which differ significantly from adjacent domains. These trends are not confined to the Bowen Basin, but have been recognised elsewhere. (Horton,1977; Grimstone,1986; Leach et al. 1987).

The major NE-SW transverse bounding structures are recognised by a coincidence of geological and geophysical features, such as strike swings, fault terminations, alignment of intrusives, but more importantly, as the termination of a uniform area of NNW-SSE structures. The trend from north to south in the basin is for younger stratigraphic units to outcrop with each successive major tranverse structure. The transverse structures terminate major structural elements within the basin such as the Mimosa Syncline, Collinsville Shelf / Comet Ridge, Nebo Synclinorium and Gogango Overfolded Zone. See Figure 1.

IMPLICATION FOR SYDNEY BASIN OF BOWEN BASIN UPPER CRUSTAL EXTENSION

INTERPRETATIVE X-SECTIONS ILLUSTRATING POSTULATED BASEMENT FAULT GEOMETRIES

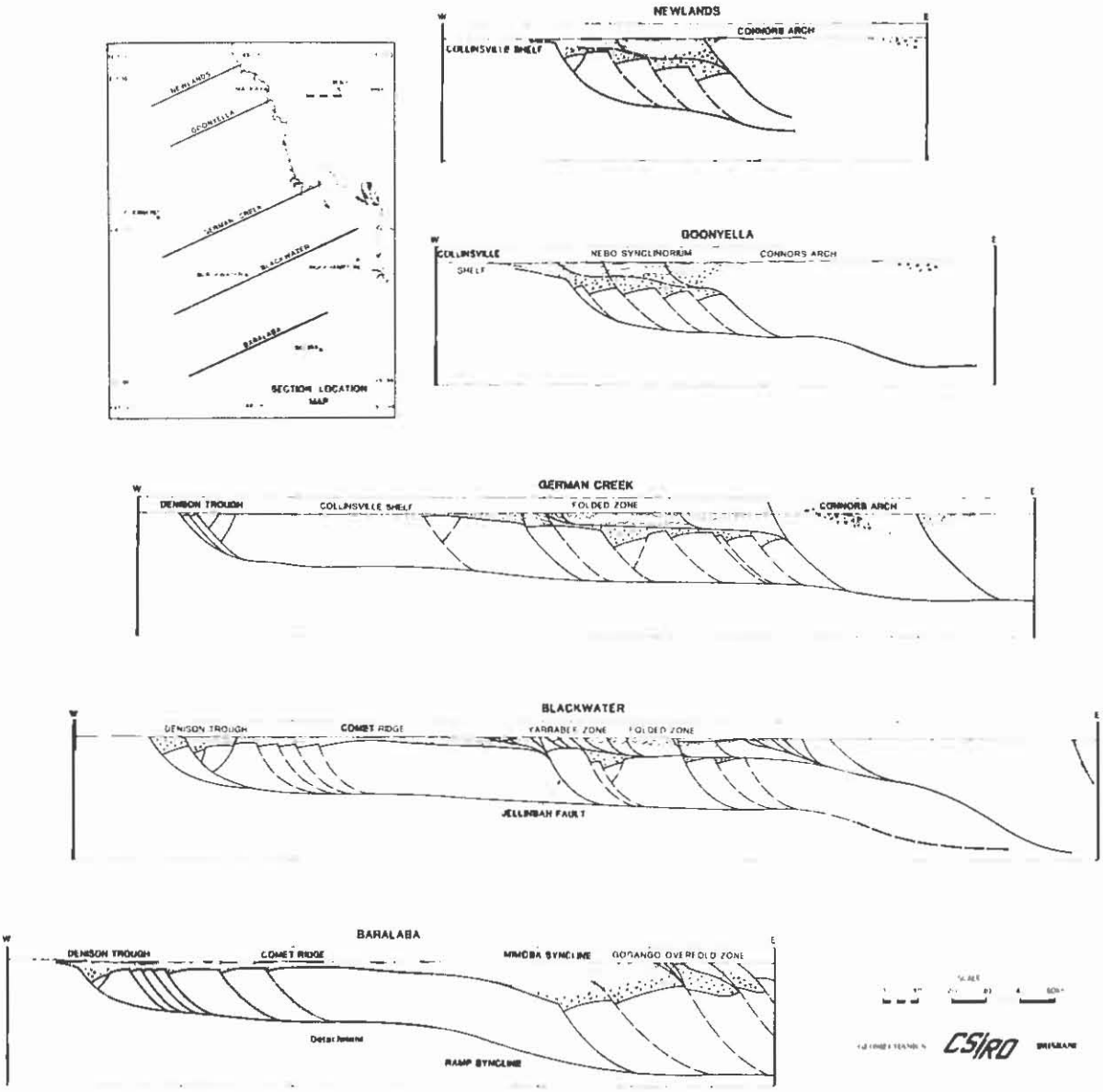

Fig. 3

An extension model has been proposed to explain the distribution of troughs and transverse domains in the Bowen Basin (Hammond 1987) Figure 2). For the Bowen Basin, domains with constant NNW-SSE features are considered to lie between transfer faults in the basement. The troughs are underlain by grabens and half grabens developed by upper crustal extension above a shallowly dipping detachment fault, composed of horizontal 'flats' and dipping ramps. It is postulated to lie at between 15 and 25 km depth. On different sides of a transfer fault, the basement can behave in very different ways, which will be reflected in the stucture and distribution of overlying basin fill sediments.

Sections illustrating the postulated basement structure beneath some of the NE-SW domains are given in Figure 3. They show how the Taroom Trough can be represented in various parts of the basin by the Minosa Syncline, Folded Zone, and the Nebo Synclinorium. Note that the geometry in the sections has been affected by Middle Triassic thrusting that reversed movement on most of the extensional faults, and thrust the eastern margin over the Taroom Trough sequence.

The trace of deep transfer faults can be seen in the basin fill cover as the transverse boundaries to domains of uniform NNW-SSE features. The intensity of disruption along this trace (referred to as corridors by Hammond 1987) varies considerably, depending on the relative movement of basement on either side of the transfer fault. Along the trace of a single transfer fault, the effects on the overlying sediments range from none to massive fault displacements and intrusions.

Between major transfer fault sites, equivalent but much smaller stuctures occur at a spacing of 10 to 20 km. The effects of these can be seen in the strike offsets in the Comet Ridge. Intrusions are located along the trace of transfer faults or in domains bounded by them (Pattison et al. 1988).

SYDNEY BASIN

If the extension model is appropriate for the Bowen Basin, it should be equally applicable to other Permian basins of eastern Australia.

The first approach was to look for evidence of NE-SW linear features that bound the gross distribution of stratigraphic units. The result of this is shown in Figure 4. There are sites where these features can be identified, and as for the Bowen basin, they line up a number of very different geological characteristics. For example the NE trend near Cessnock marks a narrowing of Triassic in the centre of the Sydney Basin, the northwestern edge of the Lochinvar Anticline, a sharp kick in Hunter Thrust and the southern end of the Gloucester Trough. The trend near Murrurundi marks the southern extent of the Jurassic, strike swings in the Permian, Hunter Thrust, Carboniferous and Devonian.

This hopeful result suggests that it is worth considering the geology between these trends, to see if it remains fairly constant within the boundaries, but makes significant changes across them. This exercise is beyond the scope of this talk, but some interesting observations can be made.

1. Major present day seismic activity is confined between NE trends passing through Newcastle and Wollongong.
2. New England granites are largely confined between NE trends passing through Werris Creek and Boggabri.

IMPLICATION FOR SYDNEY BASIN OF BOWEN BASIN UPPER CRUSTAL EXTENSION

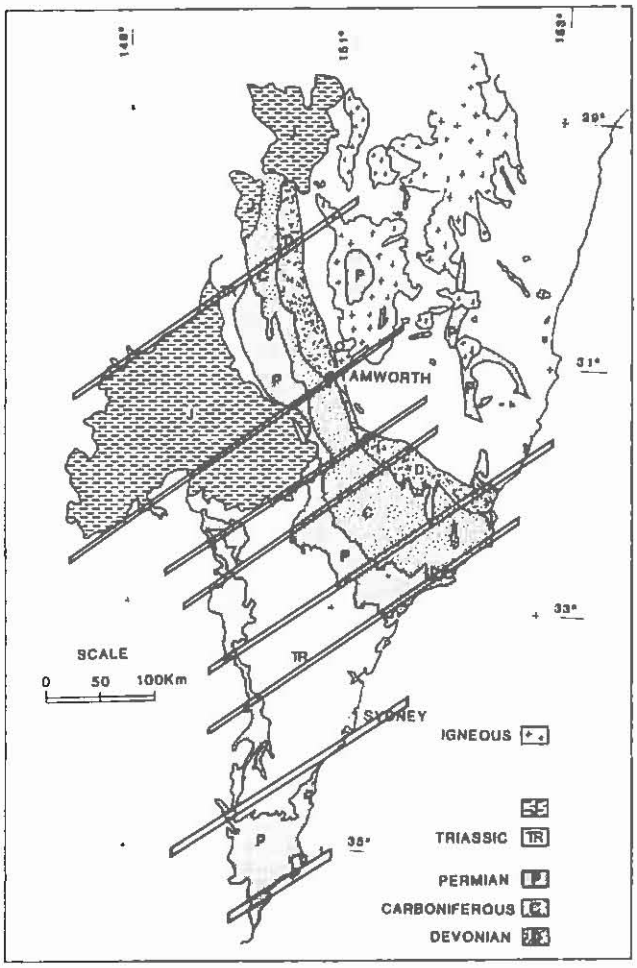

Figure 4. Geological sketch of nertheast NSW showing northeast trending geological 'coincidences'.

3. NE trends bound various intusive and extrusive locations in the Sydney Basin (see Hamilton and Pattison this volume).
4. Major Cretaceous oceanic tranforms show good agreement with onshore structures

Faults and folds within the Bowen Basin can be closely tied into the extension faults and postulated basement transfer faults. A compilation of structures in the Sydney and Gunnedah Basins was made to identify any structural domains that might be separated by NE trends (Figure 5). This was based on published maps and reports and coalfield compilations by the NSW Department of Mineral Resources. The compilation is far from complete as Mesozoic and Tertiary covers much of the basins, but some observations are possible.

1. The NE trends mark out areas where the Hunter Thrust changes its character.

2. The trend passing south of Sydney coincides with a dramatic swing in structural strike.
3. Small scale folds in the Gunnedah Basin show different orientations across the trend lines.
4. N-S structures predominate between the Sydney and Murrurundi trends, but they are warped locally by other NE trends.

A fundamental change in basin characteristics occurs along the NE trend through Murrurindi. To the north are linear basins with basal volcanics, associated further to the east with extensive underplating and granitic intrusives. This is similar in many ways to the Bowen Basin and the upper crustal extension model may apply. To the south at least to the N-E trend through Sydney, is the Sydney Basin, where N-S structures paralleling the regional trend in basement, predominate. Permian intrusives and volcanics are not common. Major grabens are not recognised, and the structures controlling sedimentation are persistent N-S normal faults. The basin in typical of lower plate crustal extension, and the trace through Murrurundi may represent the change in extension polarity from upper to lower plate extension.

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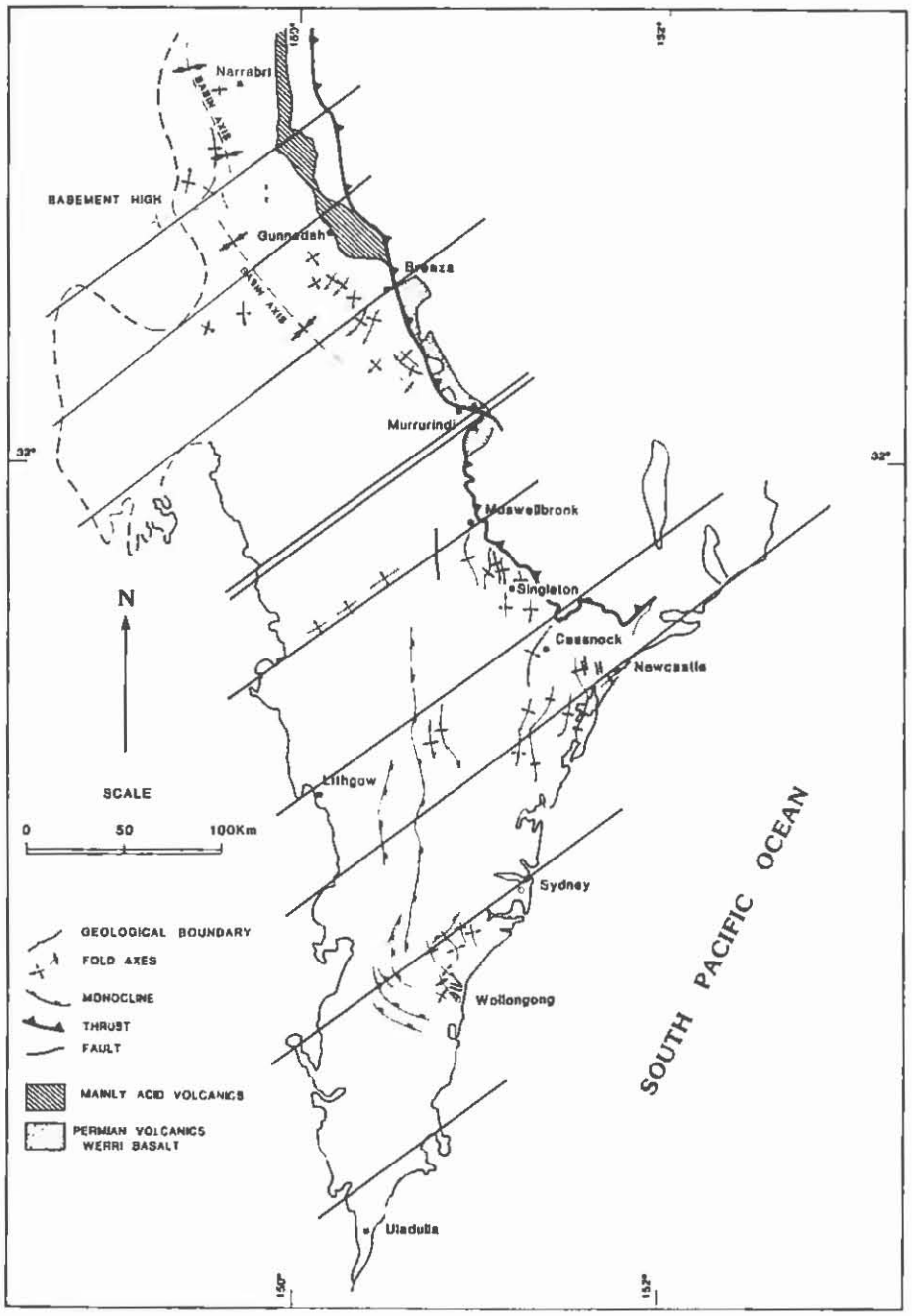

Figure 5. Geological structure and location of supected rift volcanics in the Sydney and Gunnedah Basins. The structural domains bounded by N-E trends and the effects along trends on continuous structures.

THE NATURE AND TECTONIC SIGNIFICANCE OF EARLY PERMIAN VOLCANIC ROCKS FROM THE GUNNEDAH BASIN AND THE SOUTHERN PART OF THE NEW ENGLAND FOLD BELT

E.C. Leitch[1], P.A. Morris[2] & D.S. Hamilton[3]
University of Technology, Sydney[1]
Geological Survey of Western Australia[2]
University of Sydney[3]

INTRODUCTION

Major tectonic changes occurred in northeast New South Wales during the Early Permian, with the convergent margin regime that existed during the Devonian and Carboniferous being succeeded by a regime of intraplate rifting and epi-cratonic basin development. Volcanism was widespread during the transition and extrusive rocks of this age form an important part of three lithostratigraphic associations.

Although recognition that the composition of modern volcanic rocks was closely tied to the tectonic setting in which they were erupted generated a great enthusiasm in the 1970's for using geochemical data derived from ancient lavas as a prime indicator of earlier situations, problems of alteration, inadequate knowledge of some modern eruptive environments, and preferential preservation of seemingly atypical sequences, has tempered this approach. Thus while the composition of the Early Permian volcanics is important in discussions of the tectonic transition, recognition of the change as indicated by other geological features is equally important in accounting for the variety of erupted rocks.

EARLY PERMIAN VOLCANIC ASSOCIATIONS

Three distinct Early Permian lithological associations can be recognised in northeastern New South Wales. All contain volcanic rocks and two are dominated by such material (Fig. 1). Although the age of some units has only been approximately determined it is likely that the igneous activity in each at least overlapped.

Volcanic rocks at the base of the Gunnedah Basin

Outcrops north of Gunnedah and the logs of early petroleum exploration wells revealed that at least part of the base of the Gunnedah Basin comprised Early Permian volcanic rocks. Systematic drilling in the Basin between 1976 and 1985 by the N.S.W. Department of Mineral Resources as part of a coal exploration program has greatly increased knowledge of both the nature and distribution of

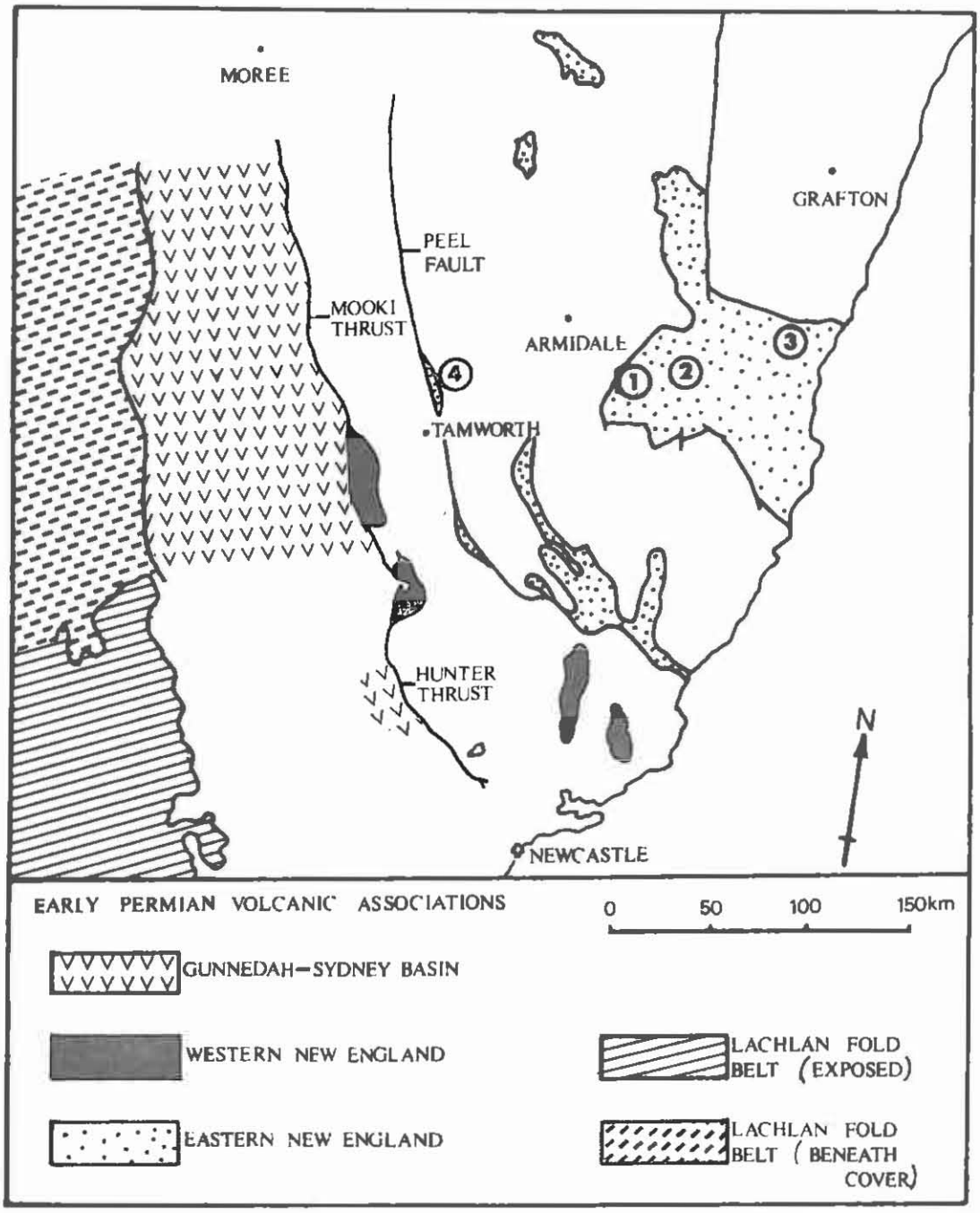

Fig. 1: Major Early Permian volcanic associations in northeastern New South Wales. Numbers in the Eastern New England association locate significant extrusive sequences: 1 - Halls Peak; 2 - Petroi; 3 McGraths Hump; 4 Willow Tree Creek.

these rocks which were penetrated by about 40 holes.

Although most of the rocks are highly altered it is clear that both silicic and mafic rocks are present. The former comprise flow banded lavas, widespread ignimbrites, breccias and ashfall tuffs that outcrop east and north of Boggabri where they are referred to as the Boggabri Volcanics. McPhie (1984) recorded sequences up to 600m thick containing rare sedimentary intercalations and a small amount of mafic volcanic material. Drill holes in the Boggabri district have shown that these rocks probably continue in the subsurface east to the Mooki Thrust and northwest towards Narrabri (Fig. 2). Silicic ignimbrites and a small amount of ash fall material also form a north-south oriented strip along the western side of the Basin, immediately east of Lachlan Fold Belt rocks that only directly underlie its western edge. These rocks are known only from the subsurface, with maximum penetration of 81.4m in DM Bulga DDH 1. The thinness of individual ash flow sheets and the absence of obvious coherent flows suggests that these rocks accumulated at a greater distance from the eruptive vent than did those around Boggabri. An essentially horizontal disposition and the prevalence of clay - carbonate alteration clearly distinguishes these rocks from silicic volcanic rocks of the Lachlan Fold Belt as intersected in DM Arrarownie DDH 1. Although their age can not be precisely determined they are considered correlatives of the Boggabri Volcanics.

Mafic igneous rocks, predominantly amygdular basalts but including dolerite (DM Howes Hill DDH 1), and possibly also silica-poor andesite, are widely distributed in the subsurface and also outcrop poorly near Gunnedah and adjacent to the Mooki Thrust northeast of Boggabri (Fig. 2). McPhie (1984) cast some doubts on the existence of extensive basaltic volcanics of Early Permian age in the Gunnedah Basin, noting the evidence for abundant later mafic igneous activity. In many of the cores we have logged,the mafic volcanics intersected become progressively more weathered up hole as the first clearly detrital Permian rocks are approached, and commonly are overlain transitionally by a colluvial phase of the Leard Formation that contains clasts of the underlying volcanic rock. These observations and the presence of Early Permian plant material in scarce sedimentary intercalations in the volcanics (Hill, 1986; Evans, 1967) demonstrate that they pre-date the sedimentary fill of the Gunnedah Basin, and we include them in the Werrie Basalt.

The mafic volcanics are particularly widespread south of Gunnedah and north and west of Narrabri. Their relationship to the Boggabri Volcanics is incompletely established. Eruptions of silicic and mafic material overlapped, but there is some evidence to suggest that the bulk of the mafic material may be younger. Part of the evidence derives from relationships in the adjacent part of the New England Fold Belt, where most mafic volcanics are slightly younger than the bulk of the silicic volcanic products (see below). In addition the lower 650m in Mid Eastern Oil's Pilliga No.1, drilled 40 km southsouthwest of Narrabri, comprised a unit of mainly mafic rocks overlying a unit of silicic volcanics.

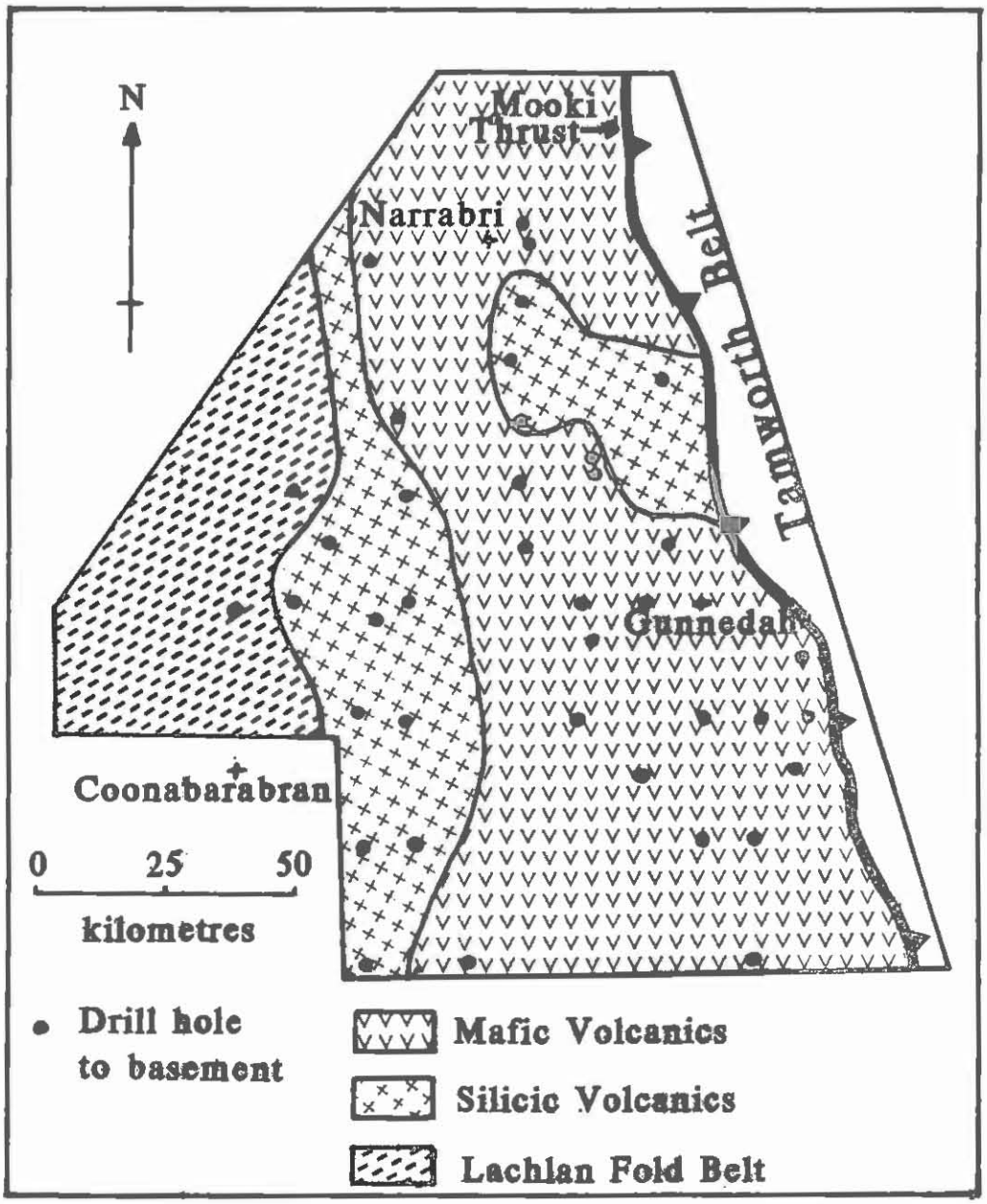

Fig. 2: Generalised map of the base of the Gunnedah Basin.

EARLY PERMIAN VOLCANICS

Volcanic rocks of western and southern New England

The presence of both mafic and silicic volcanic rocks in Lower Permian sequences in the western and southern parts of the New England Fold Belt has been widely recognised. To the north the silicic material is mainly tuffs intercalated with epiclastic volcanic-derived sediments and grouped in the Temi Formation. McPhie (1984) suggested that the tuffs were distal products of the same volcanic centres as erupted the Boggabri Volcanics. Overlying the Temi Formation are upwards of 1000m of extrusive rocks with a few sedimentary intercalations mapped as Werrie Basalt. Our investigations, principally in the North and South Temi Basins, indicate that as well as mafic rocks the Werrie Basalt includes substantial amounts of intermediate and silicic volcanics, both coherent flows and ignimbrites.

Further south the Early Permian Alum Mountain Volcanics of the Stroud-Gloucester and Myall synclines comprise up to 2000m of interstratified basaltic, andesitic and silicic volcanic rocks. Silicic material is most voluminous and includes ignimbrites and coherent lavas.

Volcanic rocks of eastern New England

Sequences of mainly redeposited clastic rocks that range up to at least 8000m thick accumulated in the rapidly subsiding Barnard Basin in eastern New England during the Early Permian. Silicic ash fall tuffs are widespread and thick piles of lavas are locally present. In contrast to the volcanics found further west there is abundant evidence that these rocks were erupted in submarine conditions; they are intercalated with marine sediments and basalts present are commonly pillowed. The two most extensive basalt lenses are at Petroi and at McGraths Hump (Fig. 1). In both areas in excess of 2000m of pillowed and massive flows, breccias, dolerite sills and rare sedimentary intercalations are present. In both cases the rocks rest conformably on underlying strata and at McGraths Hump the igneous material is overlain by a thick sedimentary succession.

At Halls Peak at least 300m of dacitic and rhyolitic volcanic rocks, including coherent flows, breccias and tuffs, occur within a thick fossiliferous earliest Permian sequence. Sedimentary rocks and bedded sulphides are interstratified with the igneous material.

PETROLOGICAL CHARACTER OF VOLCANICS

All of the Early Permian volcanic rocks are somewhat altered making petrological studies difficult. This is particularly the case for the Gunnedah Basin material where clay minerals and a range of carbonates have replaced most of the magmatic phases and as yet we are unable to determine even the range of rock types present with certainty.

Rocks from western New England are more amenable to geochemical investigation. These have frequently been described as part of a bimodal suite but data we have so far collected provide little support for this view. Taken collectively there is no indication of a scarcity of rocks of intermediate silica composition (Fig. 3), and although there are clearly geographic changes in the abundance of different rock types even when the rocks are so subdivided, no obvious bimodal character emerges. Overall the rocks are members of a typical arc association and can be considered products of a continuation of the activity widespread in western New England during the Late Carboniferous. However a comparison between the composition of Late Carboniferous and Early Permian volcanics with silica contents in excess of 68% reveals some differences: in particular K, Rb, Sr, and Ba are higher and Na, Y, Zr, and possibly Ti are lower in the former. This, together with the presence of accompanying basalts, which are not present in the Carboniferous (Wilkinson, 1971), indicates some changes in the conditions of magma generation, perhaps including an increased mantle influence in the younger rocks.

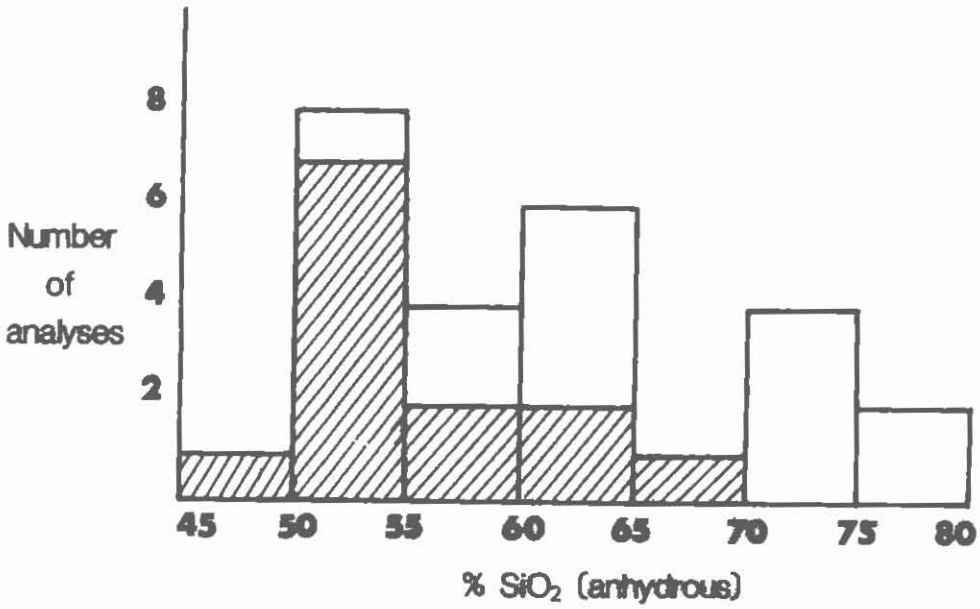

Fig. 3

Frequency distribution of various SiO_2 ranges in Early Permian Volcanic rocks of the Tamworth Belt. Shaded area comprises rocks of Werrie Basalt, unshaded rocks of Alum Mountain Volcanics.

The basic rocks from eastern New England, the magmatic characters of which have been investigated in some detail, comprise mildly alkaline within-plate basalts at Petroï and basalts with ocean floor affinities at McGraths Hump.

EARLY PERMIAN VOLCANICS

DISCUSSION

Coexistence of several distinct volcanic suites in north-eastern New South Wales during the Early Permian is a consequence of the tectonic transition that occurred at this time. Igneous rocks of convergent margin type were erupted in the western part of the New England Fold Belt and at the base of the Gunnedah Basin. There is no independent evidence for subduction in southern New England at this time and we consider that the rocks reflect the influence of lithosphere subducted beneath this area in the Carboniferous rather than indicating continued active convergence. The greater volume of intermediate and mafic rocks in the Early Permian suggests mantle material found easier egress to the surface than earlier, possibly reflecting the extensional stress field of the time.

Volcanics erupted in the Barnard Basin show no influence of subducted lithosphere. The magmatic character of the McGraths Hump basalts are consistent with extensive rifting and even limited diffuse spreading in a region of high sedimentation rate. Basaltic magma trapped at depth may have given rise to partial melting in the lower crust producing the Halls Peak silicic rocks (and perhaps the Early Permian 'S-type' granites of southern New England). A similar assemblage of geological features- basalts of ocean floor type, silicic volcanics, and a thick sequence of clastic sediments - is found in the presently active Salton Trough at the head of the Gulf of California which is a possible modern analogue of the Barnard Basin.

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A VERTICAL SEDIMENTOLOGICAL PROFILE THROUGH THE UPPER CARBONIFEROUS COAL MEASURES OF THE RUHR BASIN, GERMANY

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Introduction

At the Twentieth Newcastle Symposium two coal facies indices were presented (Diessel, 1986) which showed a close correlation with specific sedimentary environments. The examples used were taken from the Permian coal measures of Eastern Australia, i.e. they represent palaeo-environments characterised by the ascent of a deciduous Gymnosperm flora and pronounced seasonal changes between cool and moist summers and cold winters. In order to ascertain the wider applicability of the model a combined sedimentological and coal petrographical study of the Carboniferous coal measures in the Ruhr Basin of West-Germany is currently in progress. The present paper is a status report on the work carried out so far and gives an overview of the main characteristics of both coals and interseam sediments.

Methods of Investigation

The study is based on a composite section of the over three thousand metres thick Ruhr Coal Measures ranging from the Xanten Seam at the top to the Grenzsandstein (border sandstone) at the base. Stratigraphic continuity has been established for the upper 2660 m mostly by bore core logging, some measurements of outcrop sections, and, in the few portions where neither diamond drill cores nor outcrops were available, existing bore logs have been made use of. The continuous section covers the stratigraphic subgroups of (from top to bottom) Lembeck, Dorsten, Horst, Essen, Bochum, and Witten. The Sprockhöfel Subgroup at the base of the Ruhr Coal Measures has, so far, been measured only in isolated outcrops and will not be dealt with here.

The following lithofacies have been distinguished in order of increasing coarseness: 1. coal and shaly coal, 2. coaly shale, 3. shale, 4. silt-laminated shale, 5. shale-laminated siltstone, 6. siltstone, 7. sand-laminated siltstone, 8. silt-laminated sandstone, 9. fine sandstone, 10. medium sandstone, 11. coarse

sandstone, 12. conglomeratic sandstone, 13. granule conglomerate, and 14. pebble conglomerate. In the statistical analysis these have been combined to: coal, shale, siltstone, sandstone, and conglomerate.

The Ruhr Coal Measures are rich in plant and animal fossils. Both have been used in the palaeo-environmental interpretation in addition to the information gained from the lithofacies study. The following settings are distinguished: peatland deposits, subaqueous sediments, delta front sediments, flood plain sediments, and fluvial sediments.

The subaqueous sediments include all finegrained deposits in which the relevant fossils have been found. These include worm burrows, feeding traces, fish remains, Ostracods, Foraminifera, Pelicypods, Goniatites, and Brachiopods. Although the many species and genera of the above have been varyingly interpreted as ranging from fresh water to marine in origin they have been grouped together because of the probability that the organisms existed in a continuous biotope characterised by lateral gradation in salinity, rather than in separate environments.

The delta front sediments have been separated from the subaqueous sediments on the basis of increasing coarseness, the occurrence of splay deposits, a decreasing number and variety of animal fossils, and an increasing admixture of plant fossils. It is thought that only the thick sequences following substantial marine transgressions represent prograding delta slopes with frontal splays whereas the much larger number of small upward coarsening units,also grouped as delta fronts, were formed as infillings of interdistributary bays or estuaries. Some of these sediments contain distinctly tidal features, such as bimodal cross bedding, tidal bundles, and starved ripples.

The flood plain sediments are fine grained, laminated, and in some places rippled. They contain only plant fossils,coal and numerous rooted horizons. The latter have also been found at the tops of some delta front and subaqueous sediments where they probably represent delta plain environments which are grouped with the flood plain deposits when they do not display subaqueous features. Also included are levee bank deposits which are commonly strongly rooted, wedge-shaped, rippled, slumped, and consist of laminated silt- and fine sandstone.

Fluvial deposits consist mostly of sandstones,often with a basal conglomerate lag overlying an erosional contact. Drift wood is common, as well as, large scale cross bedding. In some cases bundled fore-sets and concentrations of shell fragments have been observed which could point to a tidal influence.

In most cases, individual strata have been logged to a minimum thickness of 5 cm which has resulted in an accumulation of a large amount of information. In order to present the results in a comprehensible manner a point count of 1 m interval spacing has been carried out along the 2660 m thick section, i.e. lithofacies and palaeo-environmental interpretation was recorded for each 1 m interval point.Higher orders of generalisations were obtained by calculating percentages for larger intervals (mostly 50 m) and by establishing moving averages.

Coal petrographic work is still in progress and no detailed account of the results is available at this stage,except for some general features based on results supplied by the Ruhrkohle AG.

Results and Discussion

The average lithological composition of the Ruhr Coal Measures is given below in comparison with the palaeo-environmental interpretation:

Lithology		Palaeo-environments	
* Coal	= 4.9 %	* Peatland deposits	= 4.9 %
* Shale	= 35.5 %	* Subaqueous deposits	= 15.1 %
* Siltstone	= 21.0	* Delta front deposits	= 16.4 %
* Sandstone	= 34.2 %	* Flood plain deposits	= 31.9 %
* Conglomerate	= 4.4 %	* Fluvial deposits	= 31.7 %

The comparison shows that a consideration of lithofacies alone would yield only limited information about the origin of the respective sediments. Naturally, the proportion of coal in the section would be interpreted as peatland deposits and the two percentages would match. Likewise, a large proportion of sandstone and probably all of the conglomerate would have been generated in fluvial environments. However, the percentage of deposits judged to be fluvial in origin is actually smaller than the combined amounts of sandstone and conglomerate, the balance of 6.9 % being contained in delta front and, to a lesser degree, flood plain sediments. Without the additional information provided, by sedimentary structures, textures and fossils both siltstone and shale could not be allocated to any specific depositional environment because they are shared in almost equal proportions by subaqueous, delta front and flood plain environments alike. An illustration of the varying degrees of correlation between lithofacies (as sand/shale ratio) and palaeo-environmental interpretation is given in Figure 1.

Figure 2 shows the percentage variation of the five palaeo-environments along the measured section. The section can be divided into three parts: The

upper 1000 m are dominated by fluvial and flood plain sediments. Stratigraphically downward these are followed by 500 m of predominantly marine, subaqueous and delta front deposits whereas the lower 1000 m consist of frequent alternations of marine and terrestrial deposits. The depositional instability of the lower portion of the section is also demonstrated by its smaller coal content. Coal (i.e. peat) formation seems to peak before and after the large marine transgression following the formation of the Katharina Seam,although during the marine interval few peatlands were retained.

As is to be expected, high proportions of delta front sediments are associated with, and commonly preceded by subaqueous deposits. The largest concentrations of both coincide with well-known marine horizons which in Figure 2 (lower diagram) have been named, usually in reference to the coal seams they overly. Some of these marine beds (e.g. Finefrau, Katharina, Domina, Ägir) have been correlated across Europe and may represent world-wide sea-level changes. A likewise close association exists between fluvial and flood plain deposits which carry a coal content close to the average for the whole coal measures.

A high proportion of any particular lithotype can be based on either a large number of thin rock bodies or a small number of very large ones. A comparison between the thickness distribution of the three examples illustrated in Figure 3 and their relative proportion shown in Figure 2 indicates that more often than not, high percentages are based on the occurrence of thick sediments. This is particularly true for fluvial sandstones and marine shales, but the relationship is weaker when comparing the proportion and thickness distribution of coal seams. Some isolated thick seams occur in the lower part of the section without being associated with a high coal percentage,whereas the relatively high proportion of coal following the Katharina transgression between 1000 and 1600 m is due mainly to the occurrence of a large number of thin lower delta plain seams.

An overview of the composition of coal seams (floats at 1.5 density) in terms of maceral groups is given in Figure 4 (lower diagram).The vitrinite content is mostly high and increases at the expense of liptinite in the lower portion of the section due to the rise in coal rank with stratigraphic depth (middle diagram). Although the inertinite content is moderate to low,some of the particularly high values are associated with marine deposits. Similar examples are found in Australia, e.g. Bayswater Seam. There is a steady upward decline in the inertinite content in the river and flood plain dominated part of the section which is probably similar in coal character and palaeo-environmental setting to the Lambton Subgroup of the Newcastle Coal Measures.

Finally, Figure 4 displays a diagram of the distribution of sulphur (db) in the coal seams. By Australian standards, the level is generally high and, as

expected, rises sharply in coals overlain by marine strata. However, completely unexpected and, as yet, unexplained is the very large proportion of sulphur formed in the river and flood plain dominated coals near the top of the section.

Acknowledgements

The field work in connection with the project reported here was carried out while the author was in receipt of a scholarship from the German Academic Exchange Service which is gratefully acknowledged. During this time the author was in residence at the Department of Geology of the Ruhr Universität Bochum for which special thanks are due to Prof. H. Füchtbauer. The following Post- graduate students assisted in the field, in core sheds and in many other ways: R. Conze, E. David, F. David, T. Kraft, and K. Strehlau. Bore logs,coal analyses, access to bore cores, coal samples, and generous hospitality were given by the Ruhrkohle AG, for which the following are thanked: Dr. W Pfisterer, H. Schniggenfittig, and H. Sawitzki. The author is also indebted to Dr. A. Rabitz for drawing his attention to relevant outcrops.

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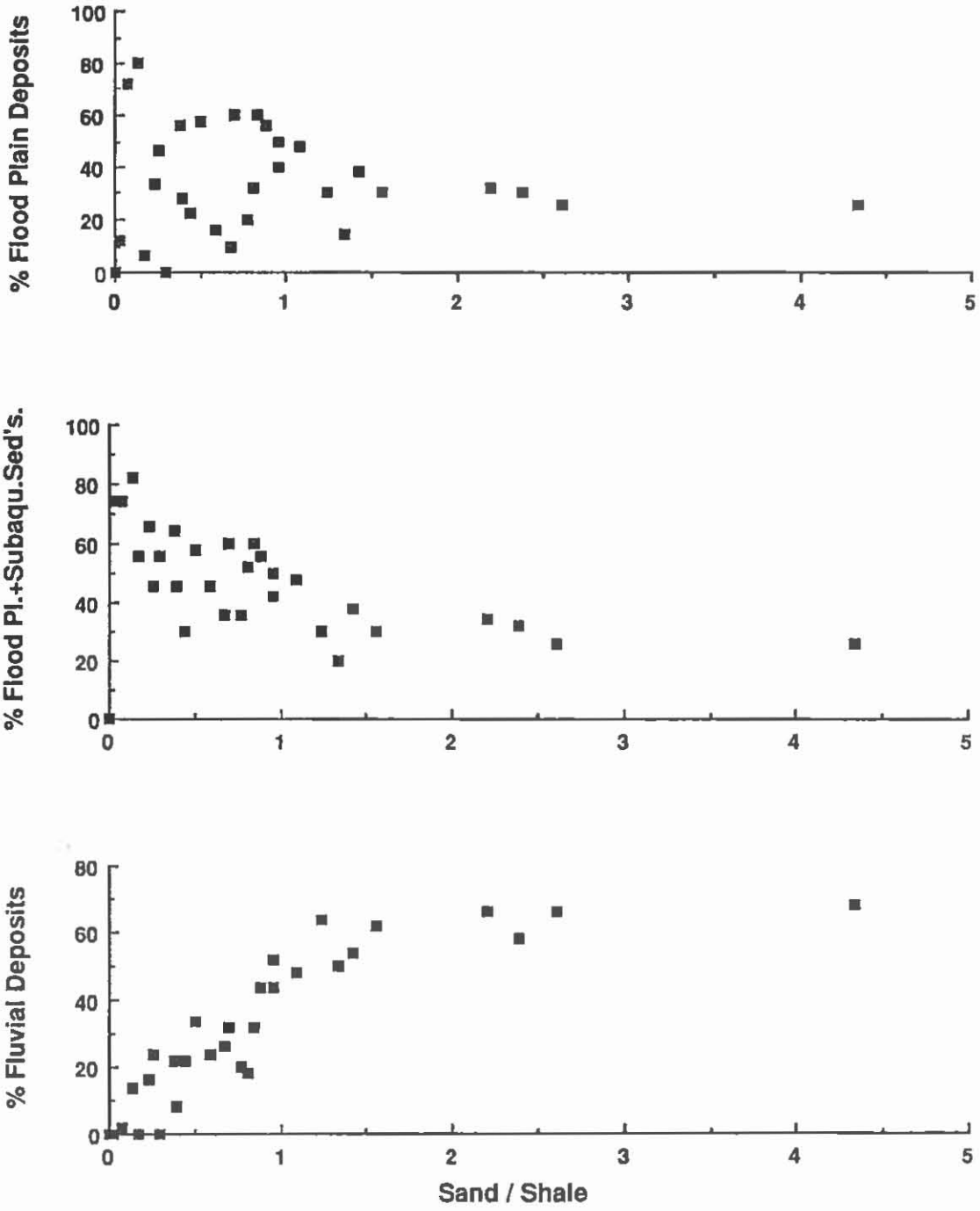

Figure 1. Three diagrams illustrating the relationship between lithofacies and palaeo-environmental interpretation. Top: Flood Plain deposits versus sand/shale ratio. Centre: Flood plain plus subaqueous deposits versus sand/shale ratio. Bottom: Fluvial deposits versus sand/shale ratio.

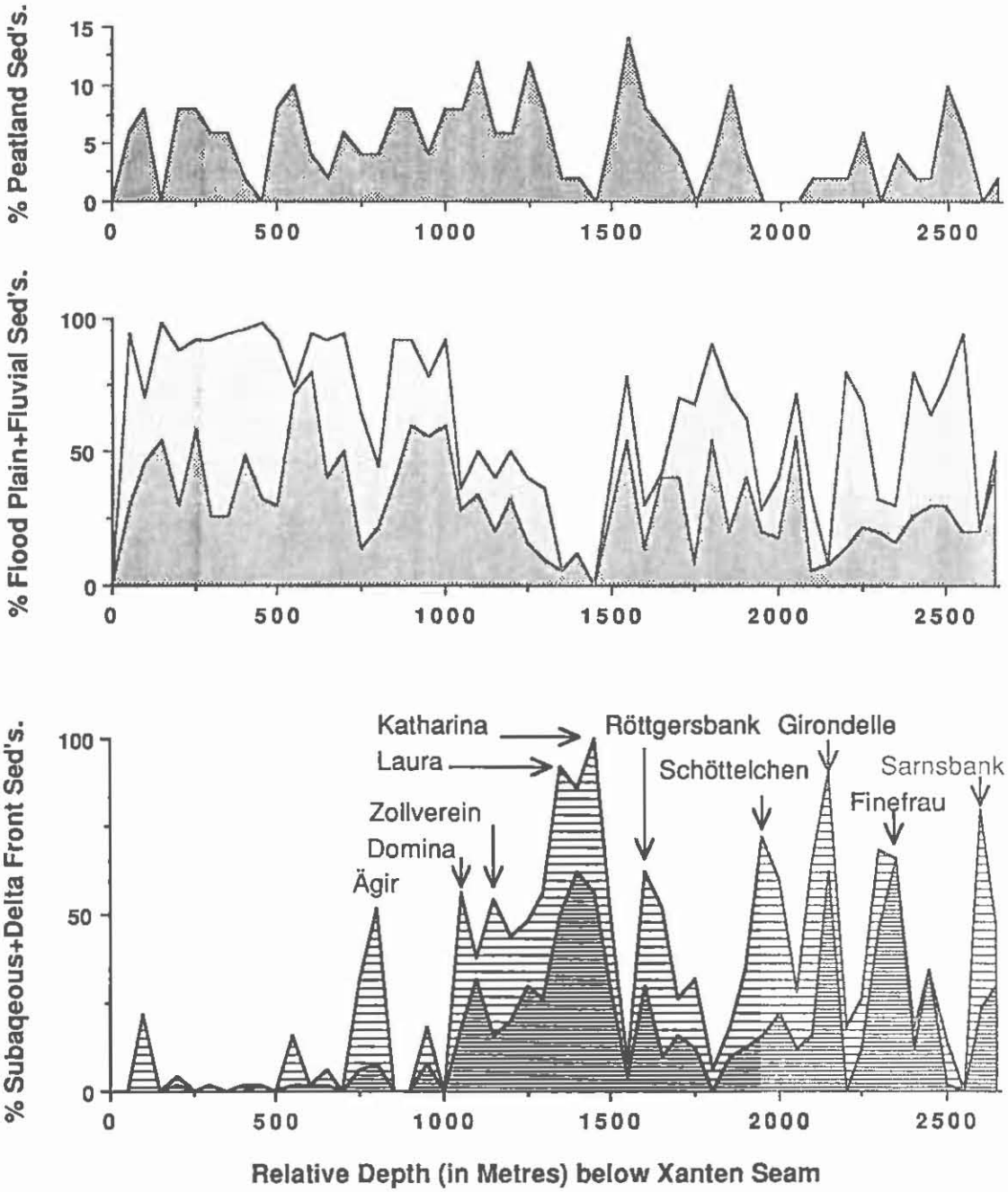

Figure 2. Three diagrams illustrating the distribution (in percent) of the five palaeo-environments distinguished in the paper through the measured section. Top: Peatland deposits. Centre: Flood plain (lower portion) and fluvial (upper portion) deposits. Bottom: Subaqueous (lower portion) and delta front (upper portion) deposits. Major marine transgressions are identified in the bottom diagram.

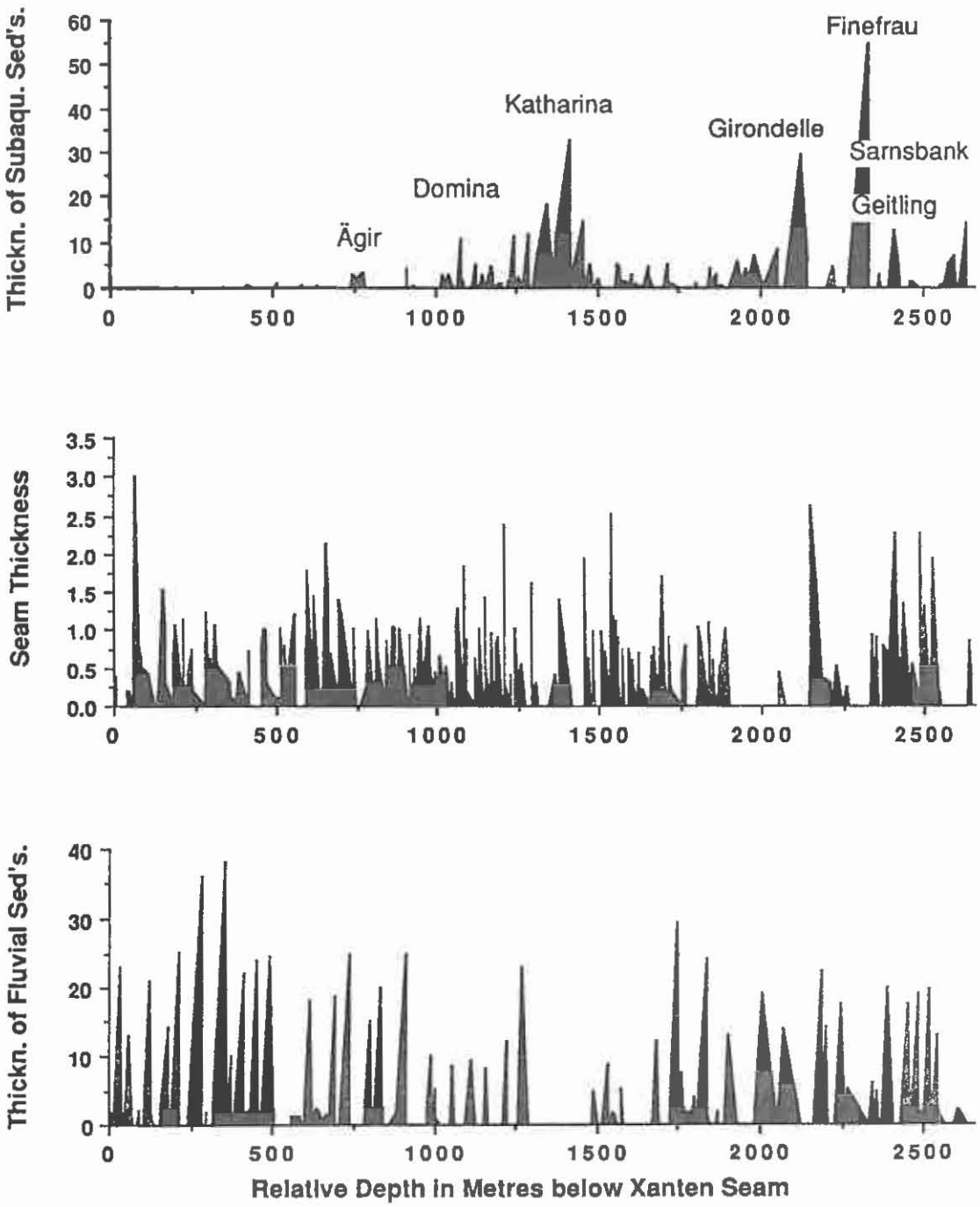

Figure 3. Three diagrams illustrating the spacing and thickness of some important marker horizons (plus palaeo-environmental interpretation through the stratigraphic section. Top: Subaqueous deposits with named marine transgressions. Centre: Coal seams. Bottom: Fluvial sand bodies with a minimum thickness of 1m.

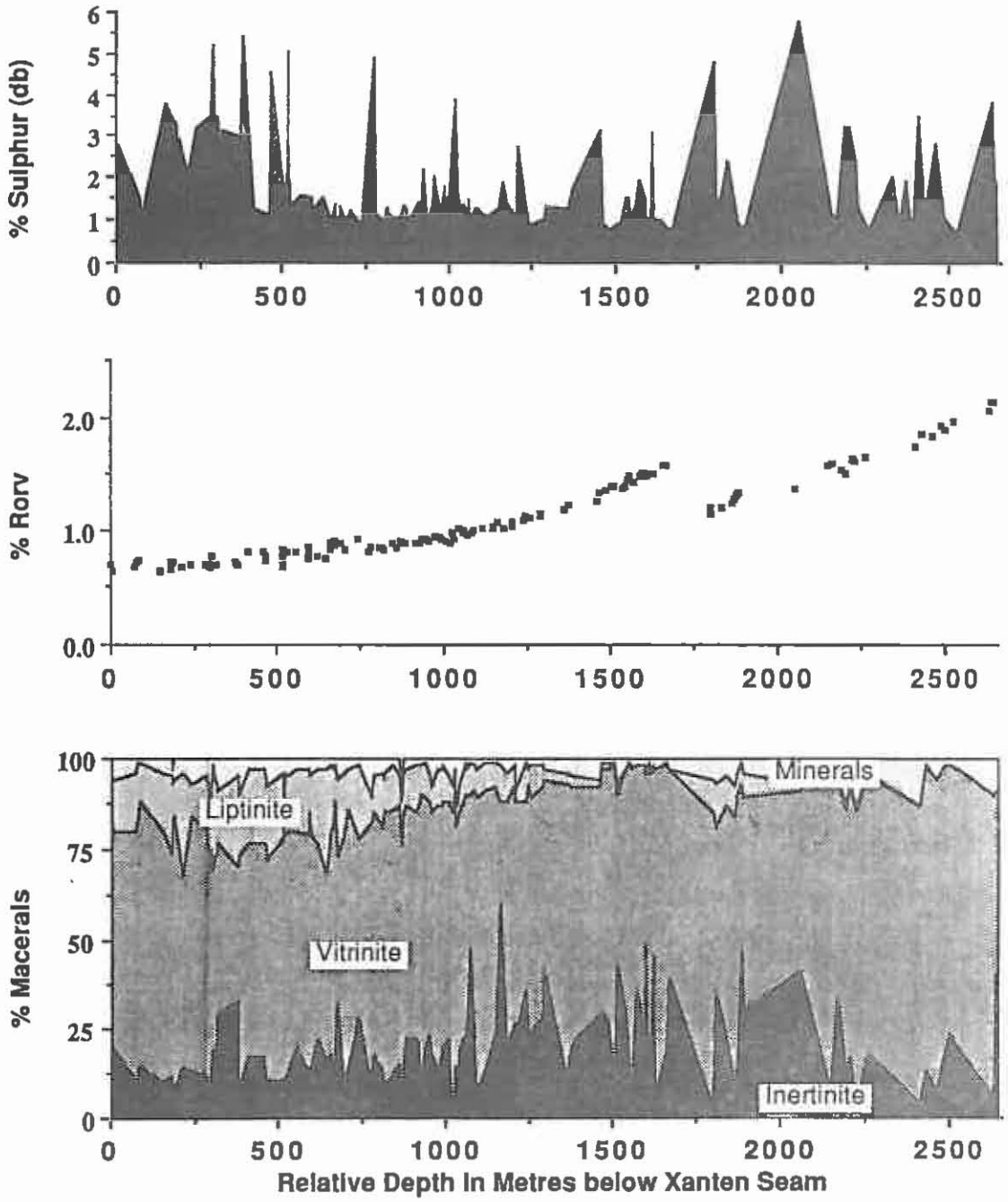

Figure 4. Three diagrams illustrating the distribution of coal type and rank through the measured stratigraphic section. Top: The proportion of sulphur (in percent db) in washed coal (floats at 1.5 density). Centre: Random reflectance of vitrinite in oil (the break is due to switching drill holes). Bottom: Maceral group distribution.

GEOLOGY, GEOLOGISTS AND THIS NATION'S FUTURE

J.L. McIntosh
Executive Director
Australian Mining Industry Council

My address today is aimed at trying to put into perspective my views of geological education, the role of geologists in the community and the benefits that geology and mining have for the Australian community.

As a student of geology, it never occurred to me that there would ever be competition for resources that did not take into account scientific assessment of all the ecological, biological and geological facts. As the Executive Director of the Australian Mining Industry Council, I am finding now that in many cases the geological value of land is being completely ignored in what is becoming an obsessive interest in the much shorter term perspective of its environmental or ecological value.

As a geologist in the field, I at no time considered damaging, spoiling or causing any harm to the ecology in the process of geological mapping and exploration.

It is almost a tragedy now to note that recent studies demonstrate that some 50 per cent of the coal fields of the Sydney Basin are no longer available to exploitation because of conflicting land use claims. I would be almost sure that most of that sterilisation has occurred because of a one-sided approach.

Where has the geological argument been? Where have the geologists been in the debate?

There is hope that geologists and the other geoscience professionals will have an increasingly loud voice in matters which affect them. The Geoscience Awareness Program, which grew out of a meeting at the 1987 ANZAAS conference in Townsville last August, is aimed at trying to overcome what was perceived as the national weakness of geoscience.

The Geoscience Awareness Program's aims, which AMIC wholly endorses and which, in fact, parallel some of AMIC's own programs, are:

- To ensure a balanced science education for all children in Australia, including an adequate level of geoscience in the school curricula.

- To increase public awareness of geoscience.

- To encourage equal opportunity in geoscience learning.

- To improve the level of funding for geoscience teaching and research.

Geologists are employed in a wide range of vocations and specialities. A recent AMIC survey of about 58 member companies showed geologists in 202 locations. The industry employed about 1000 geologists, although with a turnover of 20 per cent a year.

My understanding from the Australian Geological Society is that it has 3343 members in 1988. It is often quoted that there are perhaps twice as many geologists as there are members of the Geological Society.

It is interesting to note that 20 years ago, in 1967, the Society had a membership of only 1388 members. Of course, not all geologists are employed directly in the mining industry. Many are employed by Federal and State government instrumentalities and statutory authorities or work in universities, schools, or as consultants.

They work in a wide range of specialities and in many localities, and because of this have a wide representation in the community.

The question is, though, where are the geologists in the land-use debate?

How many geologists here have ever sat and thought about the sterilisation of economic reserves, about the bars to access to areas for exploration now being promoted by a wide range of conservation groups?

How many have taken the time to look at the conservation claims and to make an alternative statement from personal experience?

How many are concerned that exploration and mining activities are deleterious to the environment and have made some positive attempt to clean up the industry, and hence the industry's image?

By so doing, geologists are likely to further the cause of geology and their own profession.

A simple local example of community groups, many with conflicting interests, working together to overcome a problem is the Hunter Valley Coal Chain Council.

This is a body set up by the trade unions, employers and government to help move coal more smoothly from the mine to the ship. This is a complex operation involving 42 coal mines, 70 coal types, 31 trade unions, both rail and road transport, three coal loaders and a port operator.

When you look at the list of members of the Hunter Valley Coal Chain Council you will see that the explorers for coal, and the finders of the coal - those whose very being depends on successful exploitation of this valuable resource, are not being represented.

Perhaps, in the initial stages, when the coal chain was set up primarily to resolve industrial disputes, the inclusion of explorationists was not appropriate. However, it may be that in the longer term concerned geologists have an important role in having a voice in which areas are available for coal exploration and exploitation. As a result they may have a significant effect on their own well being.

Mining in Australia is a very major part of our economic activity. Mining's share of the gross domestic product has increased from 3.4 per cent in 1969 to 8 per cent in 1986/87. By comparison, agriculture, forestry, fishing and hunting contributed 4.5 per cent and manufacturing 17.4 per cent to GDP in 1984/85. Mining exports including mineral processing, make up over 40 per cent of total Australian exports in the current period, making mineral exports an important component of Australian trade. The export orientation of the mining sector has of course been steadily increasing and Australia is now a major world supplier of black coal, iron ore, copper, silver, lead, zinc, manganese, mineral sands, bauxite and uranium. The composition of value added by the mining sector has also changed with significant increases over recent years and mining capital expenditure is currently running at almost 20 per cent of total capital expenditure.

Employment Australia-wide is of the order of 200,000 people.

The value of minerals produced from New South Wales in 1985 was in excess of $3 billion. Coal accounted for the majority, of course, with a total of more than $2 billion in coal export dollars for the State in 1986/87.

Employment in the Sydney Basin in the coal and various minerals industries is in the order of 30,000 people, so that in the most indirect sense it is reasonable to assume that almost 200,000 people are directly affected by the future and the fortunes of the minerals industry in this area.

Mine production in copper, zinc, silver, gold has steadily increased over the last ten years from New South Wales and decreased in lead, tin, antimony, ilmenite, rutile and zircon.

The reduction in production of ilmenite, rutile and zircon has been dramatic since 1977, with production levels now about half the level of ten years ago. Mining firms face a complex array of government charges, regulations and controls. Total royalties paid by mining establishments to governments in 1985/86 were $941 million, a massive increase from the $585 million in 1983/84. Apart from the allocation of exploration permits and mining leases and the royalties, governments are involved in affecting the industry through activities involving foreign investment controls, coastal shipping, transport regulations, international commodity agreements, export controls, infrastructure provision, tariffs and tax concessions, export duties and inland restriction activities through national parks or Aboriginal land rights.

Let me now turn back to the question of restrictions on mining and the sterilisation of mineral reserves, and I will speak now of mineral sands.

The numbers which I have indicate that in this area on the east coast of Australia, about $3 billion worth of mineral sands have been locked away in the name of protection of the environment.

Most beaches on Australia's east coast have at some stage or another been mined. The highly desirable tourist beaches at Redhead, Port Macquarie, Forster and Surfers Paradise have been extensively mined and yet people go to them and enjoy them without understanding that mining has the potential to clean up the black sand from the beaches, improve the stability of the dunes and provide the urgently needed recreation reserves. The mining industry has to tell this story to the community.

Mining is being severely hampered by a range of activities - which governments have imposed in the land use area and also in the economic area.

A recent study, undertaken by the Industries Assistance Commission and published in January of this year, estimated the effective and nominal rates of assistance for black coal mining. It concluded that if the effective rates of assistance for black coal mining were calculated on the same basis as for the Commission's estimates of assistance to agriculture, then the measured rates would be in the order of minus five per cent for open cut mining and minus two per cent for underground mining. This is against a background of assistance to agriculture of 12 per cent and to manufacturing at 20 per cent.

Some of these regulatory impediments are major issues in which geologists, as members of the wider community and not only the geological community, have a key stake.

GEOLOGY, GEOLOGISTS AND THIS NATION'S FUTURE

In the urban areas of Australia there is a strong call for more preservation of larger and larger areas. The area put aside for national parks in this country has increased steadily in recent years. When this Sydney Basin conference has its annual meeting 22 years from now, in 2010, there probably will be no Sydney Basin area left for development - on current trends it will all be a national park.

How that fits with the population I am not sure, but it is clear that the issue of mining in national parks or mining adjacent to national parks has to be addressed, and that the present confrontationist attitude cannot continue.

The solution lies in adopting the National Conservation Strategy, something which all of us can take part in.

The National Conservation Strategy was drawn up by a consensus at a national conference in Canberra in June, 1983. This conference was attended by more than 150 delegates who all were closely concerned with the conservation or development of Australia's resources.

That consensus provided all Australians with a blueprint for the future of Australia's natural resources and environment. It means that all parties made concessions, the mining industry not the least of them. But it was something which we in the industry saw as necessary. Our own direct interests sometimes blinker us to other people's points of view, and the National Conservation Strategy provided a way to satisfy everyone's requirements for the overall good of all Australians. We walked away from that conference feeling as if a major milestone had been passed.

How sad has been the reality.

The conservation movement - or the activist elements of it - seem to ignore the Strategy in the quest for more and more, and their refusal to acknowledge that others have just as legitimate an interest in a balance between conservation and development.

The Federal Government, in what appears an increasingly unseemly chase for votes, ignores common sense to pander to the conservationists' demands. The situation is becoming so ludicrous that AMIC recently put out a statement calling on the Government to pause and take a look at the whole question of land management in Australia, to get some cohesion into its policies.

One of the factors which has led to such a deterioration in the conservation/development debate is the ability of the conservation activists to appeal to the emotions of the public. Conservation of the environment, like motherhood, is a good thing. We all agree. To oppose it is a bad thing. So opponents of the more outrageous demands of the conservationists have a major hurdle to their credibility before they can even begin to put a sensible argument.

This is an area where you, the geoscience professionals, have a role to play, and a role which I think you should play more actively. The National Conservation Strategy is worthy of your professional support and indeed of active promotion because it will inject some balance into the debate.

The voices of the industry's professionals, speaking together and speaking as individuals, would be powerful and respected support for the National Conservation Strategy, and I urge you to make your voices heard.

What I would like to leave with you today is the view that you personally have a role to stand up, and to be proactive in the role of developing a strategy to allow further geological research, further resource utilisation and further community involvement. It is no longer wise to be apathetic. If this Sydney Basin is to be studied further, then the problem of access to the resource has also to be solved.

COMPARISON OF THE STYLE OF IGNEOUS INTRUSIONS IN THE SYDNEY AND BOWEN BASINS

L. Hamilton & C. Pattison

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A remarkable feature of the Sydney-Gunnedah and Bowen Basins is the incidence of intrusions in them. Compared with other basins they contain a high proportion of intrusive igneous rock. This also applies to other Permian Gondwanan basins but generally not to coal basins elsewhere in the world. It has been estimated that a minimum of 5,000 million tonnes of coal have been lost from the Bowen Basin through the action of igneous intrusions (Hamilton 1985). Although less has been lost from the Sydney-Gunnedah Basin a minimun of at least 500mill. tonnes could be expected. It is possible that 0.1% or more of the Sydney Basin constitutes igneous rock. A considerably higher figure can be expected for the Bowen Basin, where laterally extensive sills commonly comprise 10 to 33% of stratigraphic drilling sections. Additionally, the presence of large plutonic bodies (Bundarra and Mt Gotthardt granodiorites) and isolated sills of up to 1,000m thick, further emphasise the large input of igneous material.

Consistent with other overseas Permian Gondwanaland coal basins, doleritic dykes are widespread in both the Bowen and Sydney Basins, but are especially numerous within the latter. Although dykes in the Bowen Basin have greater compositional variation, a common feature to both basins is the occurrence of dyke swarms, notably around German Creek and Eastern Creek (Bowen Basin) and Sydney, Newcastle and Mittagong (Sydney Basin). Three predominant dyke orientations prevail in the Bowen Basin, one trending east-northeast (central area), one north-north east (northern area) and the other north-west (throughout). Dykes within the Sydney Basin are predominantly north (Southern Coalfield), northwest (Newcastle area) and west-northwest orientated (Sydney and Southern Coalfield), and reflect the predominant trend of structures within each locality.

STYLE OF IGNEOUS INTRUSION IN THE SYDNEY AND BOWEN BASIN

The Sydney Basin hosts numerous volcanic necks of basic composition, particularly in the Central and Western Coalfields. Rare intermediate intrusions are known (e.g. microsyenite at Bowral) and other examples border on the ultramafic (e.g. lamprophyre, camptonite and monchiquite at Wollongong). However, counterparts in the Bowen Basin are primarily basaltic, with minor rhyolitic examples, and are generally confined along, or adjacent to, the basin margin. Furthermore, the Bowen Basin lacks the breccia pipes so typical of the Sydney Basin. Triassic cover in the Sydney Basin largely obscures any relationship that may exist between structure and location of volcanic necks. Volcanic plugs in the Bowen Basin are generally aligned in a north-northwest to northwest direction and are most likely related to crustal extension during the Late Cretaceous to Tertiary opening of the Coral Sea.

Sills are common to both regions with compositions in the Bowen Basin ranging from gabbro (isolated) to latite/trachyte/syenite (western and northern areas) to granodiorite (north-eastern area). The presence of acid intrusions can be considered anomalous with respect to Permian coal basins in general. Sills in the Sydney Basin display little regional variation, consisting essentially of dolerites, with lesser syenites.

Regarding age, intrusions in the Sydney Basin occurred over a long time span with an episodic nature having maximun activity around 250 Ma, 180 Ma and 50 Ma before the present. Nonetheless, the majority of sills, plugs and dykes are assigned to the Jurassic or Cretaceous. Cainozoic volcanics, predominantly extrusive, are also widespread and are distinguished into the Nerriga, Mittagong, Airlie and Abercrombie Provinces. Although age determinations are limited in the Bowen Basin they consistently indicate an Early Cretaceous emplacement age for sills and plutonic bodies (Webb & McDougall 1968; S.Marshalsea pers. comm. 1987). Volcanic plugs and associated dykes are Tertiary in age and belong to the Springsure, North Clermont, South Clermont or Nebo volcanic provinces.

Neither basin has been uniformly intruded. The distribution of sills in the Bowen Basin is confined to three distinct zones (Fig. 1), the most extensive stretching from the basin apex to Goonyella in the west and Bundarra in the east. The central zone extends from Dysart to German Creek, and the southern zone is confined to the Baralaba-Moura area. North and north-northwest trending structures (e.g. thrust faults) are considered to be the avenues for magma migration, with zone boundaries

defined by deep seated transverse structres or 'corridors' (Pattison et al 1988; McLennan 1988). These 'corridors' define major morphological and structural boundaries within, and adjacent to, the basin (See Mallett, Hammond & Sullivan, this volume). They also delineate the loci of all plutonic bodies and are considered to originate from an Early Permian extensional phase (Ziolkowski & Taylor 1985; Hammond & Mallett 1988). They also appear to link with the transform faults of the Coral Sea Basin and can be considered akin to the transfer faults of Gibbs (1984).

Sills in the Sydney-Gunnedah Basin also appear to be confined to broad zones, with high concentrations in the Upper Hunter Valley, Gunnedah and Wollongong-Mittagong areas. Considering the composite nature of the basins studied and the similarity of intrusive style and pattern of distribution, the applicability of a unified gross structural model is tempting. Although poorly defined, morpho-tectonic boundaries can be identified that correspond with areas of known sill occurrences, breccia pipe distributions and the sites of extrusive volcanics (Fig. 1). These are particularly highlighted by the elongate Liverpool Range volcanics, a significant 'kink' in the Hunter-Mooki Thrust, a major swing in the basin boundary and alignment with off-shore transform faults. Other boundaries are less clearly defined but can be postulated on the basis of the observed distribution of intrusions. Each boundary identified corresponds with other geological discontinuities or anomalies and are considered here to represent basement structure that influenced the thermal history of the basin.

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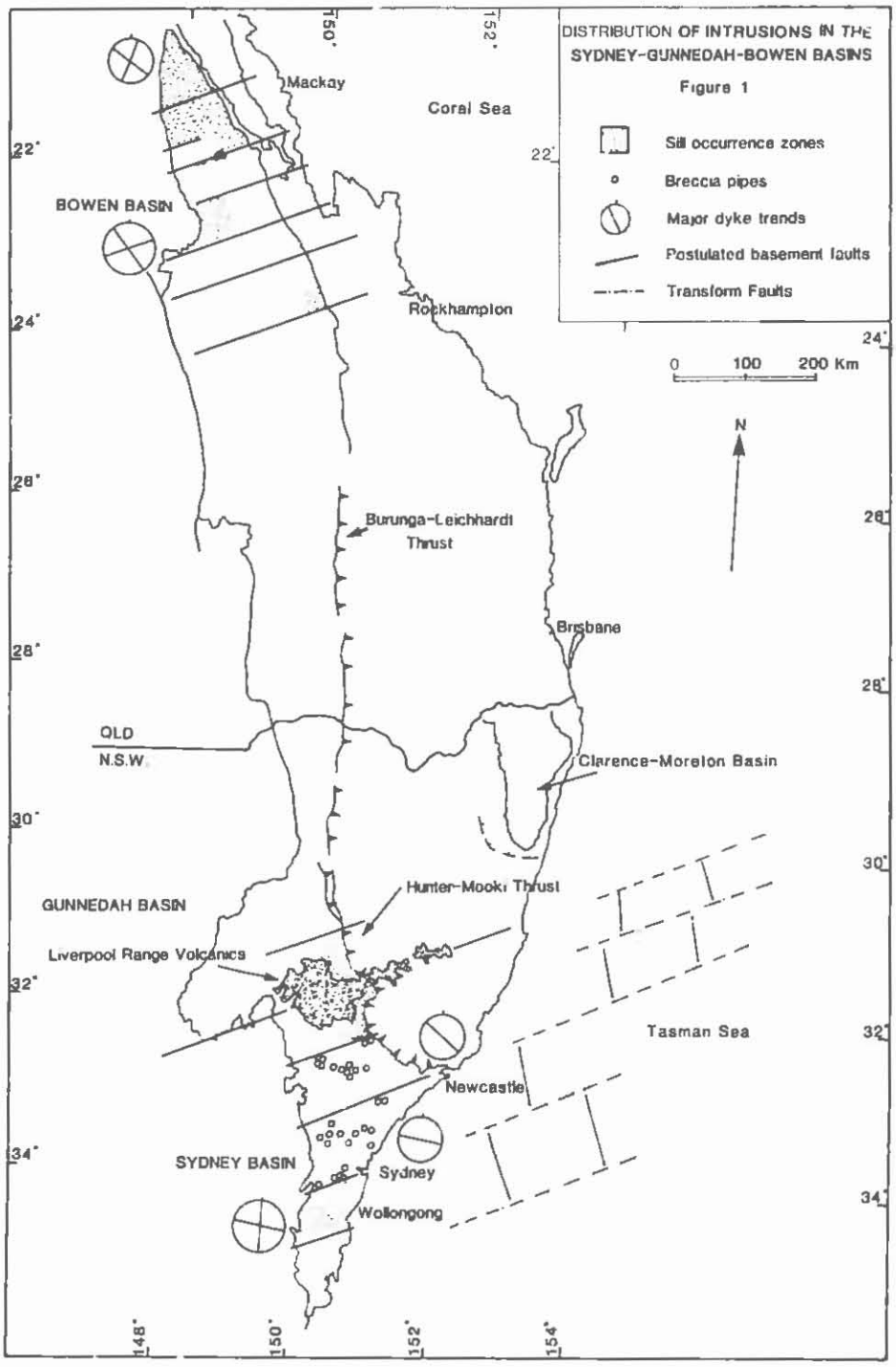


PALAEOCHANNEL DEVELOPMENT IN THE MOON ISLAND BEACH SUB-GROUP OF THE NEWCASTLE COAL MEASURES

M. Bocking, M. Howes & C. Weber
Electricity Commission of NSW

The recognition of a number of isochronous horizons in the Moon Island Beach Subgroup has permitted the charting of individual palaeochannels that form the laterally extensive coarse clastic members of the subgroup. This has lead to a model for the interrelated formation of both the coal and fluvial clastic members of the Newcastle Coal Measures.

BACKGROUND

The Electricity Commission of New South Wales has an ongoing committment to a better understanding of the geology of the Newcastle Coalfield that contributes to the successful operation of the ten collieries that supply three major power stations. The compilation of subsurface data from a number of collieries and exploration areas on the central coast over the last six years has revealed graphic patterns of sediment distribution that form part of the Permian geography of eastern Australia. Over 600 boreholes have been drilled in the area under study in the last 100 years but it was not until 1982 that the drilling of boreholes in western Authorisation 255 revealed that a massive palaeochannel existed just west of Wyong at a depth of 500 meters. This palaeochannel, which is confined by the coalesced Wallarah and Great Northern seams, now forms a conglomeratic unit up to 100 meters thick and some five kilometers wide, that is known to extend some 60 kilometers from Ourimbah to Teralba (Bocking and Howes 1986).

The existence of such channels in the Newcastle Coalfield was suggested by Branagan and Johnson (1970) but lack of borehole information and detailed stratigraphy prevented positive mapping of these features which they reported as being "lenses or irregular sheets with several discontinuous masses sometimes occuring on the one stratigraphic horizon". The Belmont Conglomerate identified by them, and recognised as having been derived from streams flowing from the north and east, is in fact the northernmost tip of the Bolton Point Conglomerate described later in this paper.

Crapp and Nolan (1975) mapped the distribution of the major seams of the Newcastle Coal Measures. Their work therefore identified the peat swamps and a number of channel margins and intersections were

inferred. Nesteroff and Crapp (1971) had earlier detailed seam relationships in the south western Lake Macquarie area, providing the first well defined pieces in the Moon Island Beach puzzle.

RELATIONSHIPS WITH EXISTING STRATIGRAPHY

The description of the large channel west of Wyong, which extends stratigraphically from the Awaba Tuff to an horizon midway through the Wallarah Coal, proved somewhat difficult in terms of the existing stratigraphic nomenclature. Essentially the channel forms part of the Teralba Conglomerate that in many places overlies the Great Northern Coal. However the channel also in places underlies the Great Northern seam and extends upwards beyond the Booragul Tuff, the Buff Point Coal, the Mannering Park Tuff and terminates midway through the Toukley Coal which is the lower part of the Wallarah Coal. The next formally named clastic unit is the Karignan Conglomerate which overlies the Wallarah Coal.

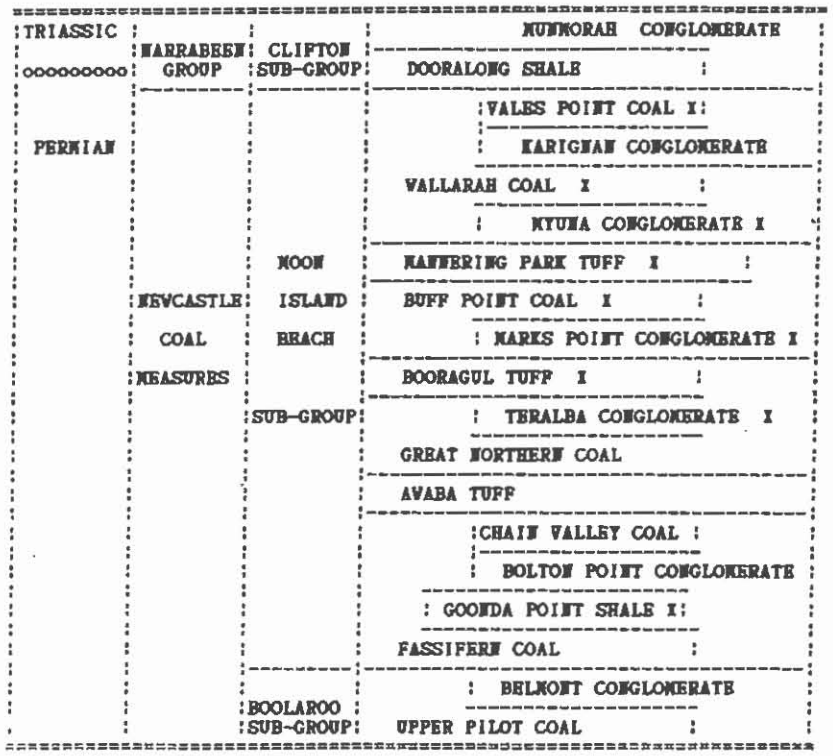
Some of the relationships the authors are suggesting are shown in Figure 1 and compared with the existing terminology. (The Standing Committee is presently reviewing the stratigraphic nomenclature for the Newcastle Coal Measures.) Fundamentally, this interpretation of the geological sequence is that of a process-oriented model, which recognises the dynamic relationship of coal forming swamps and major river channels. Each stratigraphic unit is recognised as the end result of a major landscape component (e.g. river channel, swamp, lake or volcanic ash deposit) or a collection of minor ones (e.g. overbank, splay and reworked sediments and palaeosols).A number of these units, by virtue of their extent, persistence and identifiability could have geological 'formation' status. Others which are less persistent or are contained within formations could be 'members'.

The present distribution of these geological formations and members is the end result of a number of processes, the most important of which are channel migration, switching and sediment compaction. The channel migration, which may be due to regional tilting, is facilitated by the compaction of the sediments, especially coal.

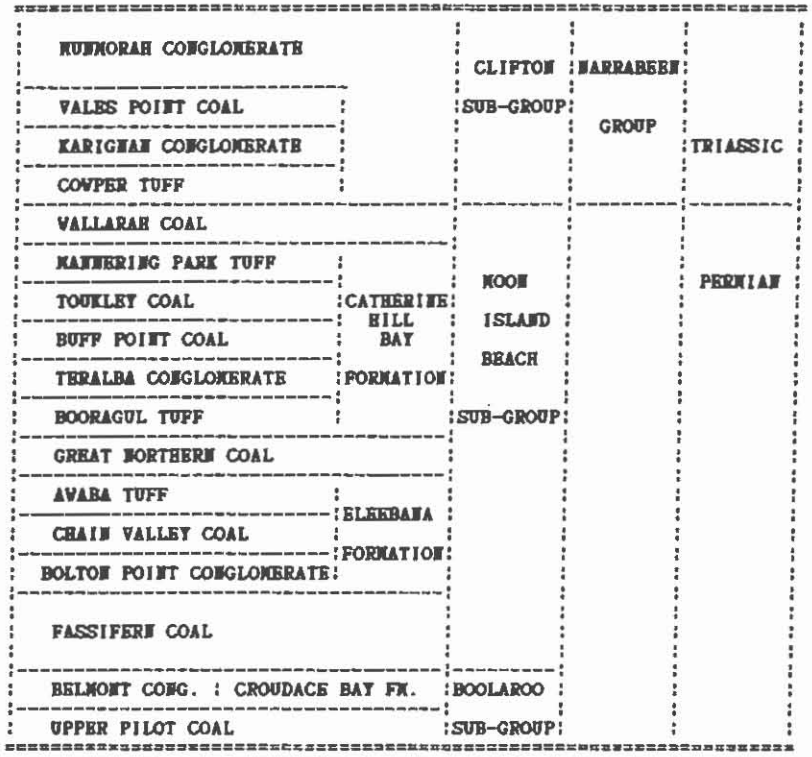
An understanding of these processes leads to a logical interpretation of the patterns and mechanisms of such important features as the continuity, quality and thickness of coal seams; the presence of 'claystone' roof strata, their origin, variability and mode of occurrence; the magnitude and composition of seam interburden ; and the existence and extent of major sedimentary structures.

THE MODEL

The Moon Island Beach Subgroup is now recognised as having been the upper part of one continuous longlasting peat swamp that is preserved as a stack of laterally extensive coal seams interlayered with varying proportions of laterally extensive claystone units of tuffaceous origin. This stack contains, relatively much thicker, conglomerate units which are the sedimentary remains of rather transient channels that migrated and switched across the peat swamps, with which they co-existed, to form relatively extensive conglomerate and



Suggested Relationships.



Stratigraphic Nomenclature.

Figure 1. Relationship of model considered in this paper to existing stratigraphy. "X" denotes informally named units or changes to the limits of existing units.

sandstone sheets up to 20 kilometers across and typically 35-50 meters thick.

THE MECHANISMS

Channel migration was the principal mechanism operating in the placement of gravel deposits in the Moon Island Beach peat swamp. It is well illustrated in Figure 2 where a cross section is taken across the Moon Island Beach Subgroup from Martinsville to Wangi Point. It is apparent that each channel has migrated east or west from its precursor as the sequence of sediments has accumulated. The only layer to break the migration is the Awaba Tuff.

A channel switch appears to have occurred in that a conglomerate member appears above the Booragul Tuff but no migration path is apparent suggesting the channel switched it's course further upstream by breaking it's banks, possibly in response to it's channel being clogged by the Booragul Tuff.

It appears channel migration may have been a function of sediment load, peat compaction and the relative density differences of peat and gravel. Regional tilting could have contributed to the timing and rate of channel migration. It is thus probable that channel migration happened regularly if not continuously.

This is illustrated in the southern part of Myuna Colliery where the Great Northern seam has progressively less coal above the channel on it's northern flank and progressively more coal beneath the channel on it's southern flank. The channel has migrated from north to south a distance two kilometers during the time interval it took to form the Great Northern seam. (A period equivalent to 3.5 meters of coal forming may equate to 25,000 years.)

Channel switching was less common but can be recognised in the geological record and was at times related to the blanketing of both channels and coal swamps by tuffaceous material derived from major volcanic eruptions. This suggests that either a choking of channels by surplus sediment or tectonic responses to the volcanism may have led to the channel switching.

Many observations have led the authors to believe that channel migration and switching do not lead to significant erosion of the coal. However there is commonly a notable absence of overbank sediments between the conglomerate and underlying coal which suggests that some erosion of the overbank sediments may have taken place. Certainly the tuffaceous claystone deposits are commonly eroded.

The sediment sequences revealed by borehole intersections of the Bolton Point Conglomerate are consistent with those of a braided (bedload) fluvial channel system. (Weber et al. in prep.)

One potentially useful relationship is becoming apparent. It would appear stone roof rolls proliferate in areas of coal seams which are overlain by migrating channel margins, suggesting that the rolls may be due to the uneven episodic loading of the peat as the channel margin migrated laterally across the peat swamp. The authors would welcome any observations in this regard.

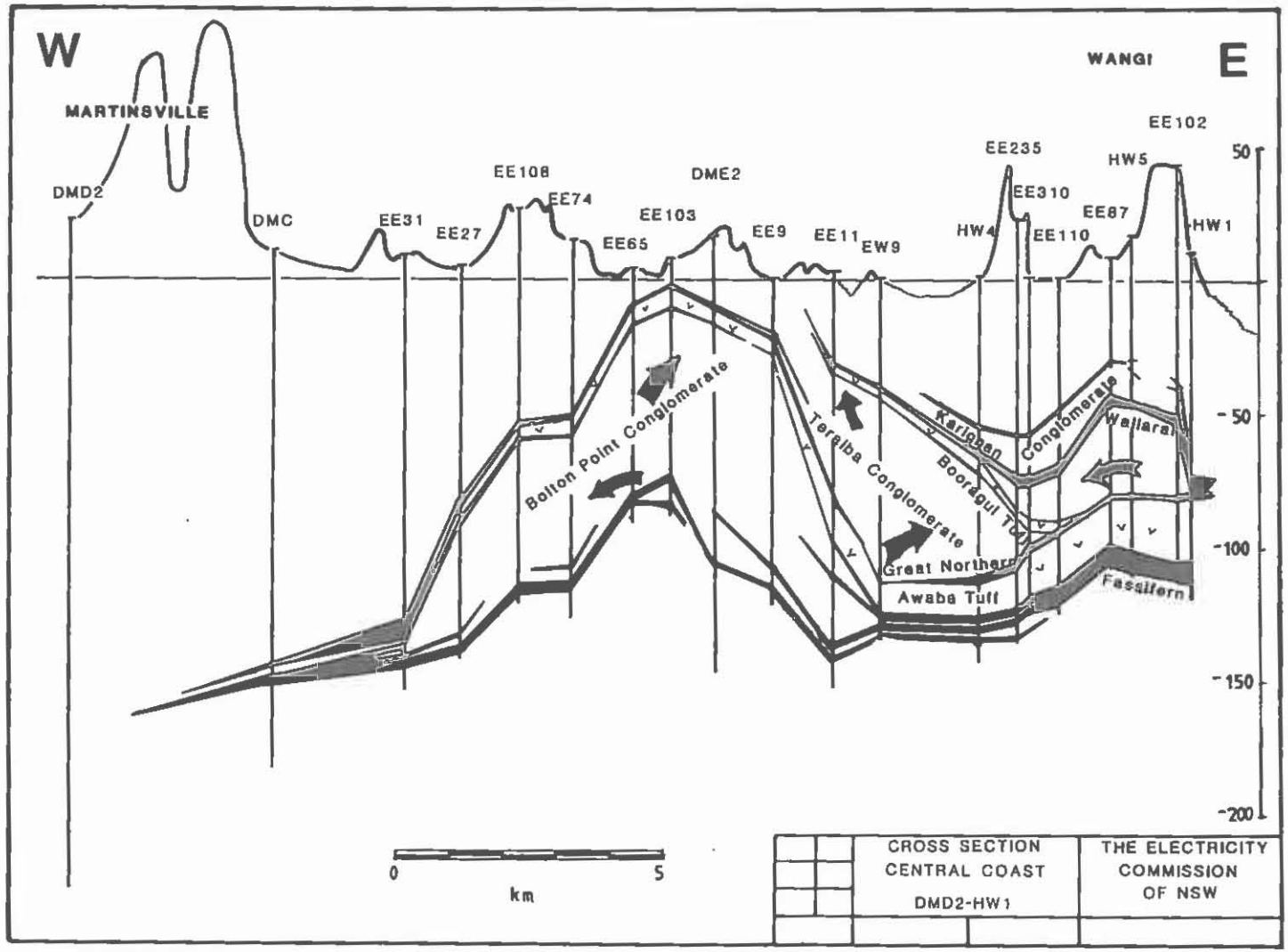


Figure 2. Moon Island Beach Subgroup cross section. Arrows show direction of interpreted channel migration.

PALAEOCHANNEL DEVELOPMENT

The work of Bocking and Howes (1986) identified the early Teralba palaeochannel where the Teralba Conglomerate lies directly above the Awaba Tuff, and indicated the extent of the sheet like development of Teralba Conglomerate created by the migration and switching of the Teralba channel. The individual components of the Teralba Conglomerate are yet to be mapped in detail. However, the authors have examined the Bolton Point Conglomerate in some detail to explain variations in the development of the Fassifern seam which is presently targetted for extensive mining as a source of power station feedstock. (Weber et al., in prep.)

The Fassifern seam has a persistent brightness profile containing a number of claystone bands that renders even relatively small parts of the seam recognisable over considerable distances. The seam contains a number of splits that can be traced with certainty. Careful mapping of these relatively unimportant members has permitted the mechanisms responsible for the economic developments of the seam to be unravelled. The lowermost portion of the seam is rather difficult to distinguish from the top of the underlying Upper Pilot Coal but above that horizon at least five discrete palaeochannels can be charted, where conglomerate exists in place of coal at a particular time. Eight time periods of Fassifern time can be recognised (FT_{1-8}) within the seam. The time periods have generally been identified between tuffaceous claystone bands which are believed to be isochronous horizons. As a result of channel migration and switching, the five channel deposits are now interlinked to form sheets of braided stream deposits. Some of the ancient watercourses are relatively straight as is shown in Figure 3, but others are more sinuous. The channels commonly reach a thickness of 35 meters before they migrate or switch and channel widths of two to five kilometers are typical.

The earliest channel mapped, that shows with certainty some downstream variation of sediment type,is shown on Figure 3 and extends for more than 40 kilometers from northern Lake Macquarie to Wyong. This channel existed in 'middle Fassifern time' or FT_{2-3}. The sediments preserved in the channel grade downstream from pebble-sized metamorphic and volcanic clasts in the confined part of the channel to a sandy alluvial braid plain with local meander belts. To the southwest the sand facies merges with interdistributary bay (or lake) deposits consisting of fine grained thinly bedded sediments.

This channel to bay development actually overlies established peat and channel sequences and so may indicate a temporary regression of the shoreline. Stratigraphically higher in the same channel the sediments coarsen indicating the gravel facies prograded downstream. It is apparent from the direction of grading and the location of the gravel facies that a second channel,which originated further east, also emptied into the bay west of Wyong. This confirms Diessel's suggestion (1980) that the Bolton Point Conglomerate was derived from the east as well as from the New England Fold Belt to the north. The subsequent channels in the Bolton Point and Teralba Conglomerate Formations were produced by the migration and switching of this same river system.

Palaeochannel Development.

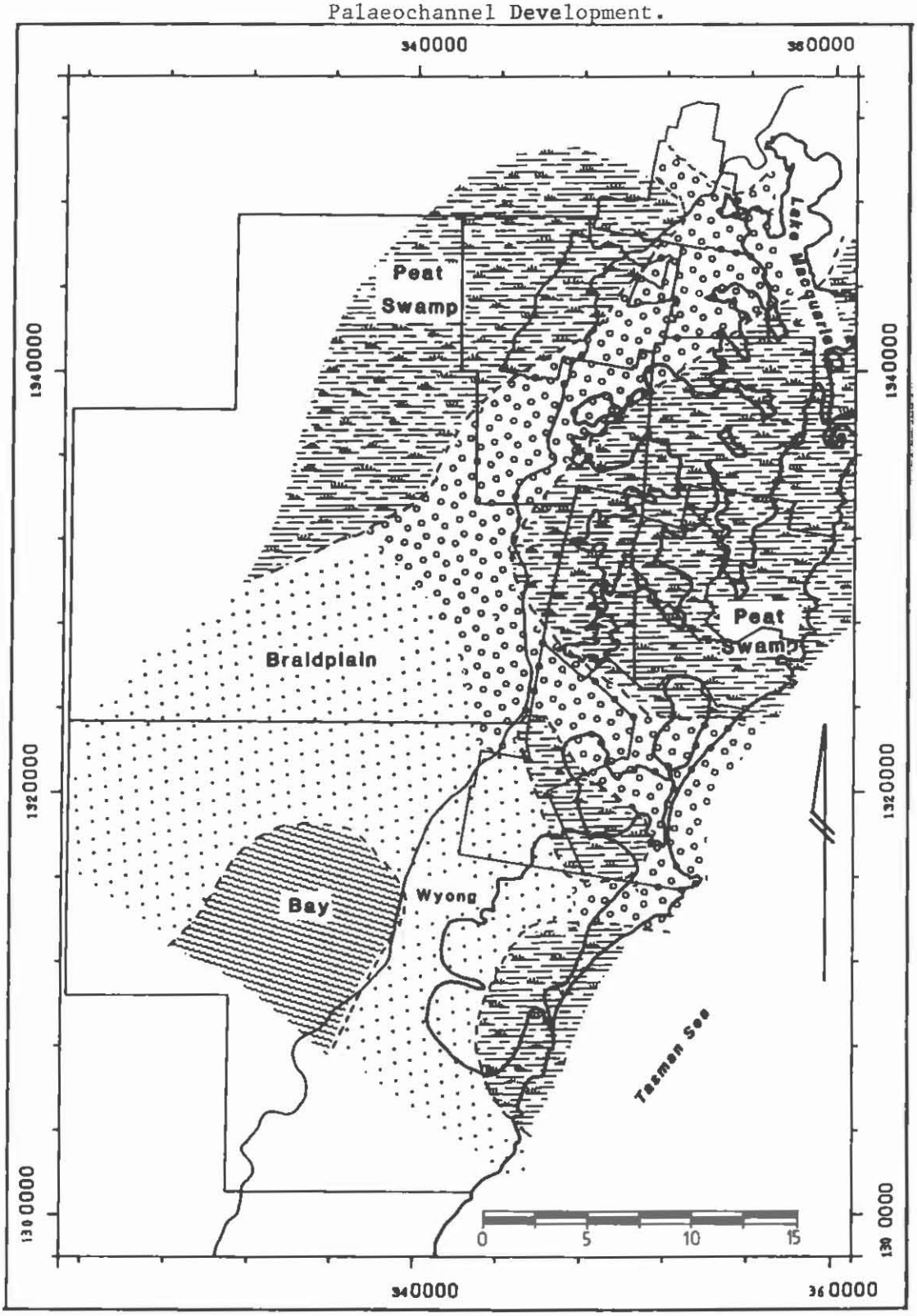


Figure 3. Palaeogeographic Reconstruction of the Bolton Point channels during mid Fassifern seam time FT_{2-3}.

PEAT SWAMP DEVELOPMENT

The thickest coal accumulations occurred in those areas where the peat was not inundated by the gravelly river deposits. How could the peat remain swampy and yet remain isolated from the adjacent sediment laden watercourse?

A possible explanation is that the swamps were elevated with respect to the river channels and that the rivers only rarely flooded the coal forming swamps. The difference in elevation could well be explained by the significant difference in the relative density of gravel (about 2.5) and peat (about 1.2). The river gravels would then rest entrenched within the peat. Any buildup of gravel approaching the peat surface would cause the adjacent peat to compact and the collapse of the channel onto the peat.

A modern equivalent of the proposed model is hard to find. Most modern day swamps exist at or near river level and are either periodically inundated by flood waters or are just lower than the prevailing water table. Some modern rivers do resemble the entrenched migrating model proposed. The Rakaia River in New Zealand is certainly entrenched and the straight sided, braided channel is migrating to the north leaving behind a sheet of gravel deposits to be progressively vegetated. (It achieves this migration by erosion rather than relative density advantages.) The channels in the middle reaches of the Brahamaputra River in northeast India are of similar dimensions to those found in the Moon Island Beach Subgroup. The Brahamaputra River drains the Himalayas which may be of similar size to the New England Volcanic Arch. Indeed the entire Assam valley in eastern India is of similar size to the Sydney Basin. Swamps do exist in the Assam, but precise information on their height above the river channel is not yet available. It is apparent, however, that the swampy conditions are due in part to the annual inundation by 2.5 meters of rain in the summer monsoon rather than just the proximity to the main channel of the river. In fact the elephant grass swamps of Kaziranga National Park, which borders the river, dry off so much during the winter that the park management can employ controlled burning. Following the summer monsoon, normal swamp conditions prevail.

It is hoped this paper has presented an acceptable alternative to the often proposed alluvial fan model for the Newcastle Coal Measures. The grand scale of river development has been obscured till now by the restricted view of the coal measures exposed,along the coast and in underground mines, and by the immense scale of the sedimentary features waiting to be discovered.

ACKNOWLEDGEMENT

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DIAGENESIS OF THE SANDSTONES IN THE NARRABEEN GROUP

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INTRODUCTION

Despite the importance of diagenesis in petroleum exploration, the diagenesis of the Narrabeen Group sandstones has not been systematically studied. The main aim of this study is to discuss the potential of the Narrabeen Group sandstones as reservoir rocks from the point of view of diagenesis. It is hoped that such a study may supply some guidance for the future petroleum exploration in the Sydney Basin.

DATA BASE AND METHODOLOGY

Eighty nine sandstone samples were used in the study. They were selected from four fully-cored bore holes - Weromba 2, Cobbitty 3, Campbelltown 5 and 2, which are located in a west-east section in the southwest part of the Sydney Basin. The sampling was based on detailed 1:100 geological logging of the four wells and taken from every significant change of lithology. The sampling interval is about 15 - 20 metres. In Weromba 2 and Cobbitty 3, however, it is reduced to as little as 1 metre in more porous sandstone intervals. The sampled sandstones vary from very fine sandstones to very coarse sandstones. Each sample was subjected to thin section, SEM/EDX and XRD studies, and porosity and permeability measurements.

SANDSTONE CEMENTS

There are three principal cements in the sandstones studied: carbonates, clay minerals and silica. In addition, a minor amount of pyrite and analcime was found. Carbonates consist of calcite, siderite, and ankerite. Of them, siderite is the most common. The authigenic clay minerals include kaolinite, illite and mixed-layer illite/smectite with kaolinite being the most common.

CALCITE: Non-ferroan low Mg calcite was found in two of the samples studied. It occurs in two forms in terms of crystal size: tiny equant euhedral crystals with a size of 4 - 6 microns and small uniform rhombohedral crystals with a size of 10 - 20 microns (Pl. 1). Both forms coat detrital grain surfaces. Ferroan calcite is

present as pore-filling, large subhedral to euhedral crystals.

ANKERITE: Ankerite cements are present as pore filling crystals, (Pl. 2) and are usually either subhedral or euhedral. The crystal size varies from 150 microns to 2mm.

SIDERITE is the most common carbonate cement in the sandstones and was found in most of the samples studied. The siderite can be divided into two types: small uniform rhombohedral crystals with a size of 10 - 20 microns (Pl. 2) and large crystals with a size much greater than 20 microns. The large siderite crystals are very common.

KAOLINITE is the most common clay mineral in the samples. The pseudo-hexagonal kaolinite flakes are about 10 microns across and they occur either as an individual flake or as stacked flakes.

ILLITE: SEM study shows that illite occurs within the altered volcanic rock fragments (Pl. 3) or on carbonate crystals.

MIXED-LAYER ILLITE/SMECTITE is a less common authigenic clay mineral in the sandstones. It is present as a thin coating layer on detrital grain surfaces or cement lining pore spaces.

SILICA CEMENT consists of two types: micro-quartz and quartz overgrowth. The former occurs either as tiny equant crystals with a size of less than 10 microns (Pl. 4) or as prism crystals whose length is generally larger than 20 microns (Pl. 3). The micro-quartz cement coats detrital quartz surfaces, fills inter-grain pore spaces, or occurs within altered detrital grains. Quartz overgrowths are the more abundant silica cement.

PARAGENETIC SEQUENCE

By carefully studying the relationships among the cements, a paragenetic sequence is generated (Fig. 1).

	Early						Late
Mixed-Layer Illite/smectite	**						
Illite					**		
Kaolinite	*				***		*
Non-ferroan Calcite		**					
Ferroan Calcite/Ankerite				**			
Siderite			***				
Tiny Quartz Crystal	**						
Quartz Overgrowth							**

Fig 1 PARAGENETIC SEQUENCE. (The number of * represents the amount of the authigenic mineral formed at different diagenetic stages).

The mixed-layer illite/smectite and the tiny equant quartz crystals are considered to be the earliest formed cements in the

sandstones. The evidence for this interpretation is that they coat detrital grain surfaces (Pl.4). The dissolution/alteration of the unstable detrital minerals release silica to pore water, which is then precipitated in the form of equant quartz crystals coating detrital grain surfaces. The decomposition of volcanic rock fragments results in the formation of the mixed-layer illite/smectite.

Following this a small amount of kaolinite is precipitated from the pore water. The textural evidence for the early formation of kaolinite is the intergrowth (or coexistence) with the illite/ smectite.

Carbonate cementation is the next major diagenetic event. Of the carbonate cements, the non-ferroan calcite is the first one precipitated. The tiny equant calcite is enclosed by the small rhombohedral calcite, which is in turn surrounded by the small rhombohedral siderite (Pl. 1). One special feature, namely coarsening of calcite crystals toward the pore centre, may be a distinctive characteristic of early cementation in a fresh phreatic environment (Loucks, 1977).

Following the calcite cementation, siderite cementation took place. This is supported by the textural relationship: non-ferroan calcite crystals are enclosed by uniform rhombohedral siderite crystals (Pl.1).

It is generally agreed that the sediments of the Narrabeen Group were deposited in a fluvial environment (Ward, 1972; Conaghan et al, 1982; and Hamilton et al, 1987). With deposition the sediments were buried and were no longer affected by the surface bacterial activity and environment. Due to the depletion of oxygen in pore spaces with organic decay, a reducing environment evolved and the Fe ions in the pore water existed in the ferrous form. After the pore water became over saturated with $FeCO_3$, siderite crystals were precipitated from the pore water.

The iron can be probably attributed to two sources. One is the detrital biotite and hornblende and the other one could be detrital Fe oxides and hydroxides.

The large crystal size of pore filling siderite and the "floating" appearance of detrital quartz grains within the siderite cement are considered to be evidence for the early formation of the siderite cement.

The major siderite cementation was followed by ferroan calcite/ ankerite cementation. In one of the sandstones studied (SN 1531.9), the uniform, rhombohedral siderite crystals are enclosed by a larger euhedral ankerite crystal (Pl. 2). This textural relationship is taken as evidence for the late formation of ankerite.

The carbonate cementation was followed by dissolution processes and the major alteration of the unstable detrital particles. The main textural evidence includes the following: 1) the secondary mold

pore space, 2) recrystallization of the uniform rhombohedral calcite crystals, 3) the presence of dissolved siderite and ankerite/ferroan calcite, 4) the alteration of the unstable materials into illite, kaolinite and quartz.

Authigenic illite was also formed during the late stage of diagenesis. This is supported by the presence of illite on the carbonate crystals. The parent material for illite could be volcanic rock fragments and mica.

Without doubt prism quartz crystals were co-precipitated with the illite and kaolinite within the altered detrital grains (Pl. 3) during the late stage of diagenesis. SEM study shows the illite/prism quartz crystals or kaolinite/prism quartz crystals forming the original outline of the detrital grain.

The next diagenetic event is the precipitation of quartz overgrowths. The main textural evidence for its formation postdating the above diagenetic minerals includes the following: 1) Quartz overgrowths enclose the stacked kaolinite flakes, 2) They engulf euhedral carbonate crystals, 3) The detrital quartz grains coated by carbonate cements rarely have quartz overgrowths.

Both thin-section and SEM studies show that quartz overgrowths occur throughout the whole Narrabeen Group. Although no quantitative analysis of quartz overgrowths has been made, the thin section and SEM studies have established the general relationship between the amount of quartz overgrowths and the detrital mineralogy. Quartz overgrowths are more abundant in the Upper Narrabeen Group, which is richer in detrital quartz than the Lower Narrabeen Group.

The formation of quartz overgrowths was accompanied or immediately followed by the third generation of kaolinite. At this stage, however, only a small amount of kaolinite was precipitated from the pore water. The textural evidence for this interpretation is the intergrowth of kaolinite with quartz overgrowths and the existence of kaolinite on the smooth surface of quartz overgrowths.

DISCUSSION OF DIAGENESIS

The diagenesis of sandstones of the Narrabeen Group can be broadly divided into two stages: early diagenesis and late diagenesis. The former ended prior to the major alteration of the unstable detrital particles and the latter began with their alteration. The early diagenesis included some dissolution/alteration of unstable detrital particles (volcanic rock fragments, feldspar and mica), which resulted in the formation of mixed-layer illite/smectite, tiny quartz crystals, first generation of kaolinite, and the major carbonate cementation. The late diagenesis consisted of the major dissolution/alteration of unstable detrital particles and quartz overgrowth.

The two broad stages of diagenesis are found in all four

wells studied. Moreover, the major authigenic minerals (kaolinite, pore filling siderite and quartz overgrowth) are present throughout the whole Narrabeen Group (from 176.4m to 763.8m of drilling depth). This distribution implies that the formation of the authigenic minerals is generally independent of the burial depth.

Precipitation of authigenic clay minerals, cementation by carbonate minerals and quartz overgrowths all result in the reduction of the original pore spaces in the sandstones. Point counting data establish the general relationship that clay matrix (including both detrital clays and authigenic clays) decreases upwards toward the top of the Narrabeen Group. This suggests that the abundance of the authigenic clay minerals in the sandstones is not the same for different stratigraphic horizons despite their presence throughout the whole group. Moreover, SEM/EDX and XRD analyses show that pore filling ferroan calcite/ankerite are present only in the lower part of the group (the part derived from the New England Fold Belt and the basal portion of the part derived from the Lachlan Fold Belt). Thus it can be concluded that the formation and the amounts of authigenic clay minerals and pore filling ankerite crystals are largely controlled by the detrital mineralogy. The formation of authigenic clay minerals largely depends upon the unstable detrital particles whereas the amount of quartz overgrowths depends upon the content of detrital quartz grains in the sandstone.

In the sandstones rich in volcanic rock fragments, the authigenic clay minerals coat detrital grain surfaces and fill intergrain pore spaces. They cause a major reduction of porosity and permeability. The late precipitation of pore filling ferroan calcite/ankerite also reduces porosity and permeability. In addition, the dissolution/alteration of the unstable detrital particles prior to the major carbonate cementation enhance the potential of mechanical compaction, which further reduces porosity and permeability.

In the sandstones rich in detrital quartz grains, quartz overgrowths are the important cement reducing porosity and permeability (Pl. 5). In this kind of sandstone, the texture controls quartz overgrowths on a small scale. In the fine-grained sandstones, the original pore spaces are small and tortuous so that the original porosity is often completely lost due to quartz overgrowths. In the texturally mature coarse-grained sandstones, quartz overgrowths are generally present as a thin veneer so they only reduce the porosity to a small extent.

In both the sandstones rich in volcanic rock fragments and those rich in detrital quartz grains, the pore-filling siderite cementation is an important process reducing porosity and permeability. The pore filling siderite cements generally reduce the potential of the sandstones as reservoir rocks although the later dissolution of them can produce secondary porosity. The coating carbonate (non-ferroan calcite/rhombohedral siderite) cements, on the other hand, are considered to improve the reservoir potential. In the samples containing the coating carbonate cements, which are always

relatively quartz rich, the porosity and permeability are good (Pl 6) (e.g. samples SN 3300.3, SN 3310.4 and SN 1531.9, the average grain size, the porosity and the permeability are respectively 0.25 mm, 17.5%, 179 md; 0.20 mm, 18.3%, 104 md; and 0.50 mm, 15%, 317 md.). The coating carbonate cements prevent the sandstones from further diagenesis (particularly quartz overgrowth).

Purely in terms of the diagenesis, the texturally mature coarse-grained sandstones rich in detrital quartz have the higher potential as reservoir rocks. Those with early coating carbonates have largely retained a major part of their original porosity. The sandstones rich in volcanic rock fragments are considered to have the lower potential as reservoir rocks.

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PLATE CAPTIONS

Pl.1, Non-ferroan calcite crystals enclosed by uniform rhombohedral siderite crystals (Weromba 2 drilling depth 300.8 m).

Pl.2, Uniform rhombohedral siderite crystals enclosed by a large euhedral ankerite crystal (Cobbitty 3: drilling depth 531.9 m).

Pl.3, Illite and prism quartz crystals within an altered detrital grain (Campbelltown 2: drilling depth 593.0 m).

Pl.4, Tiny equant quartz crystals coating the detrital grain surface (Campbelltown 5: drilling depth 468.5 m).

Pl.5, Quartz overgrowths reduce porosity in quartz rich sandstones (Campbelltown 5: drilling depth 429.0 m).

Pl.6, Sandstones with coating cement of carbonate retaining their high porosity (Cobbitty 3: drilling depth 531.9 m).

NARRABEEN GROUP

TRIASSIC DEPOSITIONAL SYSTEMS IN THE GUNNEDAH BASIN

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Based on outcrop mapping and detailed subsurface studies, the Triassic sequence in the Gunnedah Basin has been subdivided into three units: the Digby Formation at the base, the Napperby Formation in the middle and the Deriah Formation at the top. The principles of genetic stratigraphy have been applied to this sequence, with detailed lithofacies analysis, palaeocurrent studies and petrological investigations in order to understand better the depositional history of the strata and to evaluate the prospectivity of the sediments for hydrocarbon accumulation.

The Digby Formation is the product of interplay between sedimentation from the New England Fold Belt and the Lachlan Fold Belt, with the former as the major sediment source in the early stage of the Digby depositional episode, and the latter in the later stage. The lower part of the Digby Formation, referred to as the Conglomerate Interval, consists of lithic conglomerate brought in mainly by a very large alluvial fan complex derived from the New England Fold Belt in the southern part of the basin. This fan complex, which is compatible in shape, size and slope to the modern Kosi River Fan, was built up by Scott Type, Donjek Type or gravel meandering streams in the study area. Stream types changed throughout the depositional episode in response to variations in palaeotopographic relief.

The Conglomerate Interval of the Digby Formation is interpreted as the result of shedding of abundant rock fragments from the New England Fold Belt in response to elastic flexure of the lithosphere after a Late Permian to Early Triassic thrusting of the New England Fold Belt towards the west and southwest during the formation of the Hunter Mooki Thrust system.

The upper part of the Digby Formation, referred to as the Sandy Interval, is dominated by quartz sandstone. This sediment was brought in mainly by a trunk river system flowing southeasterly along the basin axis, with tributaries from the two fold belts at the early stage of its depositional period. The New England Fold Belt stopped providing sediments later during this depositional phase and the Lachlan Fold Belt became the only sediment source, supplying sediment to a southeasterly flowing trunk river and its tributaries.

With the gradual lowering of the slope between the Lachlan Fold Belt and the receiving basin, the types of streams represented in the Sandy Interval evolved from Donjek type braided or gravelly meandering streams to South Saskatchewan type sandy braided streams and then to meandering streams. Finally no more potential existed for the Lachlan Fold Belt to provide sediment to the receiving basin, resulting in a small hiatus and the formation of a paleosol horizon on top of the Digby Formation.

No obvious cause can be found for the uplift of the Lachlan Fold Belt and the additional subsidence of the receiving basin during this depositional phase. However, if a time-dependent visco-elastic lithosphere model is assumed, the uplift may have been due to relaxation of the lithosphere after stress induced by early loading of the thrust blocks of the New England Fold Belt. The small hiatus represented by the paleosol horizon may indicate that a local isostatic equilibrium was reached at this time.

The Napperby Formation forms a major regressive sequence, produced by large lacustrine - deltaic systems. The New England Fold Belt resumed providing sediments during the Napperby depositional period, so that the lake was filled up by westerly to southwesterly prograding deltaic systems fed by streams derived from the New England Fold Belt.

During the early part of the Napperby depositional episode, a widespread lake transgression occurred and a series of lobate deltas were built up along the eastern margin of the basin. Low density underflow was a major process in the prodelta areas, and prodelta slumping sometimes occurred.

During the middle part of this depositional episode, the delta system in the southeastern part of the basin was abandoned and the area was converted to a lake environment. Two elongate deltaic systems, however, were established in the central and the northern parts of the basin, with turbidites being formed in the prodelta and delta front areas.

During the late stages of the Napperby depositional episode, the south and central parts of the basin became areas of fluvial deposition. A deltaic system, however, was built up in the northwestern area of the basin, with turbidites occurring again in the prodelta area.

The rapid basin subsidence that produced the widespread lake transgression may have been caused by another episode of thrust loading of the New England Fold Belt towards the Lachlan Fold Belt. Orogen growth in the New England Fold Belt increased the potential for that area to provide sediments to the basin, so that the basin was eventually filled.

The Deriah Formation, mainly occurring in the northern part of the basin, is made up dominantly of green volcanic fragment-rich lithic sandstone, brought in by braided streams. Lavas with a Middle Triassic age and minor off-white lithic sandstones also occur in this formation,

which is probably the product of a Middle Triassic thermal episode in the New England Fold Belt.

The depositional systems established in this study can be used as a very useful tool for petroleum exploration in these sequences in the Gunnedah Basin, and as useful reference for exploration in the equivalent sequences in the Bowen Basin. The Sandy Interval of the Digby Formation, in particular, is believed to be the most prospective interval in the Triassic sequence for hydrocarbon exploration.

THE LATE PERMIAN PALAEOGEOGRAPHY OF THE AUSTRALIAN CONTINENT

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This paper presents the results, for the Late Permian, of the BMR-APIRA Palaeogeographic Maps Project. The epoch spans the Kazanian and Tatarian stages, and the Muree Sandstone - Newcastle Coal Measures stratigraphic interval. (The Kazanian as used here includes the Ufimian). Maps for three time slices have been compiled, bounded by (1) the incoming of Fauna IV of Dickins (1964, 1968) in much of eastern Australia after a previous hiatus; (2) the start of deposition of the upper coal measures in the Sydney Basin; (3) the marine incursion of the Waratah Sandstone and equivalents; and (4) the end of upper coal measures deposition.

At the end of the Early Permian, a regressive-transgressive episode left a hiatus in the sedimentary record in the Sydney Basin (McKelvey and others, 1971; Herbert, 1980) and in the Bowen Basin (Dickins and Malone, 1973; Price, 1983). A formerly marine area, extending from at least the Denison Trough to the Sydney Basin, appears to have undergone a short-lived subaerial exposure. This coincided with an episode of tectonism and possible serpentinite emplacement east of the Bowen Basin (Malone and others, 1969), both of which may have been caused by the docking of the Curtis terrane.

MUREE SANDSTONE - MULBRING SILTSTONE INTERVAL

This interval is of early Kazanian age, and ranges from approximately 256 to 258 Ma on the geologic time scale of Harland and others (1982). It is synonymous with Intervals 5 and 6 defined in the Sydney Basin by Mayne and others (1974). Elsewhere, it is represented by the lower Blenheim, lower Freitag, and lower Oxtrack formations (Bowen Basin), the upper Malbina Formation (Tasmania), the lower Wagina Sandstone (Perth Basin), the middle Kennedy Group (Carnarvon Basin), the middle Lightjack Formation (Canning Basin), and the bottom of the Hyland Bay Formation (Bonaparte Basin).

A rise in sea level inundated the Sydney - Bowen trough to form a continuous seaway, while uplift and plutonism were taking

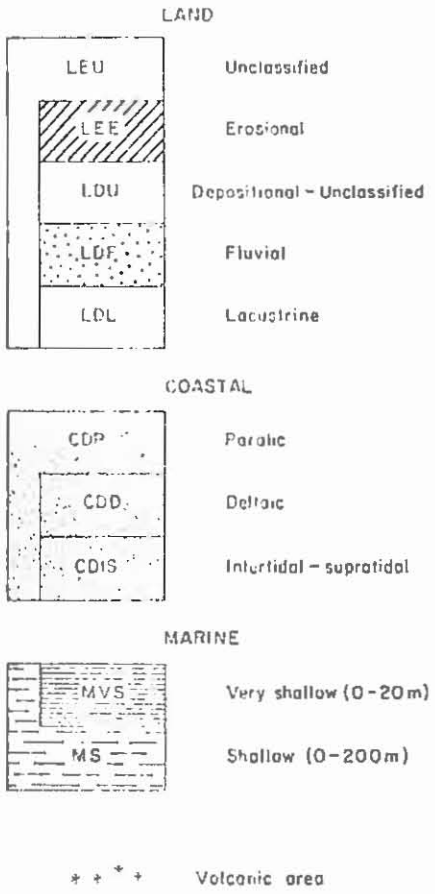

Fig. 1 Reference to environments in Figs 2-4

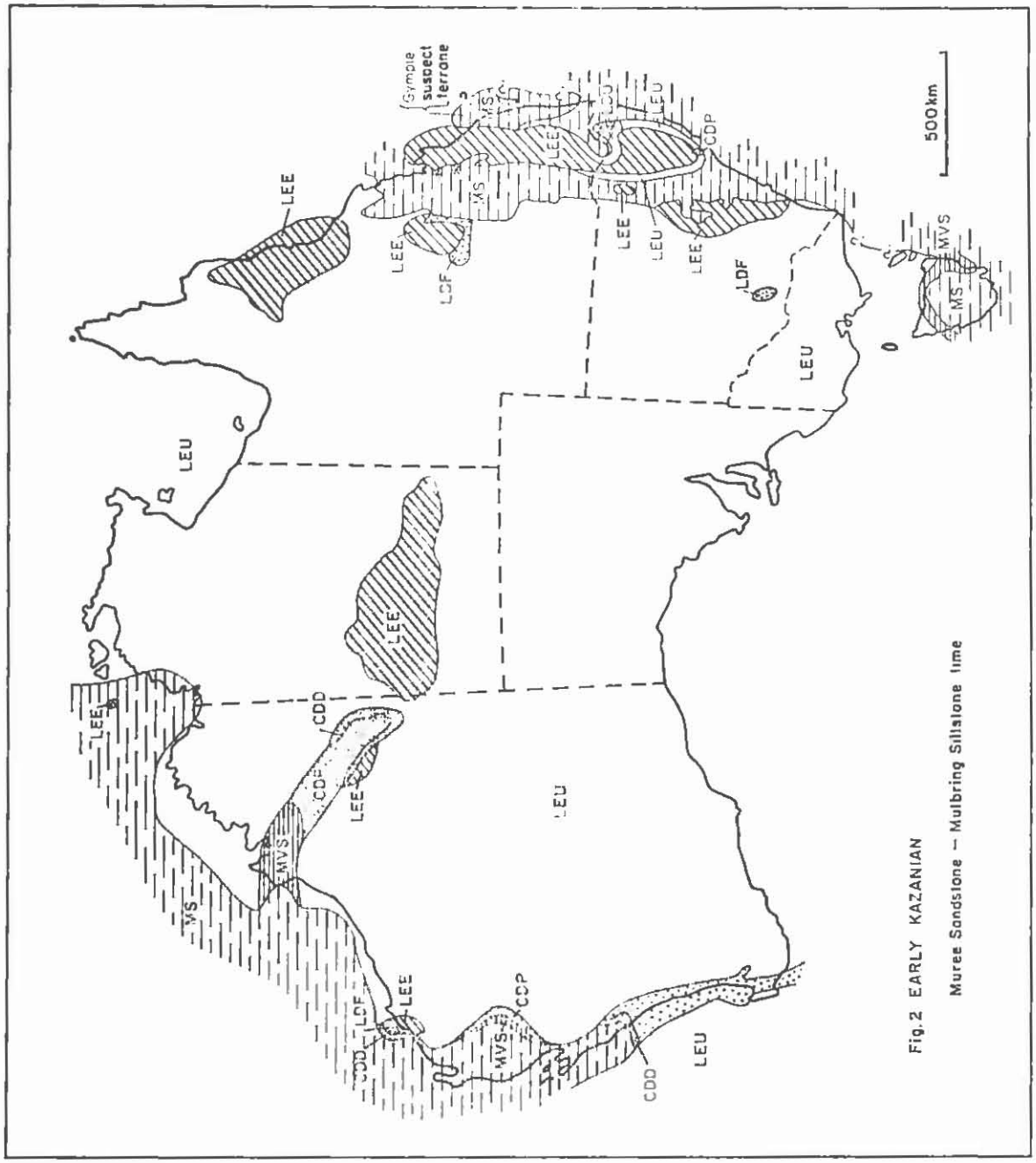

Fig.2 EARLY KAZANIAN

Muree Sandstone – Mulbring Siltstone time

place in the New England - Yarrol orogen, so that the latter comprised a large island lying east of the mainland. The sea had previously occupied the eastern half of Tasmania, and now spread across most of the rest of the state. Transgressions also occurred in the Carnarvon and Bonaparte Basins. By contrast, the southern Canning Basin, which had been marine in the Early Permian, was elevated to dry land, and the Fitzroy Trough in the north of the basin changed from marine to largely lagoonal, with a fringe of deltas at its southeastern end, and very shallow marine conditions (<20 m deep) in the northwest. Shallow marine conditions also prevailed east of the New England - Yarrol island. The Gympie area is believed to have formed an exotic terrane which did not accrete onto eastern Australia until the mid-Triassic (Harrington, 1983); because the maps are not palinspastic, it is shown in its present location, but in the Permian it would have lain an unspecified distance to the east.

Subaerial volcanism is recorded in the Drake Volcanics of northeastern New South Wales, while the Rookwood Volcanics of central Queensland display submarine spilitic volcanism.

Fluvial sediments, including coal measures, were deposited in the Oaklands Basin in southern New South Wales, and in the southern Perth and Collie Basins.

Erosional areas are interpreted, or are known to have existed, southwest of the Fitzroy Trough, in central Australia, northern Queensland, west of the Bowen and Sydney Basins, and on the New England - Yarrol island. An area also existed in the northern Carnarvon Basin, as a result of activity on the Sholl Island Fault, with fluvial and deltaic aprons on its northwestern margins. A land mass forming part of "Greater India" and probably erosional, lay west of the Perth Basin throughout the Permian.

TOMAGO COAL MEASURES INTERVAL

The Tomago Coal Measures and equivalents are middle Kazanian to middle Tatarian in age (approximately 250-256 Ma), and correspond to Intervals 7-9 in the Sydney Basin (Mayne and others, 1974). Contemporaneous units include the middle Blenheim - Moranbah, upper Freitag - Black Alley, and upper Oxtrack - Gyranda intervals (Bowen Basin), the lower Toolachee Formation (Cooper Basin), the Ferntree Group (Tasmania), the upper Wagina Sandstone (Perth Basin), the upper Kennedy Group (Carnarvon Basin), the upper Lightjack - middle Hardman formations (Canning Basin), and most of the Hyland Bay Formation (Bonaparte Basin).

The time slice saw the start of major marine regression in most basins. The Sydney and Gunnedah Basins filled up with fluvial and deltaic coal measures as clastics poured in from adjacent uplifted highs, and deltaic progradation also occurred late in the interval in the northern Bowen Basin (German Creek and Moranbah Coal Measures). A large delta complex built out into the Bonaparte Basin, while in the Fitzroy Trough the formerly lagoonal area was infilled by deltaic deposits and then

partly by fluvials. Subsidence on the sites of the Cooper and Galilee Basins caused these regions to accumulate fluvial coal measures sequences. However, on the Springsure Shelf connecting the Galilee and Bowen Basins, and in the southern Carnarvon Basin, marine transgression continued early in the interval. The eastern seaboard, Tasmania, and the Perth Basin saw little change in the degree of marine onlap. Fluvial coal measures continued to be laid down in the southern Perth, Collie and Oaklands Basins. Rifting on the site of the later Laura Basin on Cape York Peninsula, accompanied by some felsic volcanism, allowed entry of the sea in places.

Volcanism also occurred in the southeastern Sydney Basin (the Gerringong latitic eruptions) early in the interval, and later off Newcastle. A major eruptive centre developed in New England (the Annalee Pyroclastics), and there was some andesitic activity in southeast Queensland.

Erosional areas were present in the northern Carnarvon Basin, northern Queensland, and west of the Bowen, Galilee, and Sydney Basins. The large deltaic complexes in the Bonaparte Basin and Fitzroy Trough suggest considerable erosion in the central Australian hinterland, but this is not shown on the map because the exact location of eroding areas is uncertain, and at least one intermontane basin is known from the region. Some topographic highs existed in the southern Cooper and northern Sydney Basins. Granitic intrusions in the New England - Yarrol orogen accompanied uplift in the region, with the consequent stripping and removal of material to adjacent depocentres.

THE NEWCASTLE COAL MEASURES INTERVAL

This late Tatarian time slice (approximately 248-250 Ma) embraces the Sydney Basin Intervals 10-11 of Mayne and others (1974). Equivalents in other regions are the Bandanna Formation and Blackwater Group (Bowen Basin), middle to upper Toolachee Formation (Cooper Basin), the Cygnet Coal Measures (Tasmania), the basal Sabina Sandstone (Perth Basin), the Chinty Formation (Carnarvon Basin), the upper Hardman Formation (Canning Basin), and the upper Hyland Bay Formation (Bonaparte Basin).

The close of the Permian saw the establishment of dominantly continental sedimentation. After the brief eustatic sea level rise recorded by the Dempsey Formation and equivalents (Brakel, 1986), the subsiding Sydney - Bowen foredeep was once again infilled by detritus shed from actively rising highs in the orogen to the east, and to a lesser extent from westerly sources. Peatlands in the fluvial and deltaic foredeep were widespread. Coal measures continued to collect in the Galilee and Cooper Basins, with a significant contribution of lacustrine sediments in the southern parts of the latter. Fluvial coal measures deposition was also established in the Tasmanian Basin and in the sub-Laura Basin rifts, so that at this time almost every terrestrial basin from Cape York to Tasmania, and indeed to as far as the southern Perth Basin, was accumulating coal.

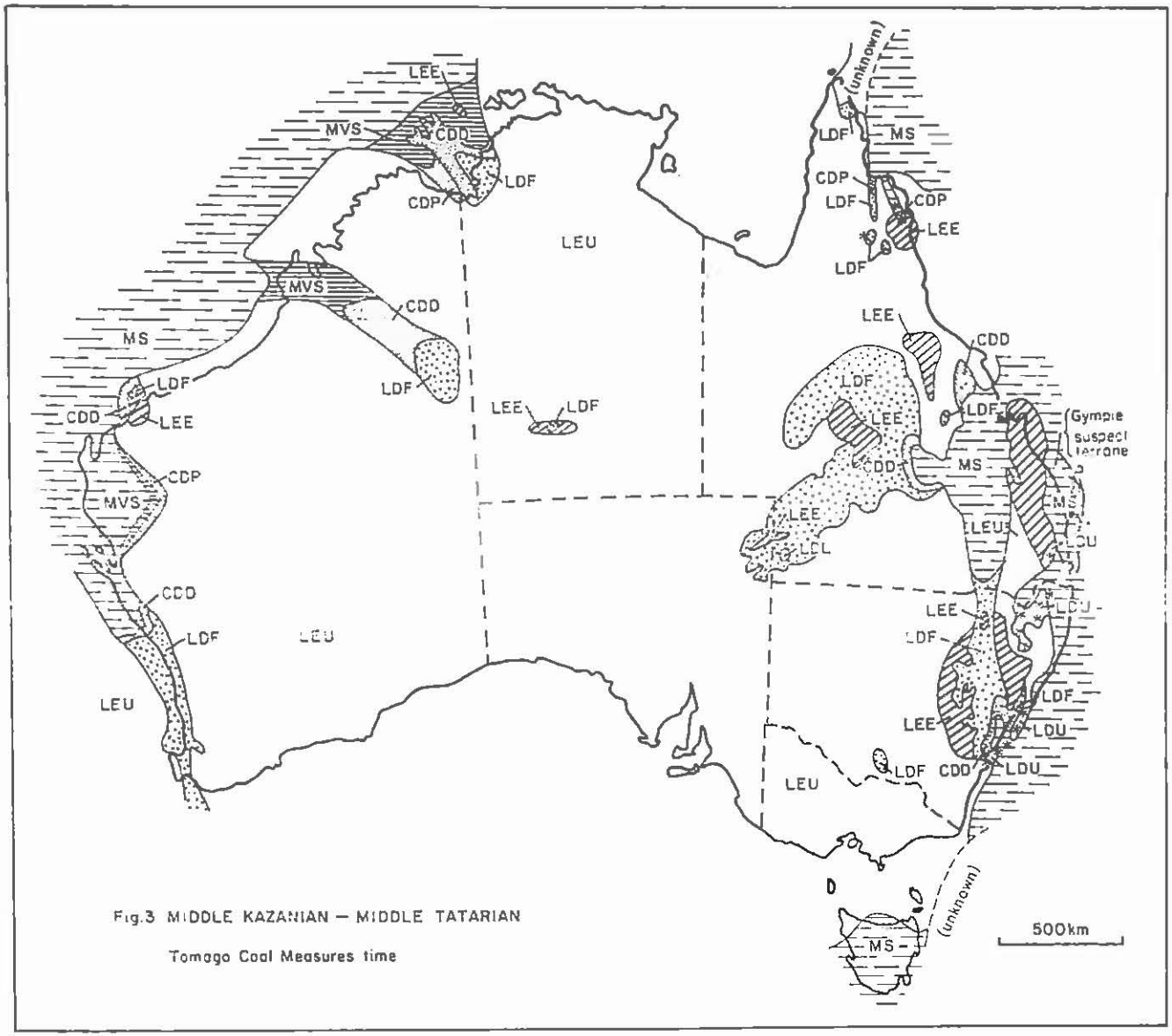

Fig.3 MIDDLE KAZANIAN — MIDDLE TATARIAN

Tomago Coal Measures time

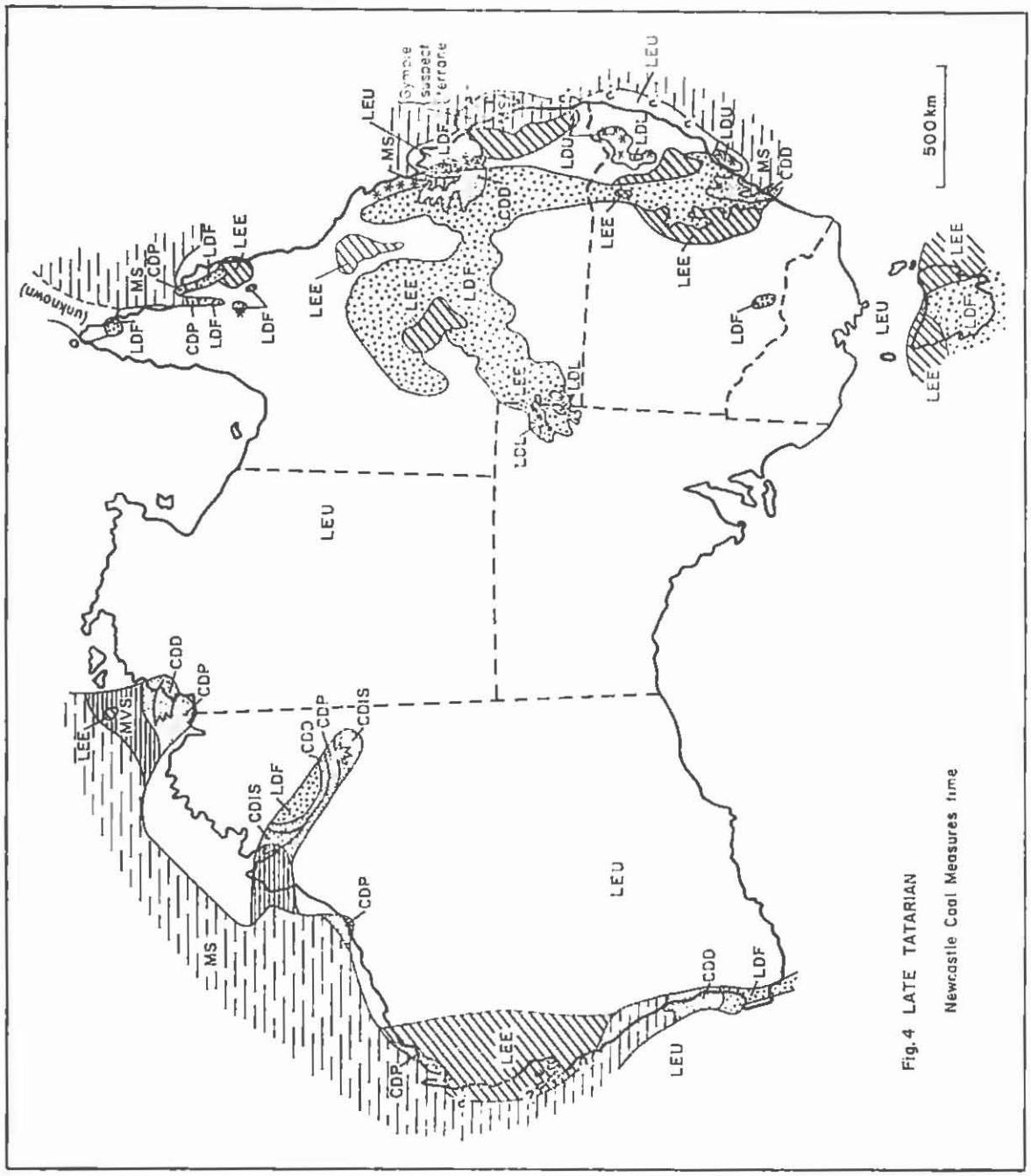

Fig.4 LATE TATARIAN

Newcastle Coal Measures time

After an initial marine transgression in the Bonaparte Basin, a delta was re-established in a lagoonal setting behind a prograding barrier bar. An interplay of intertidal flat and estuarine conditions prevailed over much of the Fitzroy Trough, whereas along its northeastern side a fluvial apron fringed by deltas received clastics from the Kimberley region. Meanwhile, a small paralic embayment (Chirup Formation) existed in the south-western Canning Basin. A late transgression occurred in the northern Perth Basin, but most of the adjoining Carnarvon Basin experienced emergence and erosion.

Postulated uplifts in the northwest and northeast of Tasmania (M.J. Clarke, written communication) would imply erosive regimes in these areas. A small part of the Boggabri Ridge in the northern Gunnedah Basin still stood above the surrounding alluvial region, as it had done since the Early Permian (Hill, 1986). The other erosional areas of eastern Australia were generally similar to those in the previous time slice.

Volcanic activity, at times intense, was evident along the eastern Bowen Basin, and continued in southeastern Queensland, New England, and on the Northumberland Ridge east of Newcastle. These centres were responsible for immense volumes of tuff being added to the sedimentary pile in the Sydney - Bowen trough.

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THE WORLD SIGNIFICANCE OF THE HUNTER-BOWEN (INDOSINIAN) OROGENIC PHASE

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The mid-Permian to Triassic folding movements and associated features are well shown in eastern Australia because of the absence of strong overprinting by the later Alpine-Himalayan Folding Phase. On the basis of information from eastern Australia and a comparison with other parts of the world, some remarkable parallels are apparent. The term Hunter-Bowen proposed by Carey and Browne (1938) is particularly appropriate and in this paper is linked with the term Indosinian which in Asia is used to describe part or all of these movements.

SYDNEY BASIN (NEW SOUTH WALES)

The beginning of the Hunter-Bowen Orogenic Phase is marked by the most widespread marine transgression of the Permian in the basin with widespread conglomerates at the base, all with Fauna IV, including the Nowra Sandstone, the conglomerates near Marulan, the Megalong Conglomerate, the conglomerates near Rylstone and the Muree Formation. All along the west side of the basin from near Bundanoon until they disappear to the north of Rylestone the basal beds of the transgression rest on pre-Permian. The first appearance of the Lochinvar Dome (and presumably other related structures in the basin) is indicated in the isopachs (Mayne et al., 1974) and the disconformity in the dome indicated by the different disposition of the Muree and the Branxton Formations. A new associated predominantly acidic phase of magmatic activity is indicated by the appearance of pyroclastics interbedded with the marine beds for example at Rylstone and at Tianjara, west of Jervis Bay, as well as the appearance of large quantities of acidic igneous detritus in the sediments. Strong movement and igneous activity continue throughout the Upper Permian with a particularly strong phase at about the end of the Permian (Dickins, in press a). In the Sydney Basin the last movements appear to be in the Middle Triassic and the completion of this phase of folding is to be found in Queensland.

NEW ENGLAND (NEW SOUTH WALES)

A marked unconformity is present between the Lower and Upper Permian (Runnegar, 1970). In the Drake area, for example, the Lower Permian is folded and affected by widespread regional metamorphism before the deposition of the relatively flat-bedded Upper Permian with Fauna IV. In this area the Upper Permian is characterized by acidic

pyroclastic activity and the Upper Permian and Triassic by granitic intrusion, see Olgers et al. (1974). The Upper Permian and Triassic of New England area as a whole were strongly affected by acidic igneous activity. Recent work on the Permian time-scale suggests the mid-Permian should be placed at about 270 Ma (Dickins and Archbold, 1988). This age has important consequences for understanding the tectonic and magmatic development of Permian, not only in Australia but also other parts of the world.

BOWEN BASIN AND HINTERLAND (QUEENSLAND)

As in the Sydney Basin, the beginning of the folding phase is marked by the most widespread marine transgression of the Permian which marks the base of the Blenheim Subgroup and the incoming of Fauna IV. In the south-west of the basin, the Peawaddy Formation transgresses across the Denison Trough which was formed as a broad Lower Permian half-graben (Fig. 1). To the east the Mimosa Syncline

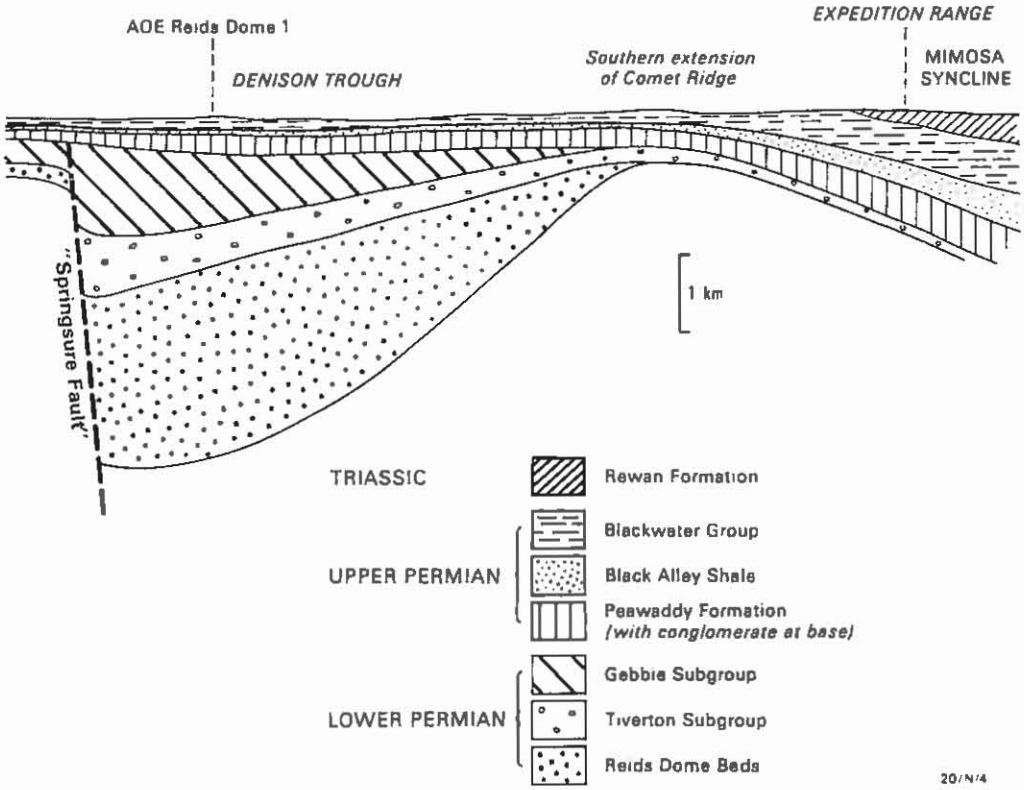

FIGURE 1. Denison Trough and western part of Mimosa Syncline showing half-graben formed in Lower Permian and transgressive overlap of Peawaddy Formation at base of Blenheim Subgroup (Dickins, in press b).

began to develop in the Lower Permian Comet Platform and continued to develop during the Upper Permian and Triassic. Further to the east one or more deep flysch troughs were formed with spilitic pillow lavas at the base of the sequence, the Rookwood Volcanics and the Boomer

Formation (Dickins and Malone, 1973). The base of the Blenheim Subgroup is marked around the basin by the incoming of large quantities of andesitic and acidic igneous detritus. The supply of

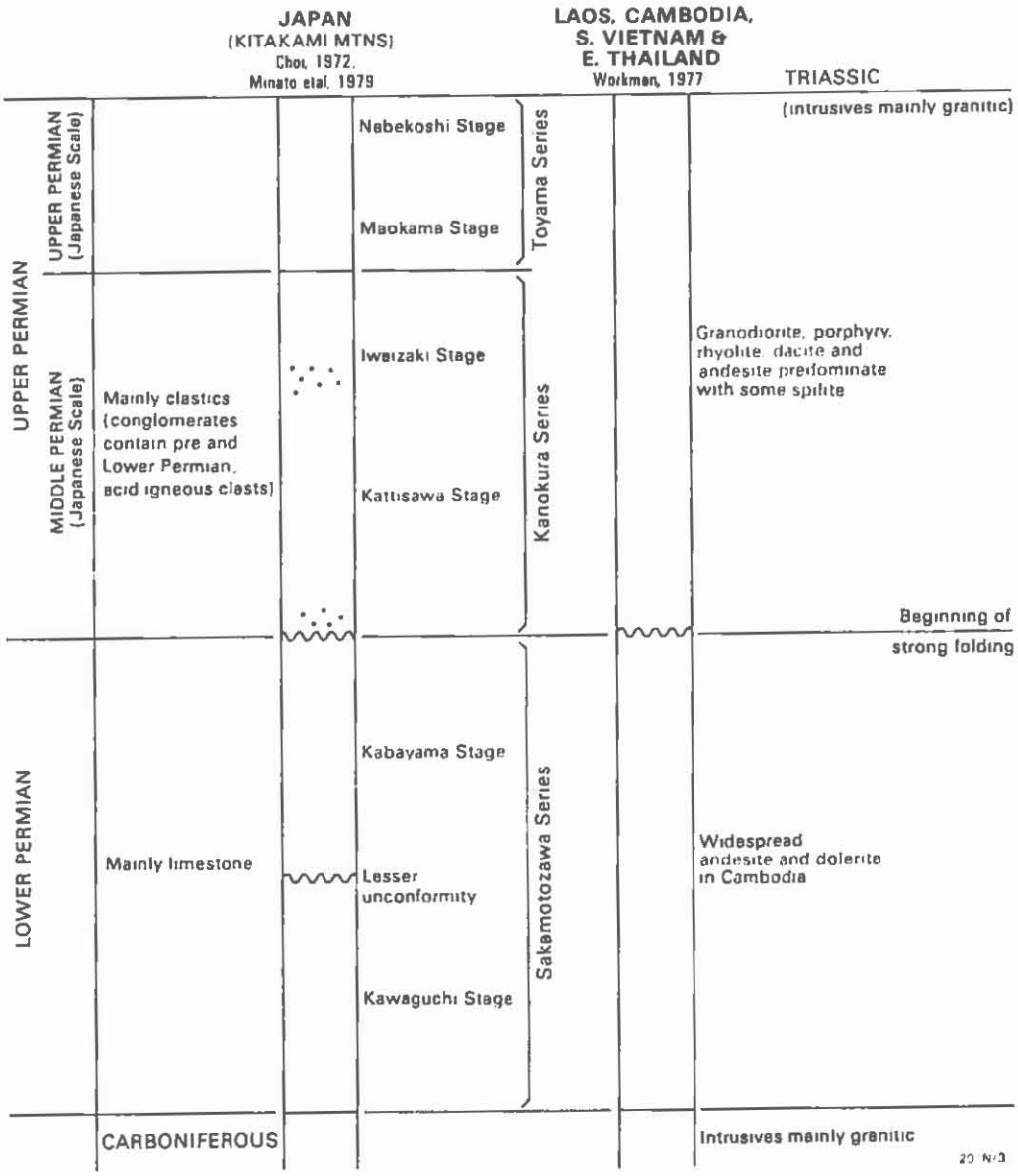

FIGURE 2. Permian sequences in Japan and South-east Asia (Dickins, in press b).

igneous material together with flows, pyroclastic deposits and intrusion continues through the Permian and into the Triassic; the type of detritus changing apparently according to the nature of the magmatic activity. A period of folding and thrusting took place in the basin subsequent to the Middle Triassic and before the earliest Jurassic. This marks the end of the Bowen Basin. The Jurassic has a

distinctly different distribution to the Permian and Triassic, reflecting a different, ?tensional, tectonic style.

UPPER TRIASSIC (QUEENSLAND)

The development of the Upper Triassic is shown in southern Queensland. The movement of this time is illustrated in the Ipswich Coal Measures, the Brisbane Tuff, Chillinham Volcanics and North Arm Volcanics (Day et al.,1983). This parallels similar developments in other parts of the world.

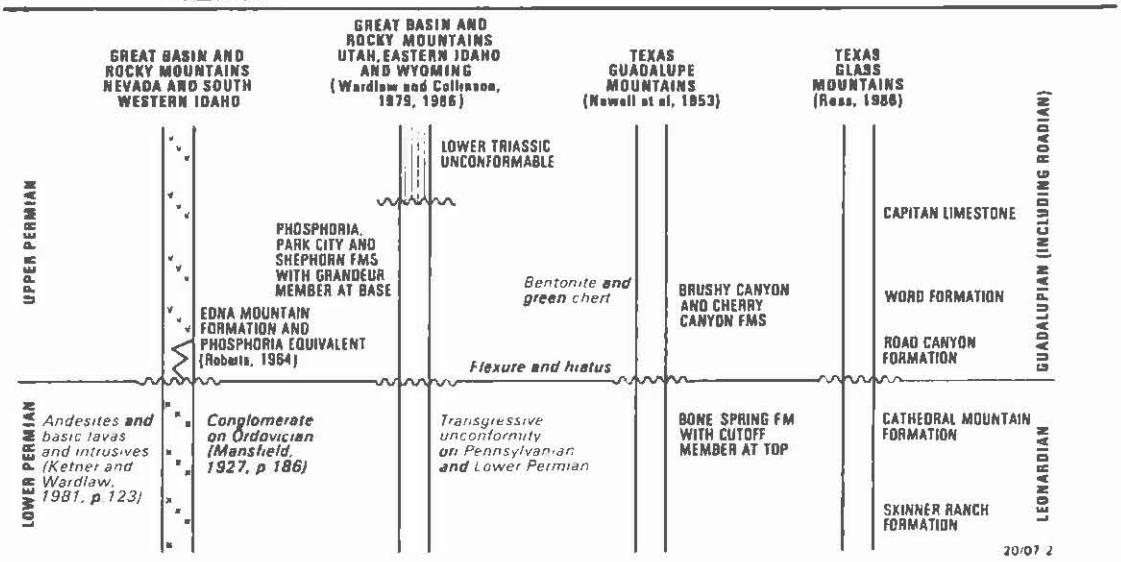

FIGURE 3 . Sequences in the western United States showing the disconformable and unconformable relationships of the Lower and Upper Permian and the transgressive overlap of the Upper Permian.

BEGINNING OF THE HUNTER-BOWEN (INDOSINIAN) OROGENIC PHASE

The beginning of this phase at about the boundary of the Lower and Upper Permian in eastern Australia, New Zealand, southern Asia, Japan, and southern Europe has been considered in Dickins (1987; in press b,c, Dickins et al. in press). To this can now be added information from North and South America (Figs. 3,4) and from Antarctica (Barrett et al.1986). The beginning of this orogenic phase is associated with a major world-wide regression and transgression.

DEVELOPMENT OF THE HUNTER-BOWEN (INDOSINIAN) OROGENIC PHASE

Parallel developments in the Upper Permian and Triassic to those of eastern Australia are recorded in all the areas mentioned above. The Upper Permian on a world scale is associated with a major regression culminating at the Permian-Triassic boundary, which along with the Cretaceous-Tertiary boundary regression, apparently represent the two major regressions of the Phanerozoic. Both correspond to a major change of life. The Triassic seems to have a more orderly transgressive and orogenic activity. The movements recorded in the Upper Triassic are particularly strong and the end of the Triassic is accompanied by another major regression. Major movement is recorded

not only in eastern Australia but in southern Asia, Japan, Europe, Antarctica and elsewhere. For the Jurassic there is widespread evidence of a different tectonic and magmatic style (Dickins, 1987, in press c).

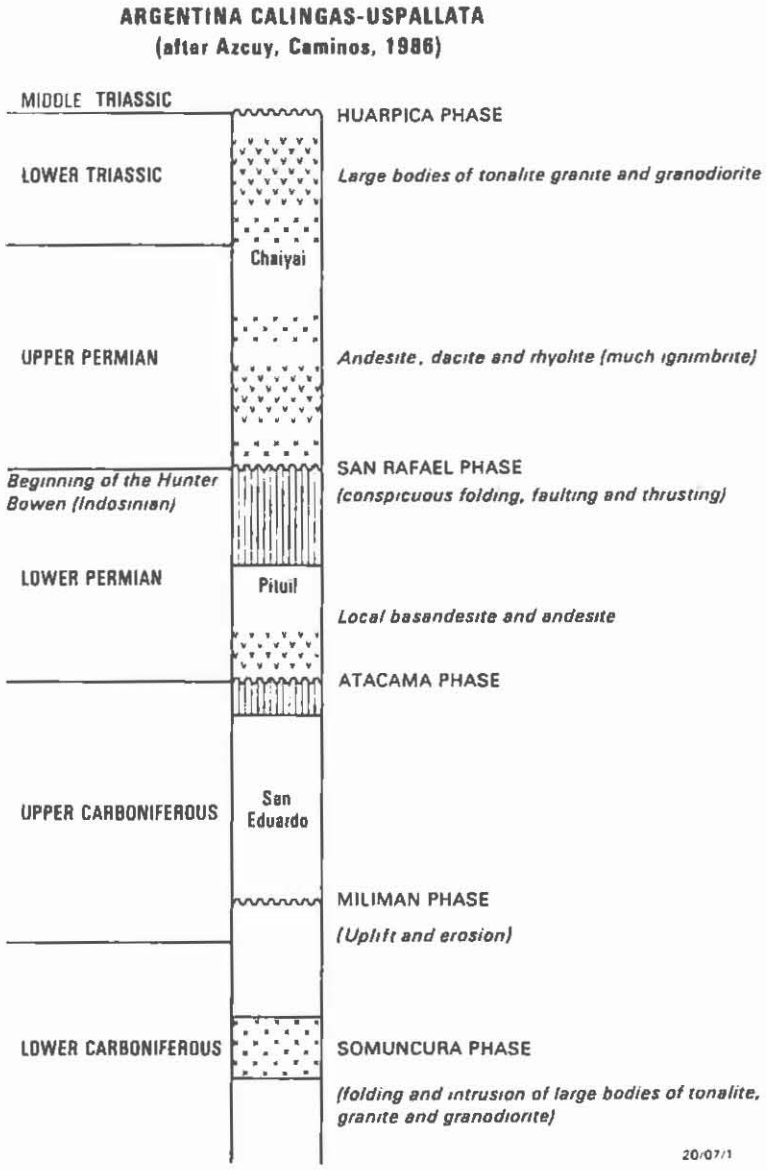

FIGURE 4. South America.

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THRUST FAULTING AT FREEMAN'S WATERHOLES

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Thrust faulting on a significant scale has previously been reported in the Hunter Valley Dome Basin Belt in Triassic Narrabeen Group sandstones near Broke (Moelle & Sutherland, 1977). An additional occurrence of thrust faulting has recently been identified in the upper portion of the Permian Newcastle Coal Measures near Freeman's Waterholes, 58360E 49300N on the 1:25000 Quorrobolong Sheet (Figure 1).

The thrust fault plane trends N60°E (magnetic) and has a mean dip of 48° to the NW. It crops out in a road cutting over a length of approximately 200 metres. The fault zone has an exposed thickness of approximately 4 metres. The thrust fault affects a sandstone unit, approximately 3 metres thick, several thinner conglomerate layers, a number of tuffaceous claystone bands and an underlying coal seam. The fault breccia consists of tilted sandstone blocks, very distorted lutite bands and layers, buckled segments of a coal seam (possibly belonging to the Moon Island Beach Sub-Group) as well as of angular sandstone and siltstone fragments. The gouge material in the fault zone is argillaceous. The size of brecciated components varies from several cubic metres to a few cubic centimetres. Recumbent folds with an axial plane trend of approximately 80° (magnetic) occur in claystone and siltstone layers.

The vertical displacement component of the thrust fault is impossible to measure at this stage, as the lower portion of the fault zone is not exposed, but it definitely exceeds 4 metres. The amount of horizontal movement is probably significant and may be greater than 100 metres.

The joint patterns of the individual segments within the disturbed zone consist of early formed joint sets, reworked joint surfaces by rotational movements, as well as of two sets that have probably been formed by the thrusting event. A kinematic analysis of the rotated joint sets portrays a deformational shortening process.

Several shear zones have been defined in the road cutting, which show marked variations in their development within different lithologies. The arenites are very distinctly affected and form wide

(up to 0.30 m) shear zones, whereas the lutaceous layers depict narrow and well-defined sets of shear surfaces. Three very pronounced shear zones occur 1.5 km further north along the road with a strike trend of N70°W. Those shear zones, together with some minor faulting and gentle folding, can probably be attributed to the thrust movement.

The interface between the distorted coal, lutites and arenite sequence and the exposed portion of the thrust plane is characterised by a certain waviness. There appears to be no preference according to lithology in the development of this uneven and wavy interface. It should be emphasised that the exposure described here represents only the upper portion of the sequence affected by the thrust, the lower boundary of this zone may not display similar features.

Portions of the fault zone appear to resemble an uncommon "down-section" type, which requires an explanation. The dominant regional structures of the area are the eastern flank of the Yarramalong Anticline and a NW-SE trending normal fault which has been mapped to the northwest of this locality and suspected to extend into this area. It is possible that this fault predates the thrust movement and may have impeded the propagation of the younger thrust movement by creating a resistant block to the south. Such a "blocking" could result in the unusual development of a "down-section" attitude of the thrust fault-zone, as only a portion of the thrust plane is seen here.

It is suggested that this thrust fault occurrence may be linked with the thrust fault near Broke described by Moelle and Sutherland (op. cit.). Thus a tectonically significant zone appears to exist well to the south of the Hunter Thrust System, but genetically related to it. Some evidence of thrust faulting with similar spatial attitudes exists in the Greta Coal workings of the Pelton and Ellalong Collieries. Similar phenomena have been reported even further south in Hawkesbury Sandstone (Branagan, 1977, Norman and Branagan, 1984). These features may be the result of a widespread thrusting event. If this relationship can be established by work now in progress, it would indicate the existence of near horizontal or low-angle thrust planes, spanning a stratigraphic sequence from the Lower Permian Coal Measures to the Triassic. Thus a considerable portion of the Hunter Valley Dome Basin Belt is possibly affected by a generally south directed thrust deformation, which has either a late Triassic or a Jurassic age.

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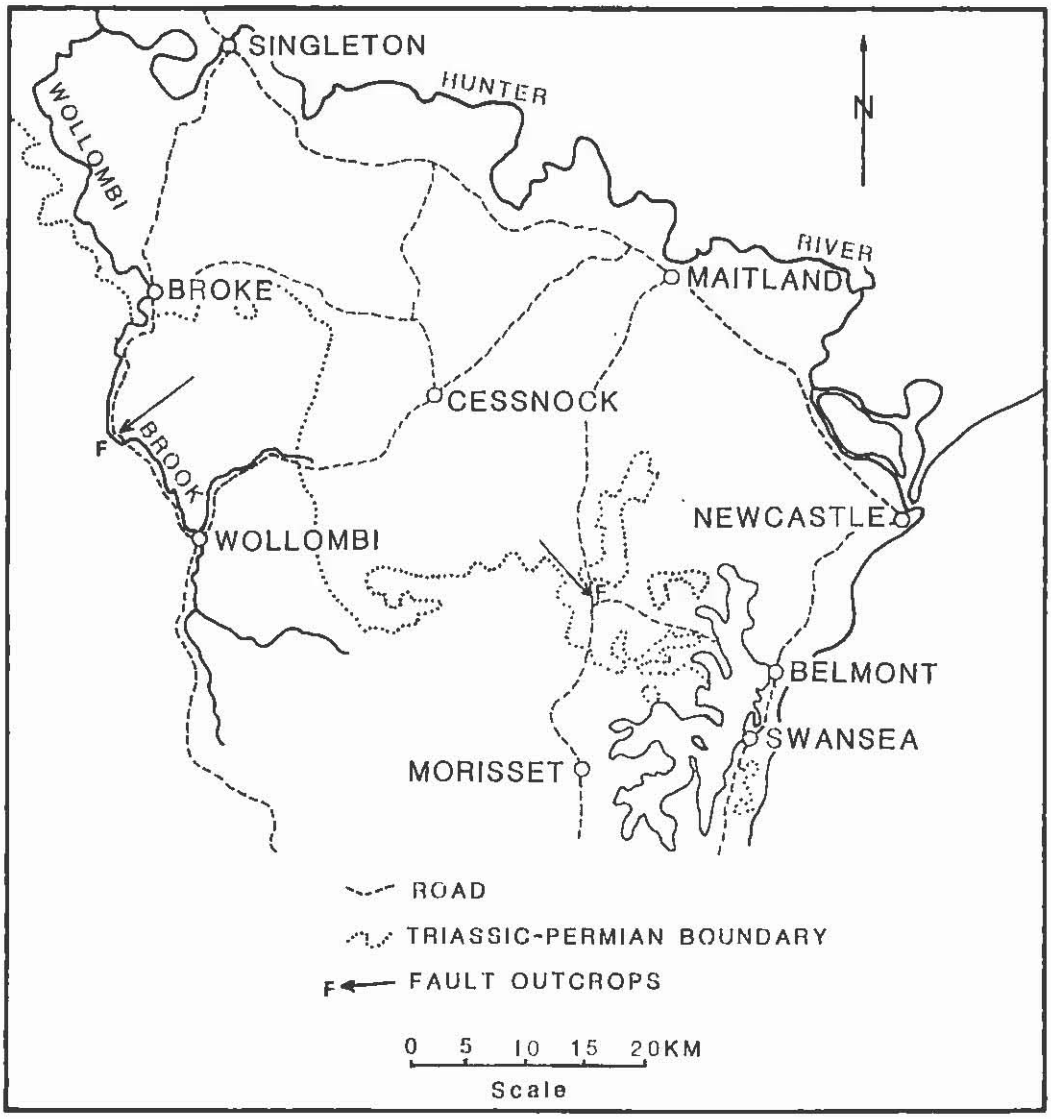

FIGURE 1
Locality Map

ROOF AND FLOOR INSTABILITY WITH THE AWABA TUFF

R. Seedsman

ACIRL, Belambi

INTRODUCTION

The engineering properties of the Awaba Tuff at Cooranbong Colliery are typical of weak and very weak rocks and can be predicted by the careful application of rock mass classification schemes. The Awaba Tuff has lower strength and deformation properties than the Great Northern and Fassifern Coals (Table 1) and is locally the weakest stratum in the Newcastle Coal Measures. The Awaba Tuff is poorly cemented and rich in montmorillonite so that it can behave like an overconsolidated clay. Free swells of 23-41% and swelling pressures of up to 5 MPa have been measured.

Table 1. Mass strength and deformation properties of Awaba Tuff and Great Northern Coal

	Density (Mg/m^3)	Modulus (MPa)	UCS (MPa)	Ø	c' (kPa)
Awaba Tuff	2.2	550	2.8	28	200
Great Northern Coal	1.4	1950	8	30	2000

Given these properties roof and floor instability could result from either a "squeezing" (overstressed) or a "swelling" mechanism. The resolution of the more appropriate mechanism is important as the former leads to a mine redesign to reduce induced stresses while the latter suggests water control as the chief preventative measure. There is no evidence of a high lateral stress field near the coal seams in the southern and western Lake Macquarie area nor is one expected.

ROOF INSTABILITY

An idealised roof profile in the presence of Awaba Tuff consists of 0.5 m of coal overlain by several metres of Awaba Tuff. With such

a profile bolting as a support/reinforcement strategy relies mainly on a friction effect whereby the bolts increase the shear resistance to slip along the interface between strata. This effect has been analysed using shear flow concepts applied to 2 monolithic beams (coal and Awaba Tuff).

Figure 1 gives the required bolt loads to prevent shear for the outermost bolts of a typical bolting pattern. For a 5.5 m roadway, 120 kN loads are calculated for the Awaba Tuff compared to 32 kN in the case of "good" shale (modulus of 10 GPa). The respective pull-out loads are approximately 51 kN and 153 kN giving factors of safety of 0.43 and 4.8. It is concluded that bolting into Awaba Tuff may be ineffective. If the bolts do fail, the coal will sag leaving the tuff unsupported.

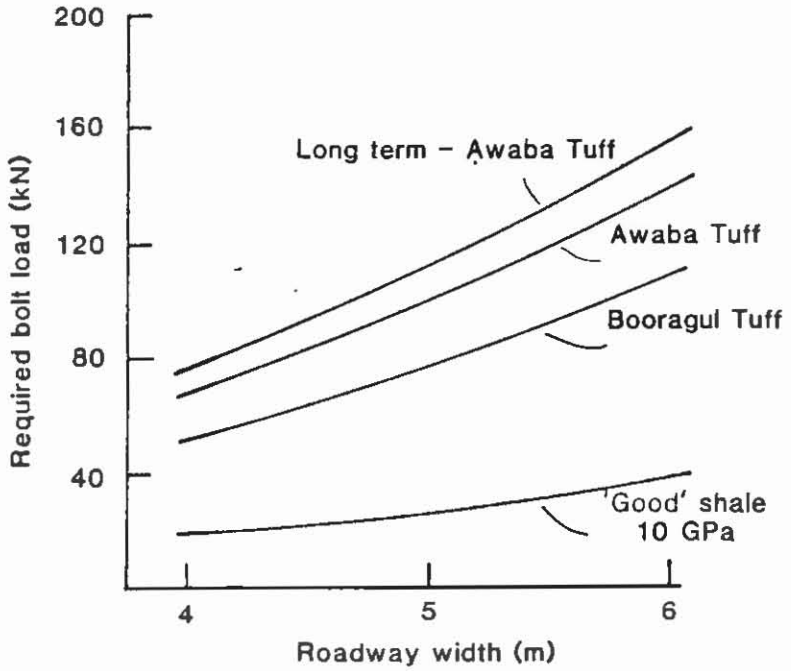

Figure 1. Required loads for the outermost bolts in a composite coal/Awaba Tuff beam with increasing roadway width (50 cm top coal, 5 x 2.5 m bolts, outer bolts 30 cm from ribs).

Voissoir beam theory has been used to analyse roof failure. Voissoir theory predicts that unsupported tuff will fail and thus load the top coal. The effect of loading can be modelled by increasing the effective density of the coal. For the coal thicknesses of interest increased loading reduces the buckling resistance of the coal (Figure 2). The induced stresses in the beam also increase so that compressive failure of the coal is possible as equivalent densities approach 20 Mg/m^3.

It is concluded that bolt failure and roof instability develop due to the low modulus of the Awaba Tuff compared to the coal. In the presence of water swelling pressures in excess of about 300 kPa could

lead to compressive failure of the coal (Figure 2). A flexible support system that would allow up to 10% strain would be required to dissipate such pressures.

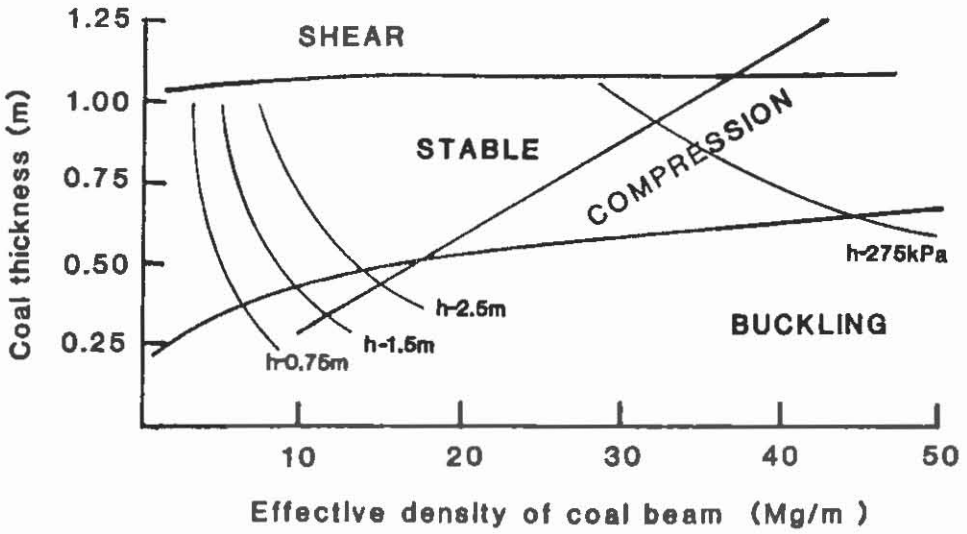

Figure 2. The stability of a loaded beam of Great Northern Coal for a span of 5.5 m (h = thickness of failed Awaba Tuff or swelling pressure).

FLOOR HEAVE

Heave associated with Awaba Tuff ranges from gradual lifting of the floor to complete closure of openings within several weeks. Field evidence shows that the role of water is problematical; in some areas heave only develops in wet sump areas while in other dry areas severe heave occurs.

Immediate elastic heave can account for approximately 12.5 mm of heave. Swelling heave when water is present could contribute 75 cm over 1.5 years or about 30 cm in 70 days assuming 6 m of Awaba Tuff is present.

Factors of safety against bearing capacity failure beneath pillars are approximately 2.6 at 100 m depth and 40% extraction. Although this factor appears high for mining applications it is low compared to values quoted in other studies of coal-mine floor heave. Plate bearing tests conducted by ACIRL (confidential report, 1986) have indicated undrained shear strengths of about 900 kPa for Awaba Tuff at Cooranbong Colliery. Using this value reduces the factor of safety to 1.6.

It is concluded that bearing capacity failure can lead to large scale floor heave by the displacement of Awaba Tuff from beneath pillars. The uneven distribution of heave can be explained thus: large heave results from pillar punching into the floor which requires continued application of load by yielding roof strata. Swelling heave leads to gradual heave in wet areas.

MINING IMPLICATIONS

Water control will be essential but not sufficient for short term stability in the vicinity of Awaba Tuff. Long term roof control may be impossible. A critical appraisal of support/reinforcement strategies is required. The distribution of floor heave depends on the behaviour of roof strata. Bearing capacity failure beneath pillars may mean that yield zones do not form in the pillars but that surface subsidence will be greater than predicted.

ACKNOWLEDGEMENTS

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STRUCTURAL CHARACTERISTICS OF THE SEDAN COAL DEPOSIT : AN EXAMPLE OF TECTONIC ANALYSIS OF DRILL CORES FOR GEOTECHNICAL PURPOSES

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1. INTRODUCTION

The Sedan Deposit, located approximately 80 km northeast of Adelaide, is an important resource of Tertiary brown coal in South Australia. It has been recognized in numerous drill holes and is currently being assessed to determine which brown coal deposit will be selected for the next major power generation project in the State. A detailed understanding of the structure and tectonic processes is necessary for the proper geotechnical evaluation of the deposit and its overburden. Geotechnical and structural studies have been undertaken at the deposit as essential parts respectively of mine planning and assessment of pit wall stability.

As part of the study a programme of field investigation was undertaken. This included locating and studying the few exposures of overburden in the area, particularly along the cliffs of the River Murray. Then tectonic defects in natural outcrops could be compared with those observed in drill cores.

2. GEOLOGICAL SETTING

The coal deposit is situated in the western marginal part of the Murray Basin. The basin developed as an intracratonic depression in response to downwarping of the Cambro-Ordovician rocks which form the basement to the coal bearing formation. The basement is mainly metasediments which have been intruded by numerous granitic rock suites in Ordovician time.

Structural aspects of the area in the geological literature are limited to general remarks by authors who worked on other problems of the Murray Basin, particularly its hydrogeology (O'Driscoll, 1960, Barnett, 1981). It is known that the Sedan Deposit developed east of the Palmer Fault, following its north-south extension. This fault forms the western boundary of the Tertiary sediments of the Murray Basin and Paleozoic - pre-Cambrian rocks of the Mount Lofty

Ranges (Figure 1). It is suggested that more important tectonic lines (lineaments) in the western part of the Murray Basin represent N-S and NW-SE structural directions (Firman, 1970).

The stratigraphy and lithology of the overlying coal-bearing sequences are summarised in Table 1. Within the mineable reserves the coal occurs in two seams. The Towitta Seam (stratigraphically highest) is the principal seam of economic interest and averages 6.3m in thickness while the Lake Moodie Seam averages 5.0m and is separated from the Towitta Seam by a layer of clay about 2m thick .

3. TECTONIC STRUCTURES, THEIR CLASSIFICATION AND CHARACTERISTICS

The coal-bearing sediments of the Sedan deposit have been affected by tectonic activity. However, bedding exhibits an almost horizontal attitude with a maximum dip of beds in the order of 3°.

In contrast, the basement rocks in surrounding surface outcrops exhibit intensive fold deformation, with steep, sometimes vertical bedding and intensive fracture and fault tectonics.

Studies of drill core have revealed a modest number of disjunctive defects of tectonic origin throughout the geological profile. From the detailed logging several types of tectonic defects and also surfaces or zones of weakness resulting from bedding anisotropy or lithofacies changes have been identified.

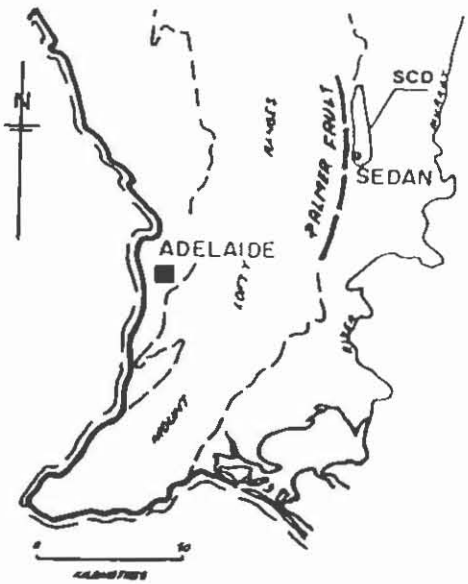

Figure 1. Location Map Sedan Coal Deposit (SCD).

TABLE 1

STRATIGRAPHY AND LITHOLOGY OF THE SEDAN COAL-BEARING FORMATION

AGE		FORMATION	LITHOLOGY	THICKNESS (m)
QUATERNARY	Holocene		Soil - unconsolidated red -brown clays with common quartz sand. Minor but widespread kunkar nodules and sheets.	1 - 2
	Pleistocene	Blanchetown Clay	Red grey green mottled clay, sometimes sandy (and silty)	6 - 20
TERTIARY	Miocene	Mannum Limestone	Marly limestones, calcarenite, quartzose sands and glauconitic clay bands, grey to yellow in colour. Numerous bryozoan and shell fragments.	20 - 35
	Oligocene	Ettrick Formation	Grey-green silty clay, glauconitic and fossiliferous (molluscs). Sometimes contains lenticular black clays and lignite clays towards the base.	Usually less than 10, aver. 2 - 7
	Eocene	Renmark Beds	Towitta and Lake Moodie coal seams underlain by carbonaceous grey, dark brown, well sorted quartzose sands usually porous and unconsolidated, grading upwards into siltstone and mudstone.	0 - 80, aver. 40
CAMBRO-ORDOVICIAN		Kanmantoo Group	Metasediments, granites, gneisses, and intruded granitoids.	Very thick

3.1 Bedding Defects

Bedding is not developed distinctly enough to form frequent anisotropy surfaces. Changes in lithology reveal the attitude of the beds and the most typical *surfaces or zones of weakness* result from sharp lithology changes, particularly along contacts between bands of soft rock, even loose sand, with strongly cemented and hard beds of organogenic and sandy limestone. Such a tendency to abrupt changes is typical within the Mannum Formation and sometimes also occurs within the Ettrick Formation.

A few *thin plastic clay intercalations* have been noted throughout the geological profile at Sedan. In some such clayey horizons there are slip surfaces which probably indicate diagenetic adjustments . These are manifested by polished, irregular *slip surfaces* in the bedding plane, particularly in zones where there are sharp lithology changes. A continuation of these diagenetic movements was a horizontal tectonic transport along the bedding producing *shear surfaces* with tectogliphes, mainly tectonic scratches. The two processes have contributed to progressive development of bedding defects and, in this way, to anisotropy and weakness of the rock mass.

On the other hand, indications of *extension along bedding partings* have also been recognised. Mineralization, mainly sulphide, occurs on these surfaces, even as thin bands in some instances. These types of bedding feature correspond to weak horizons because they are structural planes along which release of extensional stresses has taken place.

3.2 Low Angle Defects

Two genetic types of low-angle defects (up to 25°) are distinguishable in drill cores. Smooth and slickensided surfaces indicate the major role of shearing whereas defects characterised by rough or flat surfaces coated mostly by silty quartz sand were generated with a strong influence of extensional factors. However, low-angle defects seem to be a rather sporadic feature of Sedan coal-bearing formation.

3.3 Defects of Normal-Slip Type

Surfaces dipping between 50-65° predominate within the fracture network. These are shear failures. On these surfaces tectogliphes such as tectonic scratches and steplike breaks can be seen. They indicate tectonic shearing parallel to the dip direction of the defects. It indicates tectonic transport in a vertical plane, due to the normal (gravitational) stress field.

Specific transitions occur from the bedding slide/shear defects into normal-slip surfaces of shear origin. It suggests an interference of tectonic movement along the bedding and normal-slip shearing. Co-existence of more *plastic* and more *brittle* types of shear failures is interpreted here as a result of long-lasting normal-slip tectonic movements which probably started in an early diagenetic stage (the origin of more plastic defects) and were continued as an epigenetic process (the origin of more brittle defects).

3.4 Vertical and Near Vertical Defects

This type of joint is a moderately frequent feature of the Sedan deposit and is represented by fractures which display a reasonable cathetal (perpendicular) relationship to the bedding planes. The vertical and near-vertical pattern of these joints results from flat planes of beds to which they have developed as perpendicular structures. These joint surfaces show variability of morphological features among which an extensional type of failure prevails.

Shearing along these defects appears as a secondary feature superimposed on primary extensional fractures. Then, extension, a typical genetic factor forming the cathetal joint, was followed by the shearing,most probably the same which produced normal-slip structures.

4. STRUCTURAL PATTERNS AND CHANGES OF DEFECT FREQUENCY

Defects which have been identified within drill cores form patterns which correspond to structural trends of the region. It is considered that the north-south trends of normal-slip defects would be predominant following directions in the underlying and surrounding basement rocks. However, the NW-SE structural direction of normal-slip structures also seems to be accentuated.

The vertical and near-vertical cathetal joints are probably composed of the two principal systems of fractures, each consisting of two orthogonal conjugated sets. Their trends correspond to directions of such fractures within the Tertiary sediments of the Murray Basin (O'Driscoll, 1960). The most intensive seem to be joint sets in a north-south direction which are conjugated to orthogonal less intensive east-west striking sets of defects. The north-south trending joints represent longitudinal structures and the east-west would be transverse in relation to the deposit's north-south extension and the Palmer Fault trend. The two other sets of joints should be understood as diagonal fractures representing structurally accentuated NW-SE and, orthogonally conjugated to it, SW-NE fractures.

There is a variable defect intensity in the geological profile of the Sedan deposit. In addition there are visible changes of the geometry and genetic character of defects. In the upper part of the sequence, within Blanchetown Clay, there are very frequent polished surfaces and slides which are associated with specific seasonal changes of water content thus producing normal-slip or reverse-slip structures (cf. Stapledon, 1970). Less numerous, vertical and almost vertical joints have also been recognised within the Blanchetown Clay.

In the Mannum Formation there are mainly cathetal joints of a modest frequency. In the underlying Ettrick Formation the number of the same tectonic defects decreases.

By contrast, in the coal seams there is an increase in defect frequency, both of normal-slip and cathetal type. In the clay interburden which forms a clear marker separating the coal seams, slide surfaces frequently occur along the bedding. These are typical in clay sequences within the Renmark Beds.

5. TECTOGENETIC ASPECTS OF ROCK DEFECTS

The influence of tectonic factors on the Sedan Coal Deposit is manifested in weaknesses along the bedding surfaces and in the origin of low-angle dipping, normal-slip and vertical fractures (Figure 2). The defects form low strength surfaces or zones and therefore have a major impact on physical properties of rock and on all aspects of pit slope stability. Genetical features of tectonic structures indicate that tectonic processes which affected the deposit deformation were connected with:

- the structural framework of the basement and its vertical instability (Figure 2A),

- normal (gravitational) stress field (Figure 2B).

However, the patterns and character of fractures change considerably through the vertical profile of the coal-bearing sediments, suggesting the additional influence of lithology and other factors on defect development. This is particularly well observed in the deformation of the Blanchetown Clay which is related to the underlying beds of Mannum Limestone. It seems that karst processes or washed out loose sandy zones within the Mannum Formation have produced collapse structures in these sediments thus generating rock deformation within the covering Blanchetown Clay sequences. It is especially well manifested on the contact between the two formations (Figures 3 and 4).

SEDAN COAL DEPOSIT TECTONIC ANALYSIS

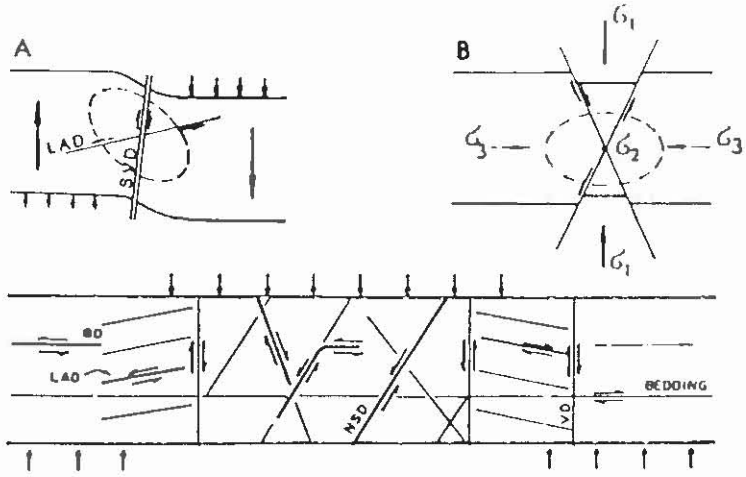

Figure 2. Generalized scheme of defects and their origins (A and B), Sedan Coal Deposit. BD - Bedding Defect, LAD - Low Angle Defect, NSD - Normal Slip Defect, VD - Vertical Defect SVD - Sub-Vertical Defect.

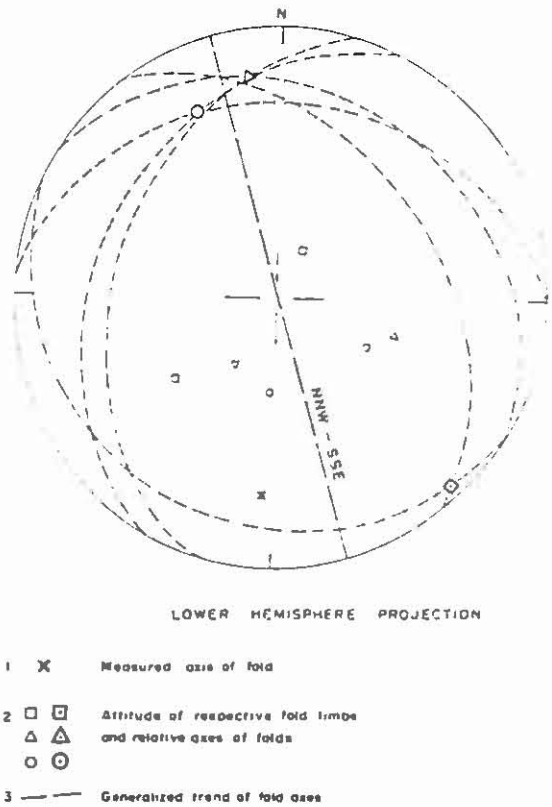

Figure 3. Interpretation of folds along the contact between the Blanchetown and Mannum Formations, Swan Reach.

In deeper parts of the Sedan sequence (within the Renmark Beds) there is a tendency to an increased frequency of polished, bedding slip and shear planes. It is interpreted as a result of the increasing role of weight of overlying rocks on compactional adjustments along surfaces creating weak bedding planes, and then continuation of these processes by tectonic shearing in the same plane.

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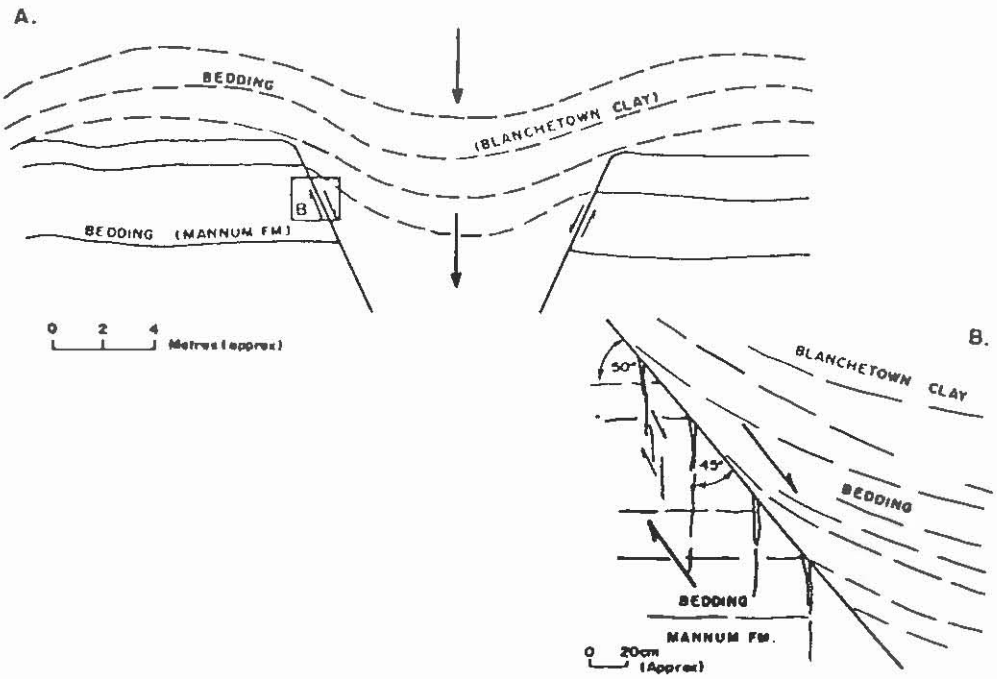

Figure 4. Sketches of small structures developed on the contact between Blanchetown and Mannum Formations, Swan Reach.

THE GEOTECHNICAL INVESTIGATION FOR THE F3 FREEWAY NORTH OF PALMERS ROAD : SITE GEOLOGY AND INVESTIGATION TECHNIQUES

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INTRODUCTION

In January 1986, the Department of Main Roads began preparing final designs for the next section of F3 freeway north of Palmers Road, near the village of Wakefield in the Lake Macquarie City Council area (Fig. 1). Preliminary design and investigation work revealed that the design would be heavily dependent on controls such as the adjacent gas and liquid products pipelines and the nearby Wakefield Road reconstruction.

A further and possibly the most important control was the site geology and the ultimate stability of the freeway cuttings and embankments. The section falls entirely within the Permian Newcastle Coal measure sequence (Fig. 2) and has a high proportion of poor construction material. The combination of spatial restrictions and the coal measure sequence materials dictated that an extensive geotechnical investigation would be required to produce an effective design.

In May 1986, the D.M.R. commissioned the consultants Longworth and McKenzie to prepare a geotechnical report for the length from Palmers Road to Minmi. This paper describes the site geology and the investigative techniques used for the first section (approx.7km.) of that study which terminates near the village of Killingworth. This section involves eight major cuttings with depths of up to forty metres.

SITE GEOLOGY

The section is situated on the western flank of the Macquarie Syncline and is influenced by the Lochinvar Anticline to the west. There is considerable thinning of formations from type sections which are typically located further east. In addition, splitting and coalescing of various coal seam makes correlation difficult. Formations are generally finer grained than in type sections and actual occurrence of conglomerate is rare along the proposed freeway site.

SITE PLAN

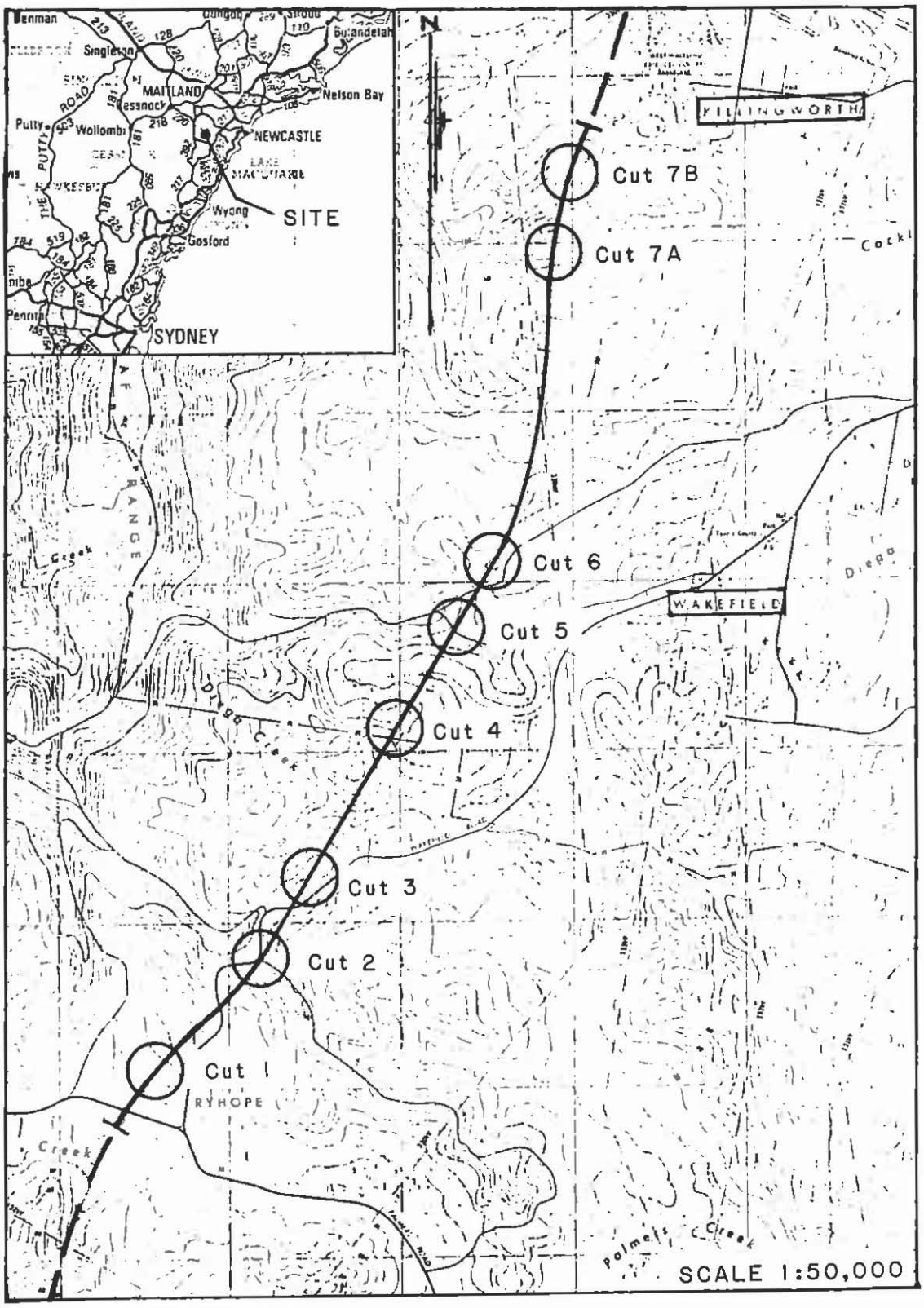


Fig. 1

The sequence includes rocks from the Moon Island Beach, Boolaroo and Adamstown Sub-groups. Contrary to the generally southern dip of the Newcastle Coal Measure sequence, the stratigraphically lowest units were found in Cut 1 at the southern end of the site and consist of sandstone and siltstone beds underlying the Montrose Seam. The Fassifern seam and associated Awaba Tuff were encountered in Cut No's 4, 5, 6 and 7A. Cuts 5, 7A and 7B also encountered a sandstone unit possibly correlating with the Eleebana Formation.

The dip of beds along the site is variable but for the greater part favours a northerly direction. Beds in the southern most cut (Cut 1) show a dip to the southeast. Beds in Cuts 2 to 4 dip to the east and northeast whilst in Cut 7A a dip to the northwest is evident. The dip of the beds along the site may have been influenced by factors evident in the Heaton Gap area to the west.

Fault and dyke structures along the site are not easily identifiable in the field but are known to exist from mine plans to the east and magnetic surveys. Regional trends in the northwest - southeast direction dominate with fault displacements of less than 2 metres most common.

Jointing is typically sub-vertical and displays a consistent trend parallel to the fault and dyke structures. Subsidiary joint directions are evident in all areas mapped, and in some cases have become the local dominant direction. The joints are frequently iron stained and in many cases are infilled by a dark grey to black clay.

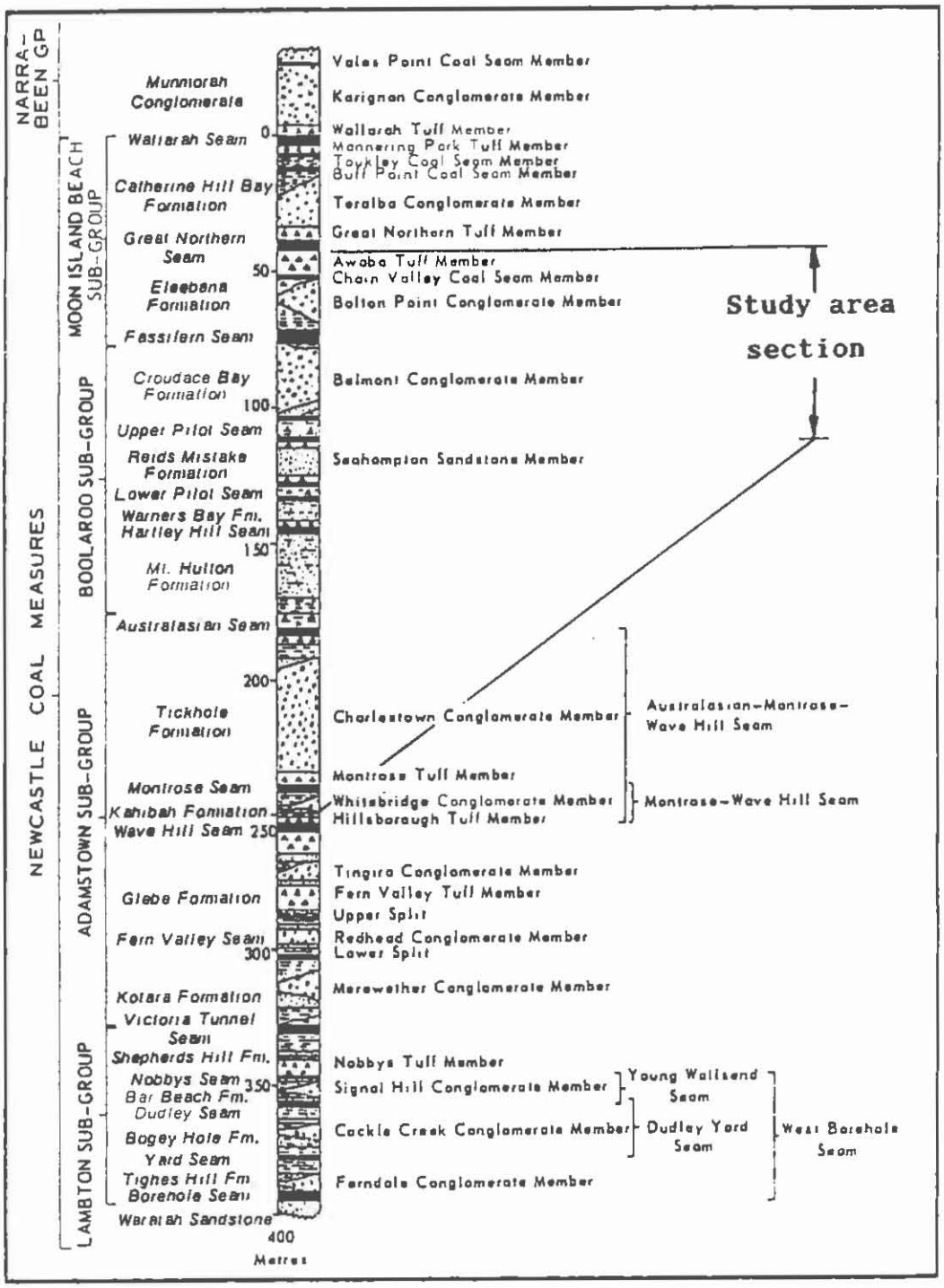
The materials encountered during investigations included conglomerates (minor), sandstones, siltstones, claystones, coals and tuffs typical of the Newcastle Coal Measures.

For the purposes of identifying rocks with similar engineering properties, the sedimentary rocks in the study area have been classified into six major units;

i) Sandstone
ii) Siltstone
iii) Carbonaceous Siltstone
iv) Claystone (associated with a coal seam)
v) Claystone (not associated with a coal seam)
vi) Coal

Hence, rocks that may be more rigorously divided into tuffs, claystones and tuffaceous claystones have been combined as claystones (eg. Awaba Tuff).

STRATIGRAPHIC COLUMN OF THE NEWCASTLE COAL MEASURES



By Diessel, 1980

Fig. 2

F3 FREEWAY INVESTIGATION

DESIGN CONSIDERATIONS

The engineering properties of the coal measure materials pose significant problems in terms of road design and construction. There is a wide variation in strength from very high strength sandstones to low strength claystones which are interbedded in irregular sequences. This results in low strength layers occurring at varying depths within deep cuttings of otherwise higher strength materials, which can influence stress regimes after excavation.

The materials show significantly differing properties to sandstones and shales in which large freeway cuttings have been constructed to the south of the site. The claystones have varying in-situ strengths but invariably deteriorate rapidly on exposure. Sandstones are typically of tuffaceous origin and whilst exhibiting similar compressive strengths, have lower shear strengths than the Hawkesbury sandstones to the south.

INVESTIGATION TECHNIQUES

The design controls and the nature of the geological materials made it necessary to employ many different techniques. Some of these techniques are briefly described as follows;

1. Borehole Drilling and Test Pitting - over 50 boreholes have been drilled on this section including slimline and large diameter for bulk sample testing purposes. Maximum depth is approximately 55m. The holes were drilled at proposed cutting and bridge sites and included both vertical and inclined holes for either stratigraphic, geotechnical or design purposes. All core was logged, photographed, surveyed and where appropriate, sampled for testing purposes.

Groundwater was monitored in boreholes using both standpipe and pneumatic piezometers. Permeability was estimated by packer testing in selected boreholes and water samples tested for conductivity and acidity.

Test pits and costains were excavated and logged on the flanks of cuttings, at selected sites along proposed embankments and in areas of specific interest.

2. Seismic Refraction - this type of geophysical survey is a powerful tool in road investigations as seismic velocities combined with other geological information give an indication of the rippability or excavatability of strata within a cutting.

3. High Resolution Geomagnetic Survey - this work was carried out to locate dyke and if possible fault structures in proposed cuttings. This work was also correlated with a previous adjacent geomag survey and an aerial geomag survey of the general area carried out for B.H.P.

The survey was carried out by making a number of parallel traverses across each cutting and recording any anomalous magnetic traces. Areas where lineaments could be seen from aerial photographs were targeted for coverage.

Problems with this type of survey on the F3 site included interference from power lines, underground pipelines and general rubbish including old car bodies which litter this area.

4. Hydraulic Fracturing - the procedure known as Hydraulic Fracturing is a technique by which the in-situ stress of a particular body of rock can be estimated. The test involves actually fracturing targeted zones within the strata by hydraulic pressure and then measuring that pressure and the attitude of the fracture to derive in-situ stress magnitude and orientation.

One site only was examined for in-situ stress, that being Cut No 2. This site was selected because of the high strength and unusual fracturing of the predominantly sandstone rock which exists at this site. High stresses were also known to exist at depth in the general area.

The results of this test which did show a high in-situ stress is of particular importance in the design of Cut 2. Allowance has been made for the likely inward movement and residual strengths due to stress relief after excavation.

5. Laboratory Testing - a wide range of tests were carried out to characterise the materials. The testing programme included;

* Material classification - includes Atterberg limits, material density and moisture content, and gradings.
* Erosion properties - included Emerson crumb test, core slaking and exposure procedures.
* Mineralogy - procedures were XRD and thin sectioning.
* Shear strength and consolidation - included shear box testing, Triaxial tests, UCS, rock modulus and shear tests.
* Compaction - both standard and rapid techniques used.
* California Bearing Ratio - as per D.M.R. test method.
* Reactivity testing - includes core shrinkage, oedometer swell and soil suction.
* Chemical testing - ph, conductivity, Fe and salt contents.

Control testing on selected samples was also carried out by separate laboratories to confirm that results were representative.

6. Monitoring - during and after construction, a programme will be undertaken to monitor stability. This will include precise survey work, acoustic emission and inclinometer monitoring. For the post-construction monitoring to be indexed, a series of background measurements and assessments will be made prior to the commencement of work.

CONCLUSION

The nature of the materials and site constraints dictated that a detailed geotechnical investigation was essential. The investigation for the first section took approximately eighteen months to complete with the final report comprising six volumes of text and supporting data.

The site conditions resulted in some techniques being used that are not readily available for more routine investigations. The procedures and experience in utilising these techniques will be invaluable for future road investigations.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance and co-operation received from all parties concerned with the preparation of both the geotechnical report and this paper.

The authors also wish to thank the Department of Main Roads for permission to publish this paper.

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CRACK FORMATION AFTER CYCLIC LOADING OF ANISOTROPIC SEDIMENTARY ROCKS

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ABSTRACT

The definition of the deformation modes and fabric movement paths within anisotropic sedimentary rocks under cyclic loading has been attempted.

The research work is based initially on a definition of crack systems (two- and three-dimensional) and on the identification of strengthening effects caused by fabric adjustments.

The aim of the research is the establishment of a model representing the stages in the cyclic deformation processes which are interaction events between "damaging" processes and "fabric modification" processes. The fabric of the anisotropic rocks is subjected to "loosening" and "strengthening" episodes in the modification process.

A distinct phase in the deformation process has been identified in the form of an interruption of reactions to loading (delayed reaction factor), probably caused by the loosening element of the modification process. The cracking modes, interactions of these deformation processes, mechanical behaviour and properties, such as K_{ic} and strength, are found to be strongly dependent on the geometry relations, fabric aspects, especially the characteristics of matrix and cement, and the boundary conditions of sedimentary rocks, and the loading conditions. For certain geometric configurations, the mechanical properties seem to be the measure of the initial fabrics, the modified fabrics and the "delayed reaction factor." Consequently, they may well be sensitive to changes of either fabric aspects or loading conditions, and the rocks may behave quite differently than expected or even fail "unexpectedly." A physical basis for the frequency effects is established; the frequency effects may be either linear or non-linear, depending on geometric relations and crack modes.

Low frequency loading of sedimentary rocks with preferred dimensional orientation may be responsible for the development of a crack type comparable to that known as fatigue cracks in metals. The

preferred dimensional orientation has originated from fluvial processes, with "current" and "gravity" being the orienting vectorial attributes.

Specimens from Permian coal measure strata and overlying Triassic sedimentary successions in the Sydney Basin of New South Wales have been investigated in the first stage of this programme. Machined specimens of medium- to coarse-grained sandstones with varying degrees of anisotropy have been tested in a MTS model 810.03 closed-loop electro-hydraulic testing device. Load cycles ranging from 41 to 695 cycles have been applied to bar shaped specimens cut from bore cores and handspecimens. The load levels have ranged from 40N to 560N.

Three components, well defined according to size, namely clasts, matrix and cement can be distinguished. The clasts consist of lithic fragments, detrital quartz and feldspar, and several accessory minerals. The matrix is commonly a smaller fraction of the clasts, and the cement is either siliceous, argillaceous or is made up of calcite.

The rocks studied and tested so far in this research programme have been selected primarily on the basis of engineering significance and from a "performance under load" viewpoint. Rocks from a deep (60 m) roadcutting under high lateral pressure with episodic energy release have been studied, as well as rocks from roofstrata subjected to low frequency cyclic loading in longwall extraction panels of several collieries. Those rocks have been compared with borecores from similar or identical sedimentary strata, that have not experienced superposed engineering loads.

The fatigue cracking processes in sedimentary rocks under cyclic loading are fundamentally different from those observed in metals in several aspects; this is principally due to the distinct differences in the fabrics of rocks and metals. Experimental observations of the mechanical behaviour of test specimens and of the microscopically developed crack patterns and "fracture process zones" at different deformation stages, point to the significant role played by the rock fabric anisotropies. The nature of the crack processes and propagations in fabrics with varying geometries, and the different types of strength anisotropies are discussed.

Cracking has been observed early at low stress levels. This initial deformation is commonly stabilised by "fabric re-adjustment" processes, which are different from the strain-hardening processes observed in metals. The nature of the geological components is responsible for the different response pattern in rocks. The readjustment of the fabric components to the brittle deformation appears to be an important factor of the total deformation process and is demonstrably highly direction dependent.

It is suggested that some cyclic loading can be safely sustained by anisotropic sedimentary rocks, if the geometric relationships

between the spatial attitudes of fabric components and stress geometries are favourable. A cyclically induced crack type in anisotropic sedimentary rocks can possibly be defined as a fatigue crack in the accepted sense of the term, but not with regard to the fracture mechanism which is considerably more complex.

The formation of "fatigue" cracks in anisotropic sedimentary rocks is also significantly influenced by the effects of unloading and cycling; it involves the interaction of the elastic field and the *cracked* field during cyclic loading and not the *plastic* field. This is an important result of the work and has implications for several aspects of the rockmechanics of sedimentary rocks.

STRUCTURE AND ENGINEERING IMPLICATIONS OF OFFSET DYKES OF THE SYDNEY BASIN

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University of Technology, Sydney and
Macquarie University

SUMMARY

Some dykes of the Sydney Basin, hosted by rocks capable of forming close spaced jointing, comprise en echelon arrays of dyke segments. The offsets form during intrusion and a study of their morphology and relations to fractures may help in determining the intrusion mechanism and in the geometric optimization of excavations which intersect such dykes.

INTRODUCTION

Many of the dykes in the Sydney Basin, hosted by rocks other than sandstone, are offset rather than forming simple tabular bodies. These offsets do not occur as post-emplacement disruptions by faulting but are formed during emplacement.

Offsets form when magma intrudes simultaneously along a number of similarly oriented, but offset, fractures. As magma advances the fractures dilate and propagate laterally towards each other until, due to misalignment, the fractures attempt to overlap. The discrete dyke segments may link by breaking the bridge of rock which separates them leaving wall-rock jogs or steps (Nicholson and Pollard, 1985). Alternatively, the dyke segments may attain stable dimensions in the plane normal to the magma flow direction (Pollard et al., 1982) and remain as discrete segments.

If the host fractures comprise a joint set which occurs only in the proximity of the dyke these fractures were probably formed by tensile stress at the tip of the advancing magma (Delaney et al., 1986). If the host joint set has a consistent distribution away from the dyke these fractures are often described as being "pre-existing" the inference being that they relate to an earlier and different stress field from that governing intrusion. But the relations between a well distributed joint set and a dyke are not simple as it is also possible that an evenly distributed joint set is "syn- or post-emplacement" formed in the same stress field as emplacement. Determining temporal relations between jointing and dykes is essential to understanding the mechanism of intrusion

but is beyond the scope of this study.

One explanation for the en echelon arrangement of dyke segments is that as the dyke advances the orientation of the minimum principal stress axis (σ_3) changes. Rather than the entire sheet rotating to this new orientation the dyke forms segments which rotate as helices to be perpendicular to the new σ_3 direction (Pollard, 1975). This model requires that the host fractures are formed by the intrusion. In contrast, if the host joints were pre-existing (an even distribution of joints away from the dyke is insufficient evidence) and formed in a stress field different from that governing intrusion then the en echelon arrangement may be formed simply because the joints are oblique to σ_3. In this case the gross trend of the dyke is perpendicular to σ_3.

FIELD DATA

Data are presented from dykes exposed on rock platforms at Long Reef (442650 - Mona Vale), Port Kembla (085809 - Wollongong) and Norah Head (676164 - Toukley) and at Prospect dolerite quarry (070550 - Prospect) (1:25000 series CMA) (Fig.1).

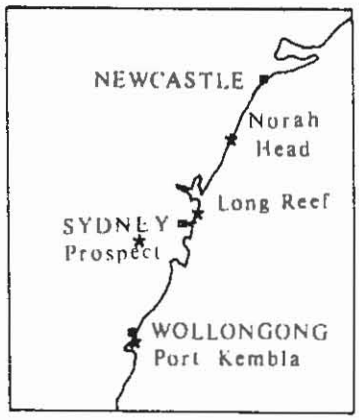

Figure 1 Field Locations

At Long Reef 250m of mafic dyke trending 335° and dipping about 80° to the NE is exposed in claystone. Of the three joint sets on the rock platform one is parallel to the dyke and more closely spaced adjacent to the dyke. The other two joint sets complete an equi-angular pattern and penetrate the dyke and so almost certainly post-date intrusion. Of the three faults which cross the dyke one has no effect on the dyke and is thus pre-emplacement, one becomes a host fracture for intrusion and is either pre- or syn-emplacement and one truncates the dyke and is post-emplacement.

The dyke comprises about 17 discrete segments which have a consistent en echelon arrangement; each successive segment being offset to the left (Fig. 2a). Most of the offsets have a spacing of about 0.75m and abrupt terminations with little overlap (Fig. 2c). In contrast, one offset has tapered terminations, an overlap of 5m and a spacing of 2m (Fig. 2d). This difference in morphology suggests that, at small spacings, overlap is prevented by the high magma pressure in each segment. The hooked apophyses seen in figure 2d are probably due to local reorientation of stresses as a result of the interaction of the two fractures (Pollard et al., 1982).

The bridge rock between segments is characterised by fractures, brecciation (Fig. 2c), and sub-horizontal planes with slickenlines (Fig. 2d).

At Port Kembla more than ten dykes trending 125° intrude the latite rock platform. Two joint orientations oblique to the dykes form a diamond pattern which can be traced through the dykes. In the vicinity of the dykes are a parallel set of joints. Numerous low angle planes with slickenfibres occur between dyke segments. Although the geometry is complicated by the number of parallel segments a consistent left handed sense of offset can be determined (Fig. 3a). In a profile seen in the headland (Fig. 3b) an offset at a lithological boundary can be seen.

At Norah Head two orthogonal dykes, parallel to two orthogonal joint sets, have numerous small wall rock jogs, but only one complete offset was found (Fig. 4c). A profile of the NE trending dyke in the headland shows a 0.2m offset at a bedding plane (Fig. 4b).

At Prospect two narrow (0.2m) dolerite dykes intrude a roof pendant of Ashfield Shale over the Prospect Intrusion. These dykes are offset at bedding planes (Fig. 4d).

DISCUSSION

Formation

Dykes in the Sydney and Newcastle districts originated from deep crustal fractures whereas dykes in the Wollongong area are thought to be part of a radial swarm (Rickwood, 1985). Discrete dyke segments place some control on the interpretation of magma flow direction and indicate a component of flow normal to the plane of exposure. The similar shape of each termination at offsets suggests any component of flow in the plane of exposure is small and so a sub-vertical magma flow direction is inferred at Long Reef, Port Kembla and, at least in part, at Norah Head. At Long Reef and Norah Head this is consistent with their proposed origin. If the dykes at Port Kembla are part of a radial swarm then although the central magma body has controlled the fracture pattern the magma has invaded the fractures from depth in contrast to the sub-horizontal magma flow directions proposed for some radial dyke swarms (eg. Baer and Reches, 1987).

Figure 2. a) Long Reef location map. b) Part of Long Reef dyke with selected joint orientations. c) An abrupt offset from location C with brecciated bridge. d) A tapered offset from location D. with selected low angle reverse fault orientations in the bridge.
Figure 3. a) Port Kembla location map. b) Map of selected dykes and associated joint orientations. c) An abrupt offset; the narrow bridge rock has suffered only minor fracturing. d) Offset at stratigraphic boundary seen in Profile on headland.
Figure 4. a) Norah Head location map. c) The only complete offset of the dykes seen. b) Offset at stratigraphic boundary seen in profile in the headland. d) Dolerite dykes exposed at Prospect Quarry are offset intermittently at bedding planes in the finely bedded shale.

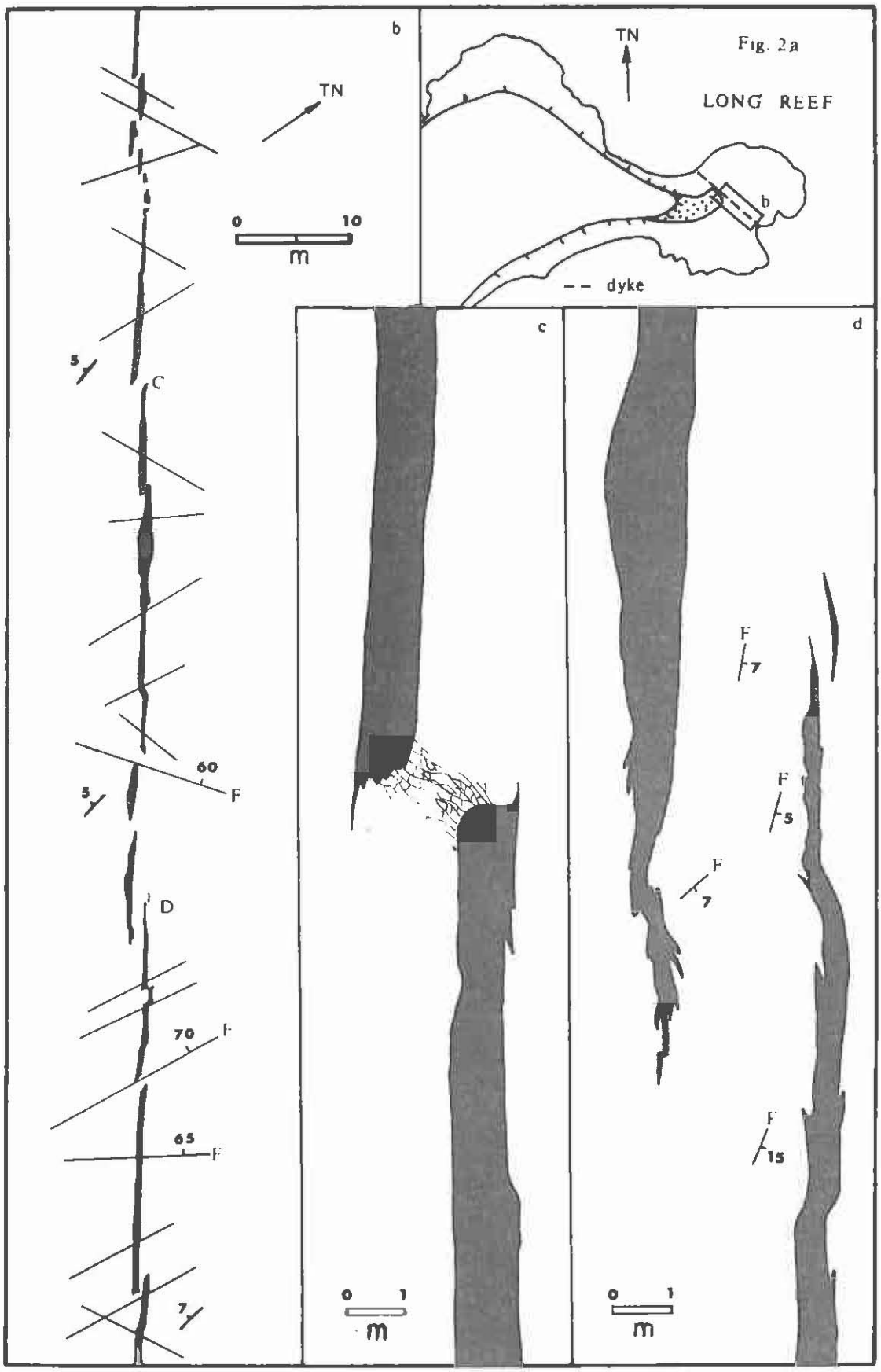
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Fig. 2a
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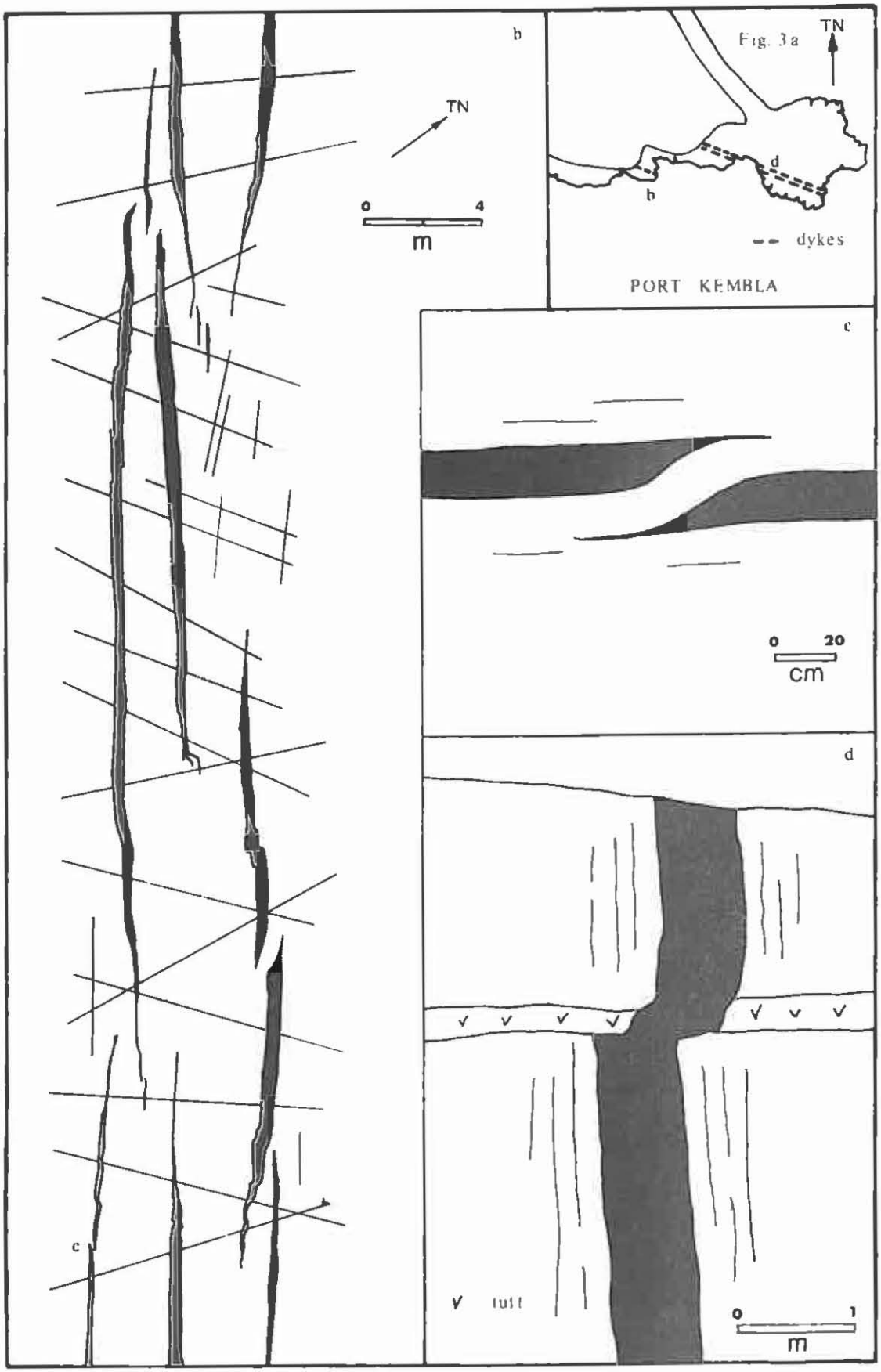
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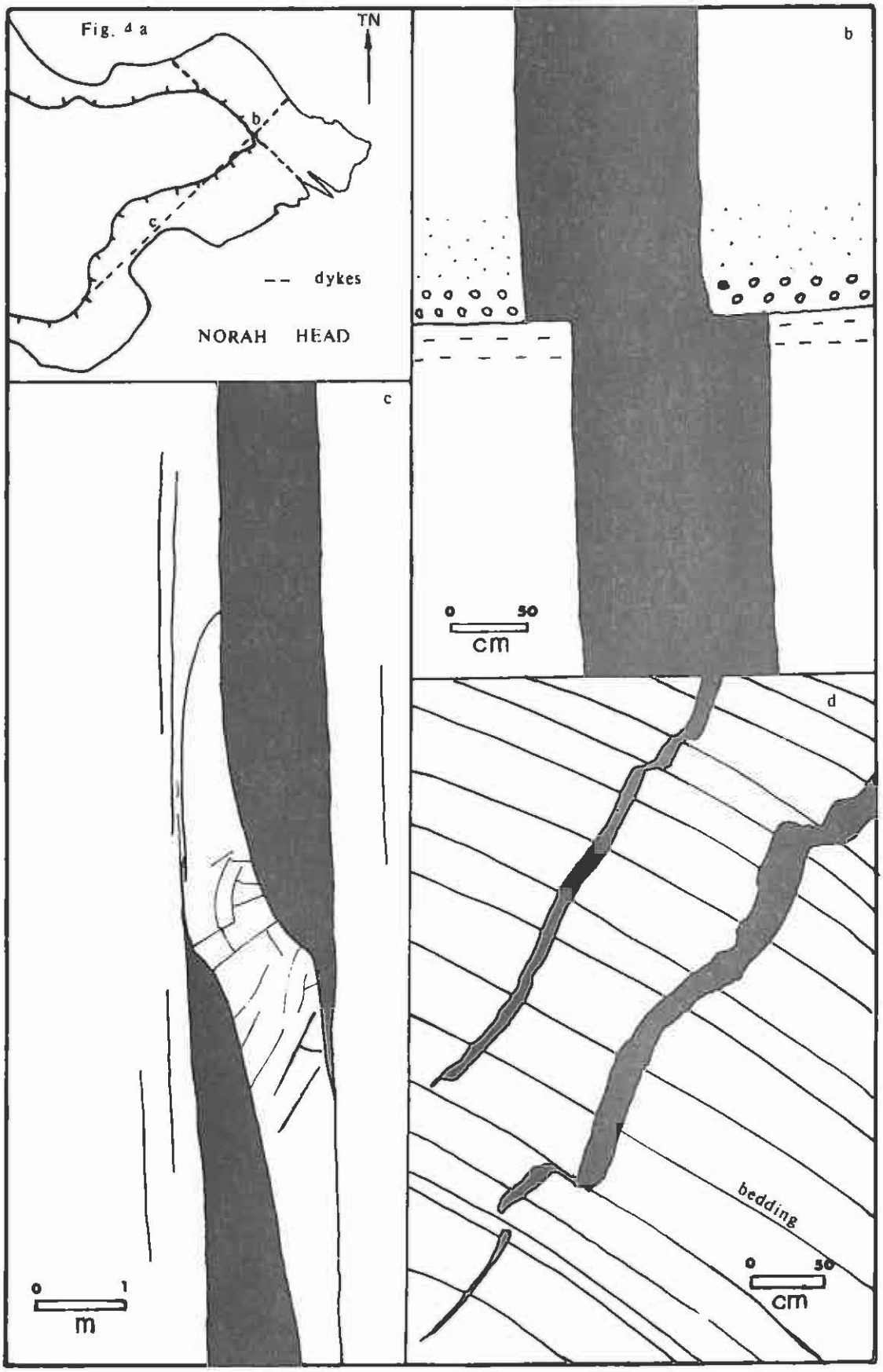
Fig. 4 a
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NORAH HEAD
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Detailed study of the distribution and orientation of joints over an extended area at each locality would be required to establish the relations between dykes and joints and propose detailed intrusion mechanisms, but the following comments may be made. At Long Reef the dyke-parallel joint set is only intermittently found away from the dyke; this is consistent with intrusion and the joint set forming together. At Port Kembla dyke-parallel joints are restricted to the proximity of the dyke and so are probably generated by intrusion. At Norah Head the joint sets are ubiquitous and seem likely to have pre-dated the dykes although some fractures have formed during intrusion (Fig. 4c). At Prospect other fractures have formed parallel to, but more than 5m away from, the dykes indicating jointing and intrusion occurred in the same stress field.

Engineering Implications

Offsetting is not an extreme case of "pinch and swell", in fact, the segments maintain remarkably constant thickness between offsets. The geometry of these dykes is systematic and predictions of their structure may be made from limited data if the parameters of their formation are understood.

Drilling through dyke arrays may give spurious intersections such as no dyke at all or two dykes where only one exists. But features characteristic of offsets such as intense fracturing may be correlated with the dyke. Where an excavation, such as a tunnel, is to intersect a potentially offset dyke establishing the location of offsets is important since bad ground at an offset may be three or four times the normal width of the dyke. Geometric optimization of an excavation in relation to an offset dyke requires locating a continuous segment of the dyke by careful study of a number of drill holes.

CONCLUSION

Poor ground conditions between and adjacent to segments, largely reflecting mechanism of emplacement, necessitates careful examination within the context of civil and mine engineering activities.

ACKNOWLEDGEMENTS

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SYDNEY FAULTS : FACTS AND FANTASIES

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Macquarie University[2]

Introduction

Continuing development in the Sydney region (Fig.1) is providing many new exposures in building sites and road cuttings which help expand our knowledge of the structural geology of the region.

In previous papers (Branagan 1969, 1977, 1985, Norman and Branagan 1984) information on faults in the Sydney region was presented and discussed. Norman (1986) and Herbert (1986) presented other data and together with Branagan (1985) referred to earlier work.

Norman and Branagan (op cit), based largely on study of the Ashfield Shale at St. Peters, suggested four types of faulting present in the region, viz steeply-dipping normal faults, high angle reverse faults, low angle thrust faults and steeply-dipping strike-slip shear zones (often brecciated). Branagan (1985) and Norman (1986) documented and illustrated these various fault types and quantified the movements to some extent.
This paper documents (a) a number of sites where low-angle thrusts have been mapped and (b) several sites where various fault types occur in close proximity.

A revised synthesis of the tectonic history related to faulting is presented.

FACTS

Faulting discussed in this paper occurs within the Triassic Hawkesbury Sandstone and the overlying Mittagong Formation and Ashfield Shale. The locations of the faults mapped are shown on Figure 1, and listed in Table 1. (thrusts only).

Low Angle Thrusts

Recent exposures in excavations in the Sydney city area (Figs.2 & 3) show a series of low-angle thrusts dipping easterly at less than 20°.

Table 1. SELECTED REVERSE FAULTS - SYDNEY AREA

Location	Grid Ref.*	Attitude	Bedding dip	Throw
A Comenarra Parkway, Lane Cove River	230-656	014°/14°E	3°W	30cm
B Comenarra Parkway, Lane Cove River	234-656	050°/66°W	3°W	?
C Delhi Road, Fullers Bridge	290-592	014°/15°W	SW?	?
D Warringah Expressway, Chandos St. exit	338-559	NS/18°W	2-3°E	1m
E Warringah Expressway, south west side	339-559	035°/18°W	2-3°E	1m
F Warringah Expressway, south west side	341-558	NS/7°W	190°/10°E	Few cm
		067°/23°NW	E	?
		NS/10°E	E	10cm
G Warringah Expressway, Miller St. bridge	343-557	033°/23°W	3°E	2cm
		? /10°W	4°E	?
H Excavation above tunnel William St., Kings X	358-501	007°/10°E	5°W	50cm
I Excavation, cnr. Market & Pitt Sts., City	342-505	NS/15-20°E	3°SE	30cm
J Excavation Waltons site, George/Park Sts., City	340-504	170°/15-20°E	2°SE	?
K Excavation, Horderns, George/Goulburn, City	341-497	NS/15°E	2°W	?
L Ashbury Brickpit**	263-473	085°/56°S	7°NW	?
M Cahill Expressway, Art Gallery of NSW	350-509	012°/12-25W	2°W	2m+?

* Grid references Sydney 1:100,000 topographic map.
** Ashfield Shale, all others in upper Hawkesbury Sandstone.

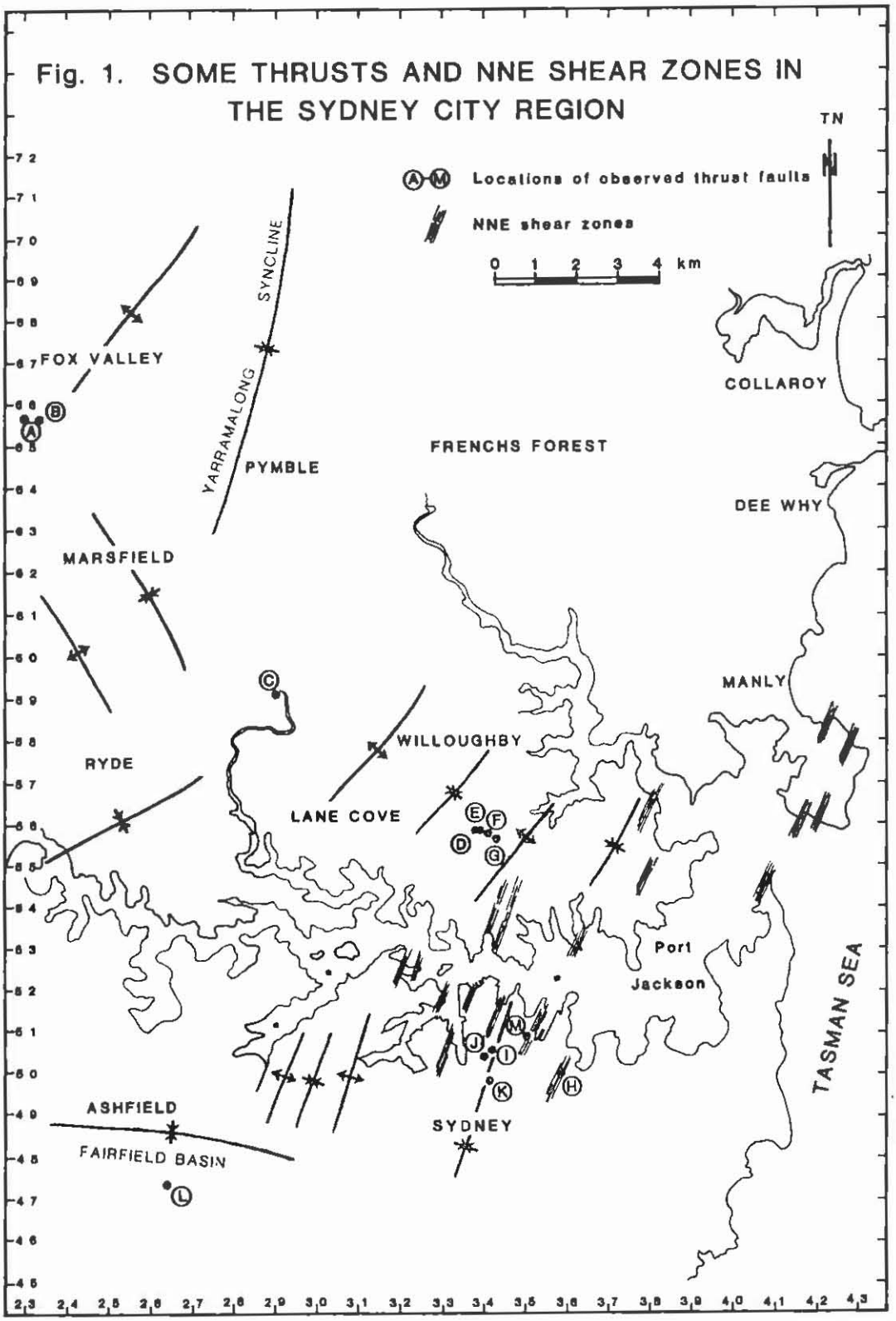


Fig. 1. SOME THRUSTS AND NNE SHEAR ZONES IN THE SYDNEY CITY REGION
TN
N
A-M Locations of observed thrust faults
NNE shear zones
0 1 2 3 4 km
FOX VALLEY
YARRAMALONG SYNCLINE
PYMBLE
FRENCHS FOREST
COLLAROY
DEE WHY
MARSFIELD
MANLY
RYDE
WILLOUGHBY
LANE COVE
Port Jackson
TASMAN SEA
ASHFIELD
FAIRFIELD BASIN
SYDNEY

The fault planes are usually well-defined over a dip direction of about 20m before flattening into the bedding, and, at times, being replaced by another fault at a slightly different level (Fig.2). The lateral extent is rarely measurable, but at site K (Hordern's) the fault can be traced for approximately 80m. Previously formed weaknesses in the strata (e.g. the bases of erosion channels) sometimes form the loci for faulting.

Brecciation may be associated with the thrusting (e.g. site C, Fullers Bridge), which may bifurcate and form a zone of displacement. Where beds can be correlated vertical displacement is usually about .5 m, but it may reach 2 m as on the Cahill Expressway near the New South Wales Art Gallery (Norman, 1986).

Shear Zones

Zones of vertical or steeply-inclined close-spaced jointing can be observed at a number of localities (Fig.1). Although those mapped close to the city trend approximately 020°, other directions occur as mapped and discussed in Norman (1986). These zones often give problems during excavation (see e.g. Raglan Road, Balmoral).

There is often evidence of small amounts of dip-slip (up to 1 m) with both normal and high angle reverse movements. In a few cases there is evidence of sub-horizontal strike slip along the fracture planes (e.g. Norman St, Normanhurst), and the rock mass may be strongly brecciated within the fracture zone (Fig.4).

FANTASY?

From these limited facts some tentative ideas about the origin of the structures are now presented.

Initiation of the thrust faults

The major observations to be accounted for in any model applicable to the Sydney region are:

(1) The recorded displacements on the low angle thrust faults are generally small. The development of the fault planes may therefore be more a stress release phenomenon than a feature related to wholesale horizontal thrusting, (see e.g. Ramsay, 1967, Fig. 7-65).

(2) The faults dip and show displacement in various directions which seem to be related to the local bedding dip. In general, the direction of thrusting is in the direction of local dip.

A series of thrusts in South wall of Anthony Hordern's site, Goulburn and George Sts. FIG.2

Bifurcating thrust, west and north walls Walton's site, Park & George Sts. FIG.3

Sheared and crushed zone, Washington Drive, Bonnett Bay.

FIG.4

(3) Thrust faults appear more common in areas of the Sydney region where beds are more strongly warped or folded. In the cores of folds complementary reverse faults may intersect or overprint each other, for example in the St. Peters brick pit (situated near the core of a basin-shaped syncline, the Erskineville Low, which can be traced through to the Darling Harbour-Ultimo area, where the plunge is gentle southerly and where a north dipping thrust was recorded in the foundation excavation for a building in Harris Street).

The model (Fig.5) incorporates the gently-folded Triassic part of the Sydney Basin succession in the Sydney City west area. A layer of Ashfield Shale and the laminated Mittagong Formation overlie a very massive unit of cemented quartz sandstone, the Hawkesbury Sandstone, which is at least 250 m thick. The Hawkesbury Sandstone in turn overlies the thinly interbedded sandstone, siltstones and shales of the Narrabeen Group.

The buckling of the very thick and competent Hawkesbury Sandstone layer results in extension of the outside surface of a buckle and compression of the inside surface of a buckle. The compressive stresses cause thrust fault failure which is sympathetic to the local dip of the beds, the faults consistently dipping away from the dip direction of the beds.

On a broader scale the thrusting might be thought of as the 'inner-basin' manifestation of a larger scale thrusting from the eastern and north-eastern edges of the Sydney Basin as manifested by the Freemans Waterhole thrust discussed elsewhere in these Proceedings (Moelle & Branagan, 1988) and the larger Hunter-Bowen thrusts recorded by Osborne (1950) and others. Such thrusting is now recognised as an important post-depositional event in many similar basins, such as the Karroo Basin (Visser, 1984).

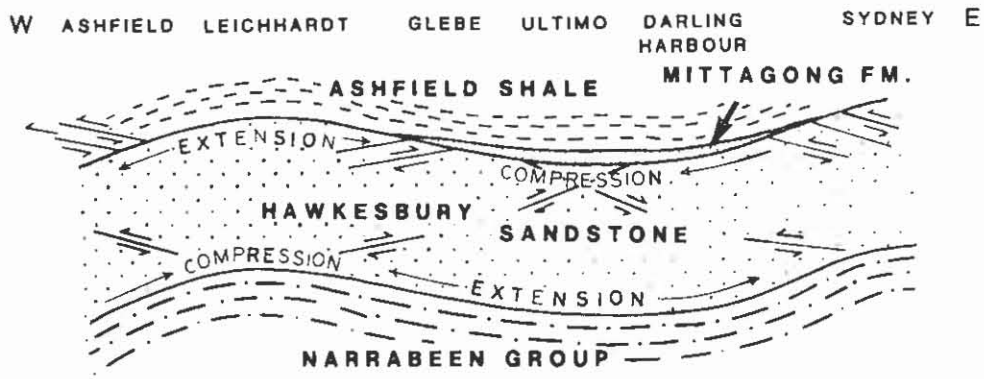
Formation of the Shears

We believe these zones were initially the result of shearing. Not enough mapping has been done to determine the spacing of the parallel zones, but they may also be related to the axes of folds such as those shown on Fig.5, which are, in a sense, 'superimposed' on broader structures such as the Botany Basin.

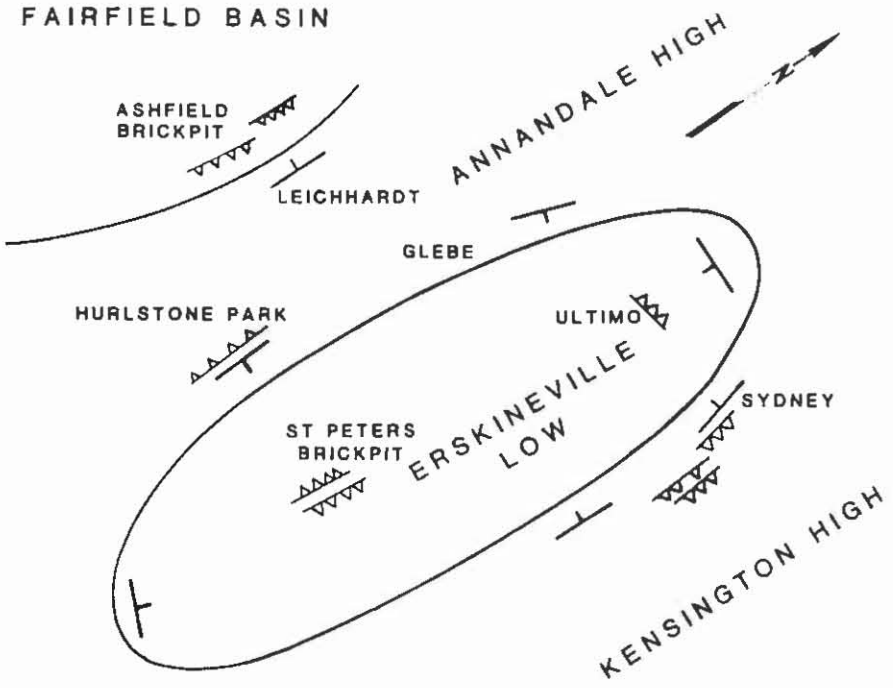
A shear couple with a dominantly northerly strike-slip component has been active, but whether it is the result of adjustments of rock in the Basin caught between the Lachlan and New England Fold Belts or between the basin sediments and the underlying basement or from some other cause can only be speculated.

The age relationship between the thrusts and large scale shears in the Sydney region is not yet clear, as both types of fault seem to have undergone several periods of movement. The shears possibly formed during an early phase of deformation, were followed by

Fig. 5. RELATION BETWEEN THRUSTING AND FOLDING



Conceptual Cross-section



Conceptual Plan

** Special thanks are due to Anne Madden for typing and to Sue Carty for drafting.

thrusting and then were remobilised.

The factual basis for this paper is limited to observations at only a few large exposures.

To complete an analysis of the structural/tectonic history of the region, many more observations are required.

With modern computing facilities, it is now possible to generate a data bank to record systematically information from all available exposures and to tie together the kind of detailed results made by Norman (1986) and found in various company files. **

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TALLAWANG MAGNETITE - A CASE HISTORY REVIEW

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INTRODUCTION

Investigations at Tallawang commenced in 1981 with an application for an exploration licence for Group 1 Minerals over an area of 64 square kilometres to the north of Gulgong (see Figure 1).

The exploration target was new mineralisation and extensions to the previously exploited magnetite deposit about 20 km north of Gulgong. At the commencement of exploration, the abandoned Tallawang open cut was held under mining lease and was excluded from the exploration licence granted to the company.

The initial concept sought to locate a suitable, dense media magnetite for supply to N.S.W. coal washeries. At the time, Australian production for this market was from Biggenden, near Rockhampton in Queensland, with imports of the order of 50,000 tpa from Canada.

HISTORICAL REVIEW

Commercial extraction of magnetite and hematised magnetite commenced from outcropping ore in 1901 by G. & C. Hoskins for supply to the Eskbank Smelting Works in Lithgow. Up to 1927, when the works closed, 510,000 tons had been produced (Griffin & Wynn 1962).

Australian Magnetite Pty. Ltd. re-opened the quarry in 1951 producing 3,787 tons of coal washery dense media until closure in 1955.

Between 1952 and 1954, Rayner (1956) from the N.S.W. Geological Survey, carried out geological mapping; and Tate (1954) from the B.M.R. completed a ground magnetometer survey in and around the quarry. The magnetometer survey extended 100 feet to the south of the quarry where the magnetic gradient was found to be considerably diminished. In later years the 1:250,000 regional geological and aeromagnetic maps were produced which covered the target area.

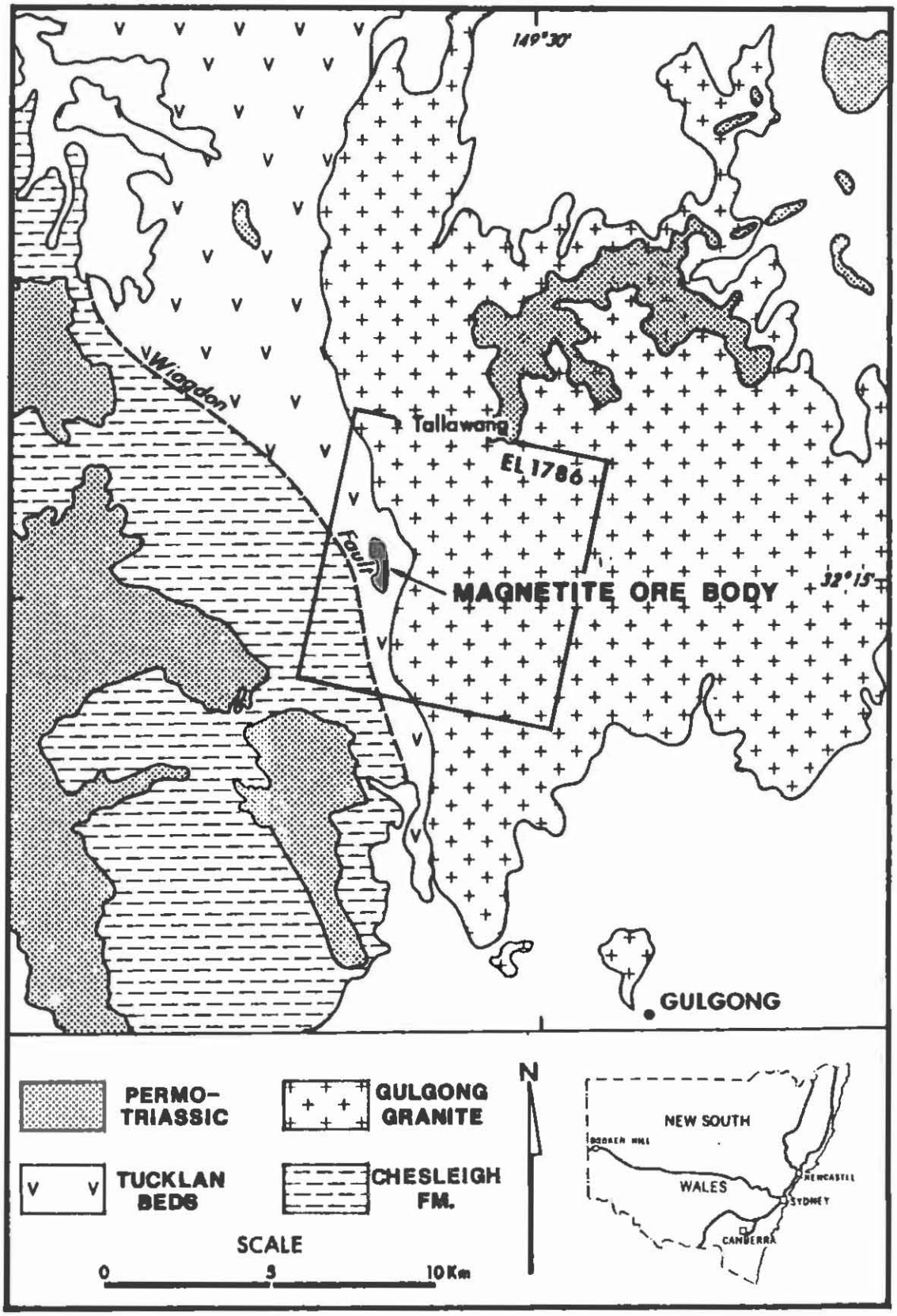

FIG.1 REGIONAL GEOLOGICAL MAP

TALLAWANG MAGNETITE

GEOLOGY

Geological Setting

The exploration licence lies near the western margin of the Sydney Basin. It is structurally part of the Capertee Anticlinorium.

Within the area the major geological features are:

i) The Silurian Chesleigh Formation of the Hill End Synclinorium is typically comprised of slates. This unit is to the west of the mineralisation and the main part of the study area.

ii) The Wiagdon Thrust is a fault system boundary between the Capertee Anticlinorium and the Hill End Synclinorium. Throughout the study area the fault is covered by alluvium, although a fault zone intersected by drill holes along the western margin of the ore body separating slates from ore host rock, may be part of the Wiagdon Thrust.

iii) Tucklan Beds of Silurian/Devonian Age are primarily comprised of andesitic volcanics, tuffs, arkoses and shales. Throughout the area they are regionally metamorphosed and in some areas thermally metamorphosed.

To the east and south of the ore body, mylonite zones outcrop within the Tucklan Beds.

iv) Permian and Triassic sediments - To the east of the area near Ulan, and to the west in the Goodiman Forest, Permian and in some areas overlying Triassic sediments of the Sydney Basin occur. To the south, a number of basal Permian conglomerate outliers are found.

v) Intrusive rocks - A microgranite occurs as the eastern margin to the ore body. Hodge (1985) mapped this body as a sill approximately 300m. thick, being concordant to the surrounding stratigraphy and regionally metamorphosed along with the surrounding Tucklan beds.

Intrusive rocks of the Carboniferous Gulgong Granite occur approximately 1 km to the east of the ore body.

A dolerite dyke cuts the ore body in the existing quarry and can be traced to the west into Tallawang Creek. This dyke clearly post-dates all other major lithological units in the area.

INVESTIGATIONS

Aeromagnetic Survey

Airborne magnetic surveys were carried out in January, 1982 as the first stage of exploration.

East/west traverses were flown, spaced 250m apart to cover the EL area, with nominal terrain clearance of 80m, and nominal sampling interval of 50m.

The airborne survey indicated a strong north/south magnetic anomaly on six (6) traverses in the vicinity of the Tallawang quarry, with a strike length of at least 1500m. The quarry area gave a peak profile of 2300 nT, while to the south of the quarry three (3) traverses gave profile peaks exceeding 1000nT in an area covered by alluvium. Low grade anomalies extend north and south along strike and may represent mineralisation at depth.

This survey also showed the relative magnetic quiet of the Devonian Tucklan beds to the east of the mineralised zone. The Gulgong Granite further east is typified by magnetic disturbance in the marginal zone.

Ground Magnetometer Survey

Initially a ground reconnaissance magnetometer survey was undertaken with a view to locating and partly delineating the aeromagnetic anomaly on the ground. East/west traverse lines were spaced 100m apart, with readings taken on stations 20m apart along the lines. Later work detailed the major ground magnetic anomaly on a 10m x 10m grid. Ground magnetometer surveys showed that the major anomaly was to the south and separate from the abandoned Tallawang quarry.

A review of the magnetic data drew the response that;

"A drill hole directed to such a target could not fail to intersect the mineralised zone."

Drilling and Laboratory Test Work

Exploration drilling followed upon completion of ground magnetometer surveys. Initially two 100 mm dia. rotary percussion drill holes inclined at 50° were each drilled to 69m depth. Hole PDH 1 was drilled from the western side of the mineralisation to the east and PDH 2 from the eastern side towards the west, giving intersections as follows:

Hole	High Grade Intersection	% Magnetics @ 700 mT
PDH 1	11m	33.9
PDH 2	15m	36.7

with low grade magnetite zones on each side of the high grade. Test

work by ACIRL at Maitland had shown the magnetite product was suitable for dense media purposes.

Upon evaluation of these first two drill hole results, a review of the project was undertaken. While it had been hoped that higher yields might have been achieved, the results were still encouraging. A preliminary feasibility study indicated that at 35% yield the product was viable, provided > half million tonnes of product magnetite was available.

Further drilling followed, including a number of diamond drill holes which gave increased magnetite yields through the high grade intersections. Percussion drilling was found to seriously downgrade the magnetite yield. The attractiveness of the project had increased significantly.

Having delineated a significant body of mineralisation within the EL the Company was able to successfully negotiate the acquisition of the mining leases encompassing the abandoned quarry. Additional diamond drilling was then undertaken in order to assess the resource in this area.

TABLE 1

MAGNETITE ORE RESERVES

MINING METHOD	HIGH GRADE Proven & Probable	LOW GRADE Proven & Probable	TOTAL
Open Cut			
Existing Quarry	136,000 t	48,000 t	184,000 t
New Orebody	345,000 t	336,000 t	681,000 t
	481,000 t	384,000 t	865,000 t
	(328,000* t)	(128,000 t)	(456,000 t)
Underground			
Existing Quarry	249,000 t	80,000 t	329,000 t
New Orebody	374,000 t	291,000 t	665,000 t
	623,000 t	371,000 t	994,000 t
	(419,000 t)	(124,000 t)	(543,000 t)
	1,100,000 t	750,000 t	1,800,000 t
	(740,000 t)	(250,000 t)	(1,000,000 t)

*(Saleable Product)

Reserves Assessment

A reserves assessment was based on the results obtained from fourteen percussion and diamond drill holes. Eleven of these holes intersected mineable thickness and grade magnetite. Two of the holes intersected orebody margins in the vicinity of the abandoned quarry. The other hole served to prove that the two orebodies are not continuous.

Outcrop mapping of the orebody was also taken into consideration during reserves estimation.

Reserves based on available data are shown in Table 1. Ore amenable to open cut mining was shown from conceptual mine planning to be from the base of oxidation to a plane 50m. below surface; while underground mineable ore is anything deeper than 50m.

In calculating reserves the following were taken into account:

- Drill hole intersection of high and low grade
- Yield from high and low grade
- Ore density
- Cross sectional area of influence for drillhole

Quantity of product magnetite as determined from test samples is shown in Table 2 compared against normally accepted guidelines for magnetic properties. All individual samples tested either met the guideline or came very close.

In addition to the reserves categorised as proven and probable, a significant possible reserve remains to be quantified, as strike extensions to the open cut reserves; as well as depth extension for underground mineable reserves.

TABLE 2

QUALITY OF 700 mT PRODUCT MAGNETITE

Test	Mean for Samples	Guideline
Magnetic Properties		
Initial Susceptibility k30 (emu/g)	0.053	>0.050
Susceptibility at 800 Oersteds, k800(emu/g)	0.055	>0.053
Saturation moment, M sat.(emu/g)	87	>80
Coercive force, Hc (oersteds)	35	>50
Chemical Analysis		
Fe	69.8%	
SiO_2	3.1%	
Al_2O_3	1.3%	
TiO_2	0.23%	
CaO	0.43%	
S	0.05%	
Density kg/m^3	5020	

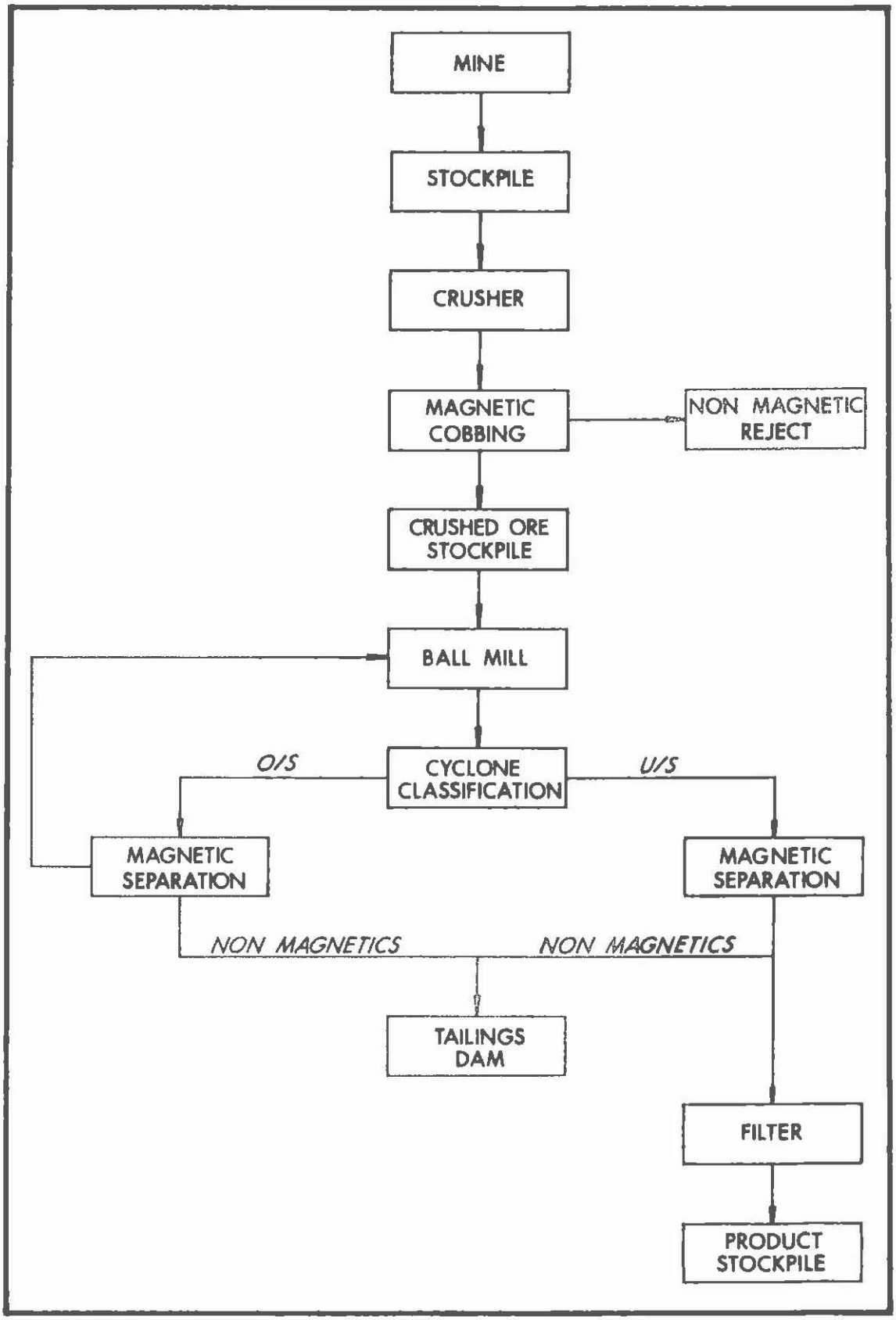

FIG.2 BENEFICATION FLOW CHART

Metallurgical Studies

A series of metallurgical studies were carried out using drill core samples. Data obtained was utilized in design of the beneficiation process for treatment of the ore. While this paper is not directed towards the detail of such work, it is important to bear in mind that the foregoing geological investigation culminates in a processing plant designed to meet a stringent product specification. Figure 2 is a flow chart through the major stages of beneficiation, which is designed to concentrate the magnetite by rejection of non-magnetic mineral particles. At the same time the process has to grind and classify this magnetite to meet the various dense media specifications on particle sizing.

On To Production

Geological investigations were largely complete by mid 1985. Before production commenced the project had to progress through:

Marketing studies	Construction of process plant
Environmental Impact Statement	Preparation to commence mining
Mining lease applications	Commissioning
Detail design	Production

During the later half of 1987 production commenced from a plant capable of 50,000 tpa of dense media magnetite.

SUMMARY

Geological investigations and subsequent development have led to the development of a strategically placed supply of magnetite to supply the N.S.W. coal industry based on the Hunter Valley mines.

ACKNOWLEDGEMENT

Eagle Corporation Ltd., producers of magnetite from Tallawang, are thanked for allowing presentation of this paper and the information contained in it.

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THE DISPERSION OF CONSERVATIVE AND NON-CONSERVATIVE POLLUTANTS IN A TIDAL ESTUARY

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INTRODUCTION

Interest in the hydraulic characteristics of estuarine regions by Public Authorities arose some forty years ago out of the necessity to cope efficiently with increasing quantities of trade wastes and waste waters resulting from industrial growth and increases in population.

As the processes which bring about the dispersion of pollutants discharged into an estuary and their removal from it are the same as those which govern the mixing of river water and sea water, many hydraulic studies were made using the fresh water as an indicator of these processes.

A gross picture of the rate of mixing in an estuary is given by the concept of "flushing time" which may be defined as the average time taken by a particle of fresh water to pass through the estuary. This time is found by dividing the total volume of fresh water accumulated within the estuary by the rate of inflow of river water. The "flushing time" concept, however, does not provide any knowledge of the processes by which the flushing of estuaries takes place and it only gives a rough estimate of the rate of dispersion of pollutant introduced at a particular point.

The flushing effect of tides is more complex, and several approximate analytical approaches to it have been proposed.

In the simple tidal prism theory, the additional storage at flood tide is provided by both river and tidal inflow. The stored water is assumed to mix completely with the storage in the estuary at low tide. On the ebb tide, the tidal inflow volume plus a volume equal to that of the river flow for one tidal cycle is removed. Since there has been a complete mixing a proportion of any pollutant brought in by the river would be flushed out each cycle. The amount depends upon the ratios of the tidal prism (volume in the estuary between low and high tide) and the volume at low tide.

It is found from observations, however, that in general these assumptions are not justified and flushing effect may be only a

fraction, perhaps one tenth of that estimated from the tidal prism concept. A modification of the tidal prism method proposed by Ketchum was to divide the estuary into segments each equal in length to the average tidal excursion of a particle of water and to assume that complete mixing took place each tide within each segment. Ketchum also indicated how allowance could be made for incomplete mixing.

Arons and Stommel extended this ideal to a "mixing length" theory, in which mixing along the estuary was characterized by an eddy diffusivity proportional to the product of the tidal excursion and the amplitude of the tidal current. Although these theories gave reasonable results for some estuaries, they were generally inadequate.

Using a different approach to this hydraulic problem, assuming steady state conditions, Stommel calculated eddy diffusivities at regularly spaced cross sections along estuaries exhibiting vertical mixing, from a knowledge of the longitudinal distribution of fresh water in them. Then by using this data, the concentrations of pollutants were calculated. Stommel emphasized that this technique was intended to apply only to vertically mixed unstratified estuaries in which vigorous tidal movements occur.

Further studies by other investigators however suggest that the restriction to vertically unstratified estuaries is unnecessary and that a one dimensional mass transport equation should hold in estuaries in which salinity and velocity vary over a cross section, provided that one deals with mean values over the cross sections.

As an example let us consider the one dimensional form of the mass balance equation for estuary type flows which are sectionally homogeneous.

Transient Shaped Diffusant Distributions

The type of flow found in sectionally homogeneous estuaries may be represented one dimensionally by the equation:

$$V(x,t) = V_f(x,t) + V_T(x) \text{ Sin } \frac{2\pi}{T}(t - \delta) \qquad (1)$$

where T is the period of oscillation of the tide,

δ is a constant representing the time shift between the arbitrary origin, and the time of slack water,

$V_f(x,t)$ is the velocity associated with the fresh water inflow at the head of the estuary, and

V_T is the maximum velocity due to tidal motion.

Let us consider the time dependent, one dimensional dispersion equation for a given mass of diffusant S, released simultaneously at a specified cross section in an estuary, then the following equation holds:

$$\frac{\partial C(x,t)}{\partial t} + V_f(x,t) + V_T(x) \text{ Sin } \frac{2\pi}{T}(t-\delta) \frac{\partial C(x,t)}{\partial x} \qquad (2)$$

$$= \overline{n}_p - \lambda C + \frac{1}{A(x)} \frac{\partial}{\partial x} E(x) A(x) \frac{\partial C(x,t)}{\partial x} - n_a$$

where $A(x)$ = cross section area of flow at x
λ = decay constant of non-conservative pollutant
n_a = rate of absorption of the substance per unit volume of solution
$C(x,t)$ = concentration of substance.

The following boundary conditions must be satisfied by the above equation:

(1) $C(x,t) = \infty$ at $t = 0$,

(2) $C(x,t) = 0$ at $t = \infty$

and (3) $\int_{-\infty}^{+\infty} C(x,t)A(x)dx = S$.

Let us write the partial derivative $\frac{\partial C(x,t)}{\partial t}$ as a forward difference replacement, namely:

$$\frac{\partial C(x,t)}{\partial t} = \frac{(C_{m,n+1} - C_{m,n})}{\Delta t}$$

and the partial derivative $\frac{\partial C(x,t)}{\partial x}$ as a central difference, namely $\frac{\partial C(x,t)}{\partial (x)} = \frac{C_{m+1,n} - C_{m-1,n})}{2\Delta x}$. Also by using a forward difference, and then a backward difference, let us write the second order partial derivative $\frac{\partial^2 C(x,t)}{\partial x^2}$ in the form: $\frac{C_{m+1,n} - 2C_{m,n} + C_{m-1,n})}{(\Delta x)^2}$

Substituting these finite difference replacements in the above equation, we obtain:

$$C_{m,n+1} = C_{m,n} \left[1 - \frac{1}{A_m} \frac{\Delta t}{(\Delta x)^2} \left\{ (AE)_{m+\frac{1}{2},n} + (AE)_{m-\frac{1}{2},n} \right\} \right]$$

$$+ C_{m+1,n} \left[\frac{-V_{f_{m,n}} \Delta t}{2\Delta x} - \frac{V_{T_m}}{2\Delta x} \text{ Sin } \frac{2\pi}{T} (t_n - \delta)\Delta t \right.$$

$$\left. + \frac{(AE)_{m+n,}}{A_m} \frac{\Delta t}{(\Delta x)^2} \right] \qquad (3)$$

$$+ \frac{(AE)_{m-\frac{1}{2},n}}{A_m} \frac{\Delta t}{(\Delta x)^2} - \lambda C_{m,n} \Delta t \quad ,$$

where $t_n = n\Delta t$.

For uniform estuary type flows, the one dimensional form of the mass balance equation reduces to the form:

$$\frac{\partial C(x,t)}{\partial t} + V(x,t) \frac{\partial C(x,t)}{\partial t} = E(t) \frac{\partial^2 C(x,t)}{\partial x^2} - \lambda C + \bar{n}_p - \bar{n}_a$$

where $$V(x,t) = V_f(x,t) + V_T \operatorname{Sin} \frac{2\pi}{T} (t - \delta) \quad . \qquad (4)$$

The finite difference equation in this case reduces to the form:

$$C_{m,n+1} = C_{m,n} \left[1 - \frac{\Delta t}{(\Delta x)^2} \{2E_n\} \right]$$

$$+ C_{m+1,n} \left[\frac{-V_{f_{m,n}} \Delta t}{2\Delta x} - \frac{V_T \Delta t}{2\Delta x} \operatorname{Sin} \frac{2\pi}{T} (t_n - \delta) + \frac{E_n \Delta t}{(\Delta x)^2} \right]$$

$$+ C_{m-1,n} \left[\frac{V_{f_{m,n}} \Delta t}{2\Delta x} + \frac{V_T \Delta t}{2\Delta x} \operatorname{Sin} \frac{2\pi}{T} (t_n - \delta) + \frac{E_n \Delta t}{(\Delta x)^2} \right] \qquad (5)$$

$$- \lambda C_{m,n} \Delta t$$

Hence we have:

$$C_{m,n+1} = C_{m,n} \left[1 - \frac{\Delta t}{(\Delta x)^2} \{^2E_n\} - \lambda \Delta t \right]$$

$$+ C_{m+1,n} \left[\frac{-V_{f_{m,n}} \Delta t}{2\Delta x} - \operatorname{Sin} \frac{2\pi}{T} (t_n - \delta) \frac{Vt \Delta t}{2\Delta x} + \frac{E_n \Delta t}{(\Delta x)^2} \right] \qquad (6)$$

$$+ C_{m-1,n} \left[\frac{V_{f_{m,n}} \Delta t}{2\Delta x} + \frac{V_T \Delta t}{2\Delta x} \operatorname{Sin} \frac{2\pi}{T} (t_n - \delta) + \frac{E_n \Delta t}{(\Delta x)^2} \right]$$

Thus for given initial and boundary conditions, the above equation may be used to find the solution to such a problem in the (x,t) space.

In order that the finite difference solution converges to the exact solution, certain conditions must be satisfied. A requirement for convergence is that the coefficients be positive. Hence we have:

$$\left(1 - \frac{\Delta t}{(\Delta x)^2}\{2E_n\} - \frac{\lambda \Delta t}{(\Delta x)^2}\right) \geqq 0$$

Therefore,

$$\frac{\Delta t}{(\Delta x)^2}(2E_n) + \frac{\lambda \Delta t}{(\Delta x)^2} \leqq 1$$

and hence $$\frac{\Delta t}{(\Delta x)^2}(2E_n + \lambda) \leqq 1$$

Suppose $\delta=0$, and we take time intervals $\Delta t=T$, such that $t_n=nT$, where $n=1, 2, 3$ etc. The finite difference solution for uniform estuary type flows in the case of uniform conditions reduces to the form:

$$\begin{aligned} C_{m,n+1} = {} & C_{m,n}\left[1 - \frac{\Delta t}{(\Delta x)^2}\{2E_n\}\right] \\ & + C_{m+1,n}\left[\frac{-V_{f_{m,n}}\Delta t}{2\Delta x} + (E_n)\frac{(\Delta t)}{(\Delta x)^2}\right] \\ & + C_{m-1,n}\left[\frac{+V_{f_{m,n}}\Delta t}{2\Delta x} + (E_n)\frac{\Delta t}{(\Delta x)^2}\right] - \lambda C_{m,n}\frac{\Delta t}{(\Delta x)^2} \end{aligned} \tag{7}$$

Suppose V_f is constant and $\lambda=0$, then we have:

$$\begin{aligned} C_{m,n+1} = {} & C_{m,n}\left[1 - \frac{\Delta t}{(\Delta x)^2}\{2E_n\}\right] \\ & + C_{m+1,n}\left[\frac{-V_f}{2\Delta x} + (E_n)\frac{(\Delta t)}{(\Delta x)^2}\right] \\ & + C_{m-1,n}\left[\frac{V_f}{2\Delta x} + (E_n)\frac{\Delta t}{(\Delta x)^2}\right] \end{aligned} \tag{8}$$

The differential form of this difference equation is ;

$$\frac{\Delta C}{\Delta t}(x.t) + V(x)\frac{\partial C(x,t)}{2x} = E\frac{\partial^2 C(x,t)}{\partial x^2} \qquad (9)$$

where $\frac{\Delta C}{\Delta t}$ is the change in concentration from one tide cycle to the next. From a previous analytical study of the similar differential equation for steady uniform unidirectional flows, namely:

$$\frac{\partial C(x,t)}{\partial t} + V(x)\frac{\partial C(x,t)}{\partial x} = E\frac{\partial^2 C(x,t)}{\partial x^2} \qquad (10)$$

the solution at discrete intervals in the difference equation for uniform estuary flows, namely when $t_n = nT$ (where n = 1, 2, 3 etc.) is a Gaussian distribution.

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ENVIRONMENTAL AND GEOLOGICAL CONSTRAINTS TO SAND AND GRAVEL EXTRACTION IN THE PEEL AND COCKBURN RIVERS, TAMWORTH REGION

V. Smith

Resource Planning, Rutherford

INTRODUCTION

Gravel bars in NSW river systems have since the establishment of the Colony been the main source of concrete aggregate materials for construction projects.

The natural stream processes that result in the deposition of sand and gravel tend to produce material that is naturally sound and resistant to abrasion, and free of excessive silt and clay. The relatively simple (and cheap) extraction procedures using front-end loaders or draglines loading directly into trucks for haulage to a processing plant make this form of extractive operation particularly attractive to the quarry operator.

In the past there were few conditions imposed on this type of operation and many extractors, particularly in country areas, have operated for many years without local Council approval. Simply the operations were not seen by authorities as warranting serious consideration. Since knowledge on any potential detrimental effects of these operations was lacking, no conditions were considered necessary.

In the last ten years or so this knowledge has improved. Most of this knowledge has been gained in the USA from the observation of engineering failures which have been attributed to nearby extractive operations (Bull and Scott, 1974). In Australia, recent studies by the NSW Water Resources Commission (Erskine, Geary and Outhet, 1985) recognised the potential impacts of sand and gravel extraction on the Hunter River. The Commission was concerned that the existing and proposed operations on the river planned to supply concrete aggregate materials to the industrial and mining developments in the Hunter Valley proposed in the early 1980's, would have serious impacts on the stability of the Hunter River channel.

Fortunately, these potential problems were recognised in advance of any serious problems or engineering failures.

In the Peel and Cockburn Rivers in the Tamworth area, several problems relating to bed and bank stability have arisen, and have been attributed, in part, to river sand and gravel extraction.

EXTRACTIVE OPERATIONS IN THE PEEL AND COCKBURN RIVERS

Extraction of gravel and sand from the Peel and Cockburn Rivers has been undertaken by a number of operators from different sites and in 1984 approximately 160,000 tonnes of material were removed from these sources (Figure 1). Because many of these operations had been established before the introduction of Environmental Planning controls, most do not have formal approval and have been operating relatively haphazardly, extracting from both the bed and banks of the river systems.

PROBLEMS AND THEIR CAUSES

A number of problems have arisen in the vicinity of these operations. These have included bank erosion and instability, loss of fertile land, lowering of the groundwater table and loss of farmer and village water supply wells and pumps.

Measurements conducted at bridges along the Cockburn River in particular, have shown that the bed of the river has been gradually degraded e.g., at Ballantine Bridge the river bed has been lowered 0.9m since 1965 exposing the concrete footings and causing concern to local authorities.

A number of causative factors have been identified and are in common with those established in the USA and Hunter River. The problems have arisen primarily because the rate of extraction of material from these rivers has exceeded the estimated rate of replenishment from source areas. Because a number of excavators have dug holes in the river bed and removed riffles from the bed of the river, bed degradation has occurred, which has resulted in overall downcutting of the channel upstream from the quarrying operation. This, in turn, has led to localised lowering of the water table and loss of groundwater supplies to wells and pumps. Channel deepening has also had the adverse effect of making the stream banks more susceptible to erosion, and increasing bank slumping and loss of fertile alluvial land.

The presence of large, long term, and well armoured point and lateral bars in the river has impeded the downstream movement of active bedload material, now accumulating at the upstream reaches of these bars. Consequently, during high river flows, further erosion of the soft alluvial terraces has occurred.

ACTION INITIATED

These problems caused serious alarm to authorities in the Tamworth area, and in late 1986, operators were ordered to cease activities until the NSW Water Resources Commission had completed appropriate studies to identify acceptable extraction areas. Because of the dependence of the region on river sources for concrete aggregates and the effect on the industry and employment, the order was later amended to permit interim extraction until the end of February 1987, at which time formal applications and environmental impact statements were required to be lodged with consent authorities.

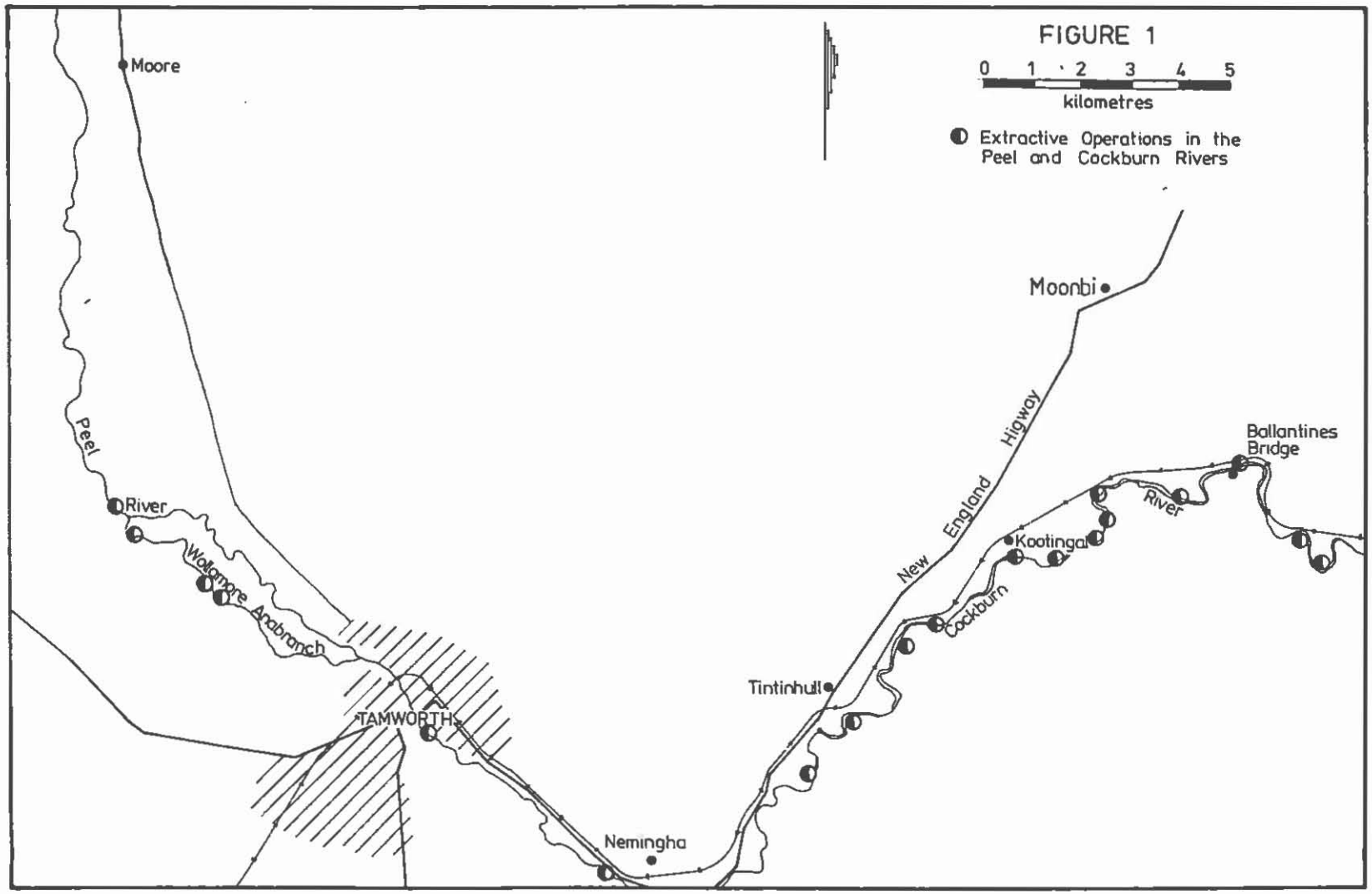
FIGURE 1
0 1 2 3 4 5
kilometres
Extractive Operations in the Peel and Cockburn Rivers
Moore
Moonbi
Peel
River
Wallamore Anabranch
TAMWORTH
Nemingha
Tintinhull
New England Highway
Cockburn
Kootingal
River
Ballantines Bridge

At the end of this time, all operators not complying were to cease activities.

SOLUTIONS

Conscious of the short time to lodge applications, Pioneer Concrete (NSW) Pty Ltd took the initiative to understand the problem and to commence appropriate studies to gain approval and to comply with the Commission's requirements. (Resource Planning, 1987).

In co-operation with the Commission, all sites from which the Company had gained consent from owners to extract were inspected in the field with Commission officers. Sites unsuitable for extraction were identified. These included those composed of active bedload, those near stream confluences, near bridges and other structures, or those subject to other environmental constraints, e.g., scenic or recreational areas.

Extraction procedures at each of the sites were established which would prevent bed degradation, bank erosion and subsequent effects. These included:

1. Maintenance of a "buffer" at the upstream end of bars.

2. No extraction in the bed of the low flow channel.

3. No removal of gravel riffles or disturbance to the active low flow stream.

4. No removal of the active bedload material.

5. No extraction from the floodplain or below river level.

6. Realignment of the river channel away from eroding banks where appropriate.

7. No extraction near pumps, water supply pipelines or bridges.

8. Extraction sites to have a floor gradient of 1 in 50 from the low flow channel to the base of the terrace and a grade of 1 in 3 to the top of the bank.

A number of beneficial impacts are expected to flow from the adoption of these procedures. Firstly, the removal of the well armoured point and lateral bars which form an obstruction to stream flows in the river will provide a well defined and wider stream course allowing the passage of active bedload material to downstream reaches. Secondly, the wider channel will also lessen the incidence of bank erosion by the removal of the obstructions which deflect the river against the easily weathered alluvial sediments.

Since the extractive operations will not extend below low flow level or create holes or random excavations, there will be no alteration to the gradient of the bed and correspondingly no risk of bed scour, or further alterations to the groundwater table.

The history of events associated with sand and gravel extraction from the Peel and Cockburn Rivers has demonstrated that close co-operation between Companies and relevant authorities can ensure that satisfactory compromises can be reached which benefit the community as a whole. In this case, the Tamworth region continues to be supplied with high quality aggregate materials, the environment of the Cockburn and Peel Rivers are protected, and the local farming community's activities are not adversely affected.

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ACKNOWLEDGEMENT

Pioneer Concrete (NSW) Pty Ltd is thanked for their permission to use information presented in their Environmental Impact Statement.

SYDNEY REGIONAL ENVIRONMENTAL PLAN No.9 - MANAGEMENT OF EXTRACTIVE RESOURCES IN THE SYDNEY REGION

I.B.L. Paterson

NSW Department of Mineral Resources

INTRODUCTION

The gazettal of the Sydney Regional Environmental Plan No 9 — (Extractive Industry) in October 1986 represented the culmination of a joint effort by the New South Wales Department of Environment and Planning, and Department of Mineral Resources to develop a management strategy for extractive resources in the Sydney region.

Extractive resources, or construction materials as they are also commonly termed, comprise materials such as sand, gravel, hard rock aggregate, and clay/shale which are used for construction purposes. Most of these materials are not classed as minerals under the Mining Act (1973) and hence the Department of Mineral Resources does not have any statutory control over their exploitation. However, the Department is the recognized authority on these commodities and has been providing advice on their management at both State and local government level for many years, particularly since the late 1960's when assistance was provided to the then State Planning Authority during preparation of the Sydney Region Outline Plan.

Extractive resources are essential to the well-being of modern society and are used in large quantities. However, because of their comparatively low unit value they must be obtained from sources as close as possible to the point of use in order to minimize transport costs. This requirement frequently brings extraction into conflict with other land uses, such as residential development or recreational land uses, particularly in the case of major population centres. Such conflicts can lead to the sterilization of valuable resources and make it necessary to obtain materials from more remote sources at significantly higher costs which must ultimately be passed on to the community at large.

Sydney, being the largest population centre in New South Wales, consumes a large part of the State's production of extractive materials. Prior to about 1960, the amount of conflict between extraction and other land uses in the Sydney region was relatively

low. Subsequently, however, the level of conflict increased significantly, as did public awareness of, and opposition to, extractive industry. These factors (together with changes to the environmental and planning legislation) made it more difficult to obtain approval for the development of new sources of extractive materials. The difficulties of developing new resources were exacerbated because individual proposals were generally considered in isolation, on an ad hoc basis rather than in the context of the regional availability of, and demand for, extractive resources. As the problems associated with the development and management of extractive resources increased it became obvious that a regional planning approach to extractive resources was required if severe shortages of extractive materials were to be avoided, and if the future development of extractive resources was to take place in a coordinated, rational manner. By the late 1970's available reserves of certain types of materials had already reached critically low levels and this led the Department of Minerals Resources to seek the assistance of the Department of Environment and Planning in formulating and implementing a management strategy for important extractive resources in the Sydney region. It was subsequently agreed that such a stategy should be prepared and that it should be in the form of a regional environmental plan.

WHAT IS A REGIONAL ENVIRONMENTAL PLAN?

A regional environmental plan (R.E.P.) is one of the types of instruments established under the Environmental Planning and Assessment Act (1979) and is intended to allow important planning issues to be resolved independently of local planning issues. Regional environmental plans are initiated and prepared by the Department of Environment and Planning and have wide scope and form. They may address broad issues such as land use allocation within a region and provide a framework for detailed local planning or they may be restricted to one particular issue or land use.

The first stage in the preparation of a regional environmental plan is the preparation of a regional environmental study (R.E.S.) which provides background information for the plan, assesses the various issues involved, and is used as the basis for a draft plan. Both the study and the draft plan must be publicly exhibited and any submissions must be considered before the plan is finalized.

The Sydney region extractive industry plan is the first REP to deal with a single issue over an entire region and is also the first to deal specifically with mineral resources.

PREPARATION OF THE PLAN

The plan and preceding study were prepared jointly by officers from the Department of Environment and Planning and the Geological Survey of New South Wales. The regional environmental study was exhibited in 1984 and the draft plan in May 1986. After

consideration of the numerous submissions received on the draft plan and subsequent amendment, the finalized plan was released in October 1986.

The extractive resources covered by the plan are construction sand (fine aggregate), coarse aggregate (river gravel and hard rock aggregate), clay/shale, loam (soil), dimension stone, flagging stone, bush rock, and peat. However, the plan concentrated on sand, coarse aggregate, and clay/shale, as these were the most important commodities and were those for which regional management strategies were most urgently required.

A comprehensive inventory of extractive resources is an essential pre-requisite for a plan of this type. Such an inventory had already been established by the Geological Survey over the previous decade through a series of regional resource studies, individual resource investigations, and the collection and collation of data from industry. The information from these sources was updated where necessary and summarized in a series of position papers on the various commodities produced between 1980 and 1982.

THE PLAN

The principal aims of the plan were to:

- identify regionally significant resources (both currently exploited and potential sources)
- protect these resources from unnecessary sterilization
- protect existing extraction sites from hindrance by encroaching urban development
- facilitate the development of potential sources of extractive materials to ensure that the Sydney region's foreseeable future needs can be met as far as possible from local sources
- ensure that extraction operations are undertaken in an environmentally acceptable manner.

The plan consists of two parts; a statutory instrument and an accompanying report which are intended to be read in conjunction.

The planning report contains background information on the plan, an explanation of its aims and objectives, and planning recommendations on the future development and management of extractive resources.

The statutory instrument is a document which gives statutory effect to the policies and recommendations outlined in the planning report. It is accompanied by a series of schedules and maps which identify and categorize the resources to which the provisions apply.

The plan takes precedence over other environmental plans within the region and is to be reviewed periodically to take account of new developments or discoveries.

A total of 64 clay/shale, construction sand, coarse aggregate, and dimension stone resources are identified in the statutory instrument as being of regional significance and are identified by means of maps, property descriptions, mining lease numbers, or permissive occupancy numbers.

The resources identified in the schedules are divided into four categories. Most of the resources are included in Schedule 1 (59 areas) which comprises existing extraction sites and a number of resources considered to have potential for future extraction. The second group (Schedule 2) consists of two deposits (the Pitt Town and Maroota sand deposits) which are considered to have potential for future development but which should be the subject of management plans to ensure that extraction is undertaken in a coordinated and environmentally acceptable manner. Schedule 3 comprises one resource (the Richmond Lowlands sand and gravel deposit), which is considered to be an important potential source of extractive materials but one requiring further investigations to define potential extraction areas, as well as further environmental investigations. The final group (Schedule 4) comprises those resources (the Colo and Macdonald Rivers) from which extraction is prohibited by the plan for environmental and/or other planning reasons.

Some important existing or potential sources of extractive materials for the Sydney region were not included in the schedules because they occur outside the region covered by the plan, are subject to other regional plans or planning initiatives (e.g. Penrith Lakes Scheme), or, in the case of offshore sand resources, because their inclusion in the planning instrument would be inappropriate. However, these resources are included in the planning recommendations within the planning report.

WHAT THE PLAN DOES

The statutory instrument contains a number of provisions relating to the resources identified in the schedules. These provisions are intended to:

1. Permit or prohibit extraction from regionally significant resources.
2. Protect these resources from unnecessary sterilization by incompatible land uses.
3. Ensure that future extraction operations are conducted in an environmentally acceptable manner.
4. Provide a framework for assessing future development proposals.

The main provisions of the plan are discussed below.

REGIONAL ENVIRONMENTAL PLAN NO 9

Approval or Prohibition of Extraction

The plan makes extraction a permissible land use (with council consent) within most of the sites identified in the planning instrument (those in schedules 1 and 2) and a prohibited use within the two areas in Schedule 4, the Colo and Macdonald Rivers.

This provision overrides and amends any existing local planning instruments. In the case of areas where extraction is permitted, it is now possible to make a development application for a new quarrying operation or for the expansion of an existing one, even if the existing zoning does not permit extraction. Previously, it was necessary in such cases to have the zoning changed (by means of a local environmental plan) before a development application could be lodged. This is a costly, time consuming process and frequently proved to be an insuperable hurdle.

The fact that the plan makes extraction a permissible use within a particular area does not however, allow extraction to proceed without complying with all the normal environmental impact assessment procedures, nor does it guarantee that any specific proposal will be approved.

Protection of Resources

The resource protection provisions are the most important element of the plan and are particularly significant because they provide for the first time a statutory role for the Department of Mineral Resources in extractive resource management.

The plan prevents councils from approving developments other than extractive industry within certain resources without first obtaining the concurrence of the Department of Mineral Resources. This provision applies to all the areas within which extraction is permitted by the plan with the exception of a very large area of potential clay/shale resources between Penrith and Camden, which because of its size, was excluded for practical considerations.

In order to prevent the sterilization of resources by encroachment of land uses incompatible with extraction (especially residential development) the plan requires that the concurrence of the Department of Mineral Resources and the State Pollution Control Commission must be obtained before a council can approve development within a specified distance (either 500 m or 1000 m, depending on the commodity concerned) of existing extraction sites. This provision has the effect of providing a buffer zone around these resources.

In addition to the above measures, the plan prevents councils preparing draft local environmental plans which prohibit extraction from regionally significant resources and also requires councils to consult with the Department of Mineral Resources when preparing plans which would permit developments other than extractive industry within any of the resources where extraction is allowed. Councils

must also consult with the Department of Mineral Resources and with the State Pollution Control Commission when preparing local environmental plans which would permit residential subdivision within specified distances (500 m or 1000 m) of these resources. In both these cases, the council is obliged to consider any representations that may be made by the two authorities.

Quarry access roads (i.e. those constructed for the purpose of, or principally used for, quarry access) are protected by a provision which prevents residential subdivision within 100 metres of the road.

Environmental Control

The plan specifies certain environmental matters which must be taken into account by councils when they are determining development applications for resources identified in the plan.

Councils cannot grant development consent for such applications unless they are satisfied that noise and vibration levels will be in accordance with the State Pollution Control Commission guidelines, that the impact of the proposal on water quality and hydrology has been properly assessed, and that the proposed rehabilitation measures are in accordance with the guidelines of the Soil Conservation Service of New South Wales.

The plan also requires councils to consider any plans of management which have been prepared for the resources identified in Schedule 2 of the instrument before consenting to any extraction proposal within these resources. In the absence of a plan of management, councils must consider the impact of extraction on the existing or likely future use of the site and adjacent lands. In addition, the Department of Environment and Planning must be consulted when a management plan is prepared. Details of the matters which should be addressed in the preparation of a management plan are provided in the planning report.

Assessment of Future Extraction Proposals

The planning report contains a series of recommendations concerning the future development and management of extractive resources within the Sydney region, and some resources in areas outside the region which currently supply or have the potential to supply the Sydney market. These recommendations are intended to provide guidelines for the consideration of future extractive resource development proposals and to highlight any environmental issues which have to be addressed before extraction can proceed.

The planning instrument includes a clause which requires councils to take account of the planning recommendations in the planning report when considering development applications for extraction on land identified in the plan. Councils must also forward a copy of the environmental impact statement to the Department of Mineral Resources and must take account of any

comments made by the Department.

CONCLUSION

As the plan has only been in force for about 18 months it is still too early to assess the extent to which it has succeeded in fulfilling its purpose. However, there is little doubt that the plan, which is the first of its type in Australia, represents a major step forward in the planning and management of extractive resources in the Sydney region and that it will help to resolve many of the problems which have been experienced in the past.

The plan should ensure that future extraction proposals are considered in a regional context rather than in isolation, as was frequently the case in the past. It should also help to ensure that adequate resources of material are available to meet the Sydney region's requirements for the foreseeable future.

The plan should prevent further unnecessary sterilization of resources and has already proved successful in preventing or modifying some proposed developments which could have sterilized particular resources or unduly restricted existing quarrying operations. There have been some complaints, particularly from councils, about excessive work loads and delays in determining development applications due to the concurrence and (to a lesser extent) consultation provisions of the plan. However, steps have been taken by the Department of Mineral Resources and the State Pollution Control Commission to minimize these problems by streamlining the processing of such matters and to reduce the number of cases which have to be referred for concurrence.

The plan is the first of its kind and is expected to be the forerunner of similar plans in other areas of the State. A draft regional environmental plan has recently been prepared for extractive resources on Crown lands in the western part of the State and plans have also been proposed for the Hunter and Illawarra regions.

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TECTOGENETIC ASPECTS OF THE TELFORD BASIN, LEIGH CREEK COALFIELD, SOUTH AUSTRALIA

W. Bogacz[1] & I. Kivior[2]
Geo-Mining Consultants, Dernancourt[1]
Electricity Trust of South Australia, Eastwood[2]

The coal-bearing formation of the Leigh Creek region is associated with an intramontane depression of the late Triassic - early Jurassic period (Veevers et al., 1984). These sediments are preserved in four rather small basins containing sub-bituminous coal (Fig. 1). The basins are aligned meridionally over a distance of approximately 20 km. Mining operations are confined to the Telford Basin in which the most complete coal sequences have been deposited. The Telford Basin forms an elliptically shaped depression with especially favourable conditions for the sedimentation of the coal-bearing sequences (Townsend, 1979). However, the tectonic deformation of the Telford Basin is more complex than that of the other basins.

The present studies were carried out with special emphasis on the following tectogenetic problems since it is obvious the tectonics of the Telford Basin have the greatest impact on mine planning:

- mesostructural aspects of rock defect development,
- tectogenetic analysis of the Basin boundaries,
- bedding and bedding defects genesis,
- genesis of joint and cleavage network,
- geometry and origin of fault zones.

All these tectogenetic aspects have an influence on an understanding of the complexity of the structure and tectonic evolution of the Telford Basin.

The coal-bearing sequences were examined in detail to identify the genetic character and kinematics of rock defects. The defects show specific features of morphology which correspond to processes of failure and result from the tectonic regimes forming the Basin structure.

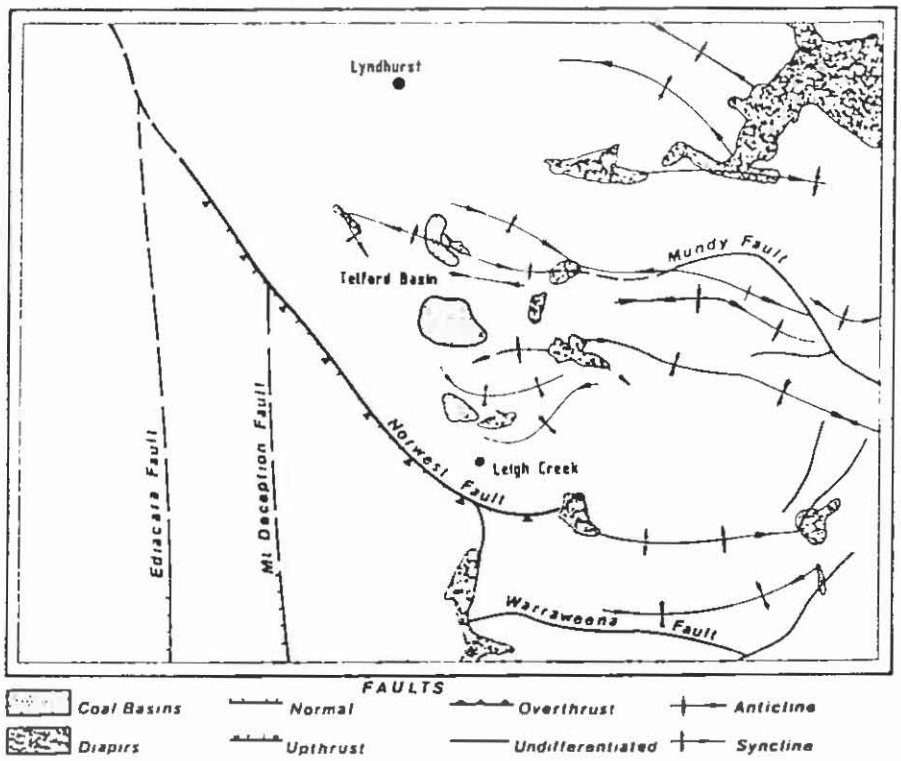

Figure 1. Tectonic sketch of the Leigh Creek Coalfield region

In small scale, structures have been distinguished indicating extensional conditions of rock failure. These are mainly feather structures, the fascicular variety and concentric, rarely radial modifications. These structures are often mineralized and are concentrated especially in the northern margin of the Basin. Analysis of principal directions of their propagation has shown that development of extensional rock deformation for the most part took place in a horizontal or near horizontal plane.

Minor structures which manifest a transition from extensional to shear features are present as well. Among those, defects which form en echelon patterns, fringe structures and tectonic ribs are the most common throughout the Basin. The axes of propagation are as a rule horizontal or almost horizontal thus confirming, on one hand, development of failures in the same plane and, on the other hand, participation of shear components in these rock deformations.

However, there are frequent manifestations throughout the Basin of the increasing role of shear mechanisms in the genesis of rock defects. Shear processes of failure are represented by the presence of slip planes or slickensides, smoothing of defect surfaces, and generation of tectogliphes such as step-like breaks and tectonic scratches.

Most of the joint and cleavage surfaces exhibit shear origin. Intensive shear features can be observed in and adjacent to the fault zones or along numerous bedding planes as well. Geometry and features indicating directions of such failure propagation suggest that major tectonic transport took place in a vertical plane in a normal stress field.

The strike of beds describes a rough ellipsoid, and the beds dip towards the Basin centre. Along the northern and north-eastern boundaries there is an erosional contact with the coal-bearing sequences dipping at 15° -25° (up to 30°), unconformably overlying the pre-Cambrian basement (Fig. 2). But the western and southern Basin boundaries are delineated by flexure-fault tectonic contact (Bogacz, 1986). In this case, the bedding displays a much steeper attitude, up to 55°, compared with the attitude of the surrounding basement beds which rarely reaches 30°.

This local increase in the dip of the basin sequences is rather a result of intensive rotation and flexural bending of the beds in the vicinity of these bordering faults rather than a consequence of regional folding.

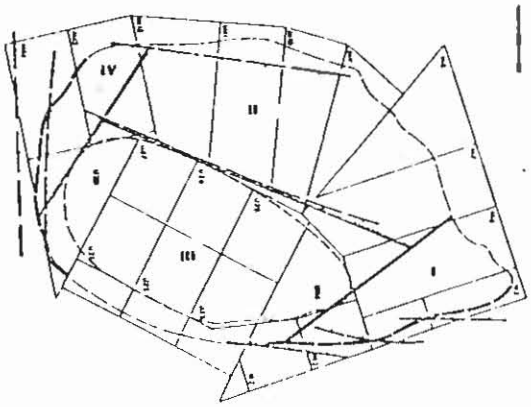

Figure 2.

Main faults of the basement and variability of attitude of beds, Telford Basin.

- BASEMENT FAULTS
- DIP OF BEDS > 30°
- DIP OF BEDS < 30°

I & IV - VERY DIFFICULT GEOLOGICAL-MINING CONDITIONS
II - DIFFICULT GEOLOGICAL-MINING CONDITIONS
III - SIMPLE GEOLOGICAL-MINING CONDITIONS

The flexure-fault boundaries to the west and to the south seem to be connected with synsedimentary and later vertical movements along the basement faults. However, the north and north-eastern basin margins exhibit basic primary non-tectonic character. Along these sections of the Basin there have been formed characteristic peripheral faults adjusting their trends to the arcuate shape of the Basin. These faults exhibit the normal-slip type features of tectonic movement, but their surfaces are vertical or near vertical (75° - 90°) usually dipping towards the Basin centre. Sometimes they dip in the opposite direction at 85° to 90° forming steep reverse faults. The peripheral faults have been produced by an adjustment of the Basin sequences to its elliptical shape and by the increasing difference in the subsidence and downwarping of the basin sequences with respect to the adjoining basement.

The tectonic compensation for the different subsidence was the origin of peripheral faults in marginal zones of the basin. It could be connected with the re-activation of diapirism (or some similar type of geological activity eg, a magmatic body which could be formed in the deep basement) in the Triassic which is common in this part of South Australia and produced numerous brachysynclines and brachyanticlines in the region (Coates et al, 1973).

The elliptical shape and the inward directed dips of the beds have created a tendency for rock mass movement along the bedding surfaces to the middle of the Basin as a result of the gravitation and normal stress field. This process corresponds to folding and has occurred both during sedimentation and in the epigenetic stages.

The bedding defects resulting from this structural tendency are represented, in general, by shear zones which developed along the bedding anisotropy surfaces, especially when sharp lithology changes occur. In detail sets of associated fractures and derived folds in the bedding plane have been developed (Figs. 3 and 4).

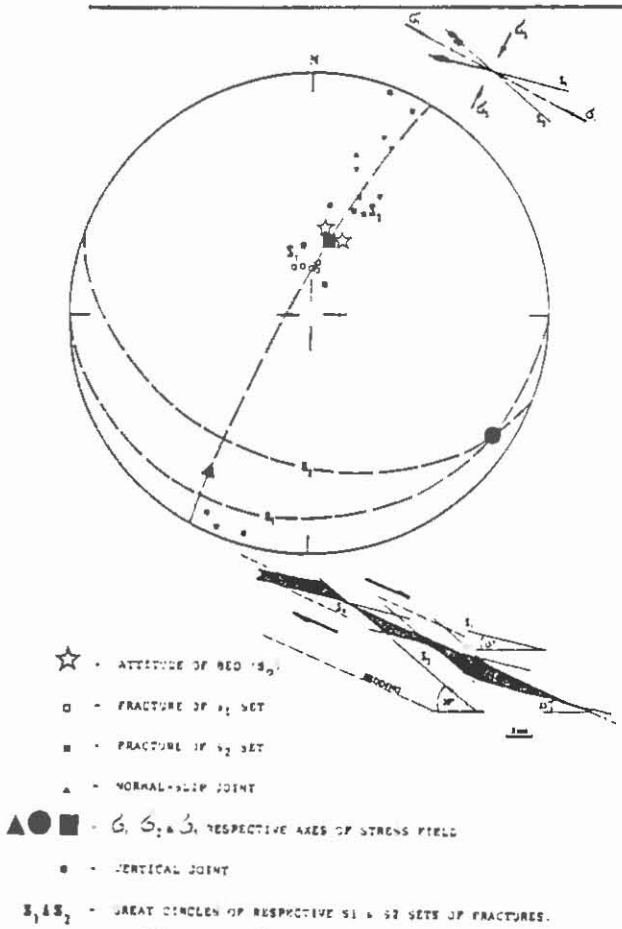

Figure 3.

Structural characteristics of a shear zone along the bedding, mining area U26.

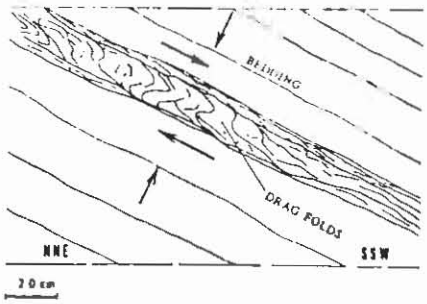

Figure 4.

Drag folds along the bedding in clayey sequences, mining area U26.

Displacements along the bedding planes with an amplitude of several metres occasionally appear. They are interpreted as bedding faults originating in the same normal stress field. Compensation of space resulting from the fault formation (displacement) may be an origin of thrust-type faults in the deeper parts of the basin, however, in a different thrust-creating tectonic regime (Bogacz & Kivior, 1988).

The tectonic movement along the bedding was a long lasting process developing simultaneously to normal-slip faulting and fracturing. The genesis and systems of these faults are closely related to the elliptical shape of the basin. Most frequent are normal-slip faults dipping at 45° - 75° which form two-set system of complementary conjugated longitudinal or near longitudinal faults. Their axes of conjugation parallel the strike of the beds, following the elliptical shape of the Basin. Some of these faults were rotated during folding as much as 15° towards the centre of the Basin (Fig. 5). For this reason, the homothetic faults of the system are steeper while the antithetic ones are flatter than the typical 50° - 65° dipping normal-slip faults.

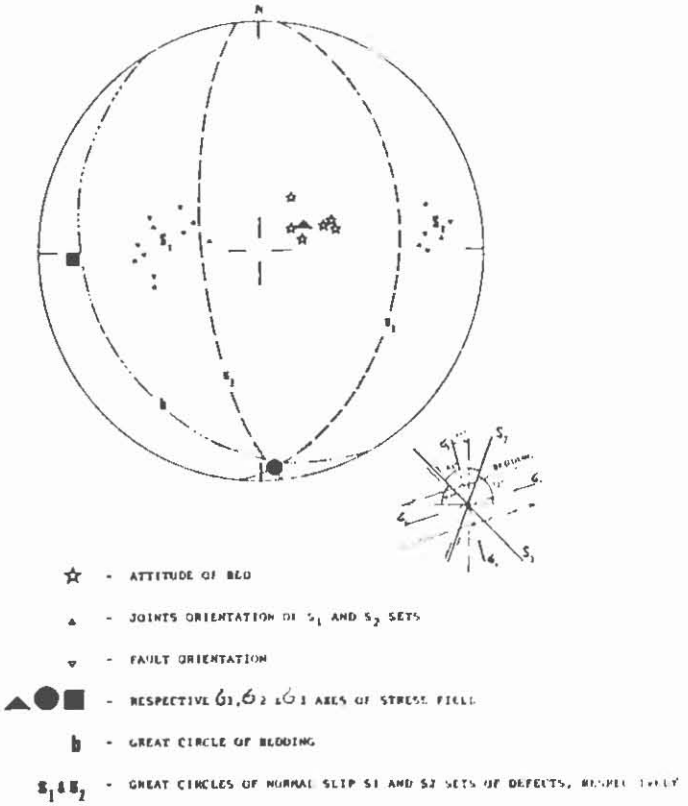

Figure 5.

Rotation of the longitudinal normal-slip joints and faults, mining area M8

This rotation of faults and observed transitions of the normal-slip defects into bedding defects suggest interfingering and superimposition of the two tectonic activities in time and space. Normal-slip faulting seems to be a continuous process which started before or simultaneously with the rotation of the beds (folding) and continued in the post-rotational period.

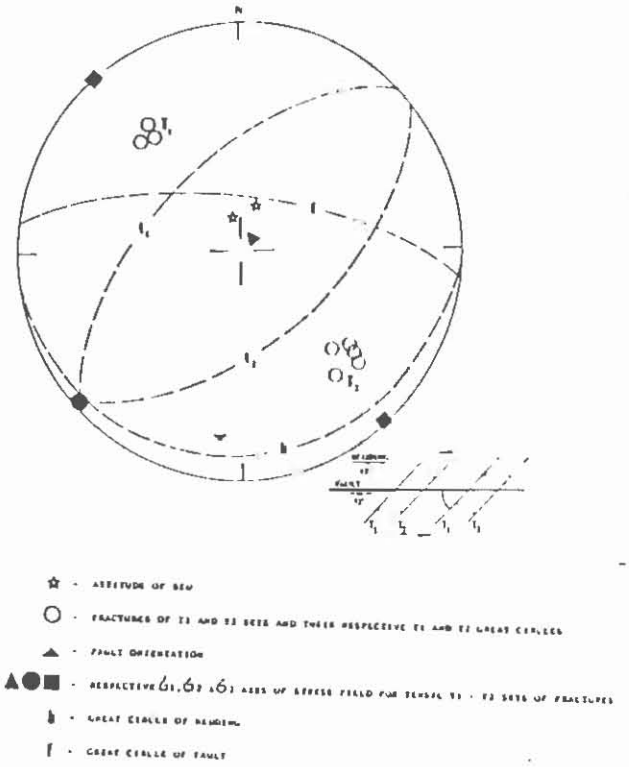

Figure 6.

Relationship between longitudinal faults and derived tensile defects

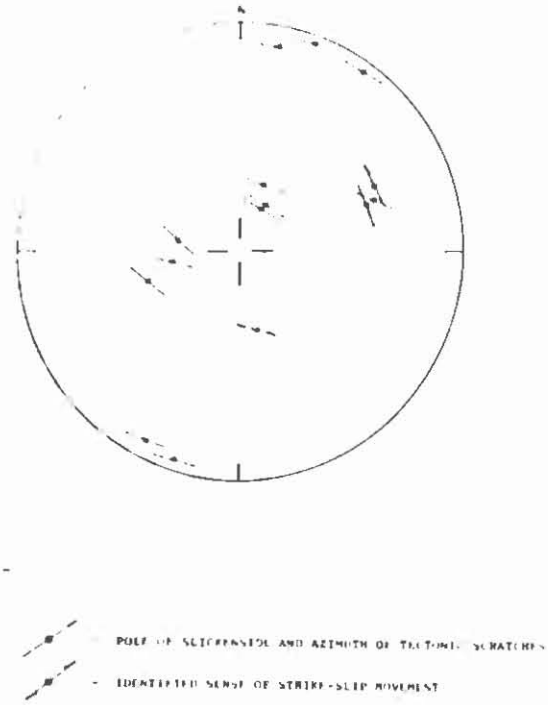

Figure 7.

Strike-slip tectonic scratches on differently oriented slickenside surfaces throughout the Telford Basin.

At the same time increasing angles of dip have created a permanent tectonic transport along the bedding. It is intensively developed in marginal areas of the Basin where the tectonic boundaries were established.

Tectonic rejuvenation of the region has also contributed to the complexity of the Basin structure. The normal-slip faults and associated cleavage of the NE - SW direction, concentrated along the northern periphery of the Basin, are interpreted here as secondary structures. They are in a tensile position with regard to a primary sinistral strike-slip movement (or tendency towards movement) along a WNW - ESE trending discontinuity in the basement (Figs 2 and 6). This is confirmed by the occurrence and directions of the strike-slip tectonic scratches which also occur within the youngest coal-bearing sediments (Fig. 7).

This suggests that the strike-slip movements were associated with the late stages of tectonic evolution, probably with the Tertiary rejuvenation and brittle deformation of the rock.

The extensional opening and mineralization by gypsum and sulphides of the bedding fractures and occurrence of numerous minor extensional structures which are especially well observed in the northern part of the Basin seem to be also connected with the same tectonic rejuvenation.

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'JOINT FILLINGS' IN SOME PERMIAN AND TRIASSIC ROCKS OF THE SYDNEY BASIN

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ABSTRACT

Some joint sets in several Permian and Triassic rockmasses of the northeastern Sydney Basin have been "filled" by a variety of sedimentary (shale, mudstone) and igneous rock derived (basalt, tuff) materials (Adamson et al., 1987).

The swirled texture of the igneous derived material suggests an intrusive fluid mode of emplacement, possibly associated with some gas pressure. The sediment based fill shows evidence of plastic flow deformation and appears to have been emplaced from lower layers by lateral compression and also by lateral extension.

The "fill" materials generally weather readily. Variations in the rate of weathering depend on the composition; sediment derived materials appear to be most resistant.

The engineering implications of these occurrences are significant, especially as some "filled" joints in areas of proposed road cuttings reach widths of 0.50 to 0.80 metres.

The features described here probably also provide indicators for regional tectonic phases and mobility, resulting predominantly in a shortening of Permian and Triassic rocks by thrusting.

The phenomenon of the "filled" joint sets may be part of larger brittle deformation events that have affected rocks in the Sydney Basin during post-Triassic time.

INTRODUCTION

Numerous sites with small intrusions (veins) of fine to medium grained grey "clastic" material have penetrated Triassic and Permian sediments in the north-eastern portion of the Sydney Basin. The majority of these occurrences has not previously been recorded, whilst some observed in a relatively small area near Newcastle have been misinterpreted.

The larger intrusions listed in Table 1 are well documented and have been the subject of considerable study. Their major dimensions are measured in metres and kilometres and hence are obvious features while the intrusions described in this study have much smaller dimensions (mm to m). Their density of occurrence at some sites ranges from four to ten veins per metre.

These small intrusions have received very little attention in the past, although during the initial field work it became obvious that they possess unusual features and may not be attributable to surface features or explained as injections from above, but are intrusions from below. This paper presents the results of an investigation into their distribution, characteristics, and possible mode of formation.

PREVIOUS WORK ON INTRUSIVE ROCKS IN THE SYDNEY BASIN

Fahey (1979) identified 65 locations, in the Toronto-Killingworth area, of what he described as clastic dykes which he concluded had been injected from above, with overlying sediments being the source materials.

Other authors refer to clastic dykes in the study area but the subjects of their studies differ from the intrusions dealt with in this paper. Gibbons (1973) reported a sandstone dyke intruding the volcanic breccia of the Minchinbury diatreme. This rock is different in appearance to the present study material and contains early Jurassic spores. The best known clastic dyke in the Sydney district is that at St Michael's Cave near Avalon. Data on this feature has been summarised by Herbert (1983).

A considerable body of literature on intrusive rocks in the Sydney Basin has been produced during the last 90 years. Geographic distribution and geological examination of intrusive volcanic breccias in parts of the Sydney Basin have been well documented. Crawford et al. (1980) summarised the data and listed numerous references to these diatremes. The latest work on igneous intrusives in the Sydney Basin has been on dykes and diatremes by Rickwood (1985) who produced a most comprehensive inventory for the area between Port Hacking and the Hawkesbury River, and who also refers to occurrences outside those limits and includes a very extensive reference list.

GEOLOGICAL BACKGROUND

The Sydney Basin in the area of interest consists of a sequence of Cainozoic, Mesozoic and Permian sediments resting unconformably on a basement of Palaeozoic igneous, metamorphic and sedimentary rocks.

Table I

MEDIUM TO LARGER INTRUSIVES IN THE SYDNEY BASIN

Intrusive	Composition	Dimensions and Frequency
Dykes	Basaltic	Width, several metres or less Length, up to several km Common
Sills	Basaltic and syenitic	Thickness, from <1 m upwards Area, from <1 ha upwards Not numerous
Plugs and flows	Basaltic	Area, from 1 ha upwards See Fig. 1 for east limit of distribution
Diatremes	Volcanic breccia and basalt	Area, from 1 ha upwards See Fig. 1 for east limit of distribution

Table II

THE SEDIMENTARY SEQUENCE IN THE SYDNEY BASIN

QUATERNARY	Coastal and riverine deposits	Clay, silt, sand and gravel
TERTIARY	Terrestrial colluvial and alluvial deposits	Flow debris and clay, silt, sand and gravel and laterite
TRIASSIC	Wianamatta Group	Shale and minor sandstone
	Hawkesbury Sandstone	Sandstone and minor shale
	Narrabeen Group	Claystone siltstone sandstone conglomerate
PERMIAN	Newcastle Coal Measures Tomago Coal Measures Maitland Group Greta Coal Measures Dalwood Group	Claystone siltstone sandstone conglomerate tuff and coal
BASEMENT OF CARBONIFEROUS VOLCANICS, SEDIMENTS AND OTHER PALAEOZOIC ROCKS		

GEOGRAPHIC AND STRATIGRAPHIC DISTRIBUTION

Recent examinations of over 200 sites with clastic and pyro-intrusives distributed between Surveyors Creek, near Mt Sugarloaf, in the north and Warragamba in the south have produced evidence that these intrusives occur in rocks with a stratigraphic range from the Tomago Coal Measures to the Upper Hawkesbury Sandstone.

Much of the area under study is rugged country serviced by few roads and elsewhere considerable areas are composed of Wiannamatta Shale and Cainozoic alluvial deposits, both of which lack suitable outcrops.

No obvious stratigraphic and geographic limits have yet been established for the intrusive sites. The intrusions appear to be concentrated in clusters separated by barren areas and, based on data presently available, there seem to be fewer occurrences in Hawkesbury Sandstone than in the older strata. This conclusion may have to be revised.

TERMINOLOGY

(a) The material

The terms *clastic intrusive* and *pyro-intrusive* have been chosen as descriptive names of the veins with no generic implications. Pyroclastic intrusive was originally considered, but discarded, as the word 'pyroclastic' implies a material ejected and deposited on the earth's surface, and the combined term seems to be contradictory.

(b) Morphology

The intrusions do not adhere to the normal concept of igneous intrusions as encountered in the Sydney Basin. Their size is much reduced compared to that of dykes and sills which they most closely resemble in other aspects. The emplacement pattern shows a great variety of forms, often even in the one intrusion.

The term *dyke* describes many of the occurrences where the visible intrusion is close to vertical, fairly straight, several metres long and between 50 mm to 400 mm wide. At the other extreme are *veins*, typically 500 mm long, a few millimetres wide and tapering out at each end like gashes. Both these terms suffer from lack of rigorous definition.

In addition, the term *dyke* seems inappropriate to describe part of a complex of interconnected veins in the style of a stockwork where the veins are up to 200 mm thick. However, in most cases the exposures are limited in size and the true form and extent of the intrusions can seldom be seen. Thus the terms *dyke* and *vein* for the thicker intrusions tend to become interchangeable and usage depends on the amount of visible outcrop.

JOINT FILLINGS

STYLE OF FIELD OCCURRENCES

These intrusions have been observed mostly on sites of sandstone pavements or exposures in roadside excavations. Some of the best exposures were found in quarries and open cut mines. Some sites contain a multitude of veins with various orientations, whereas elsewhere only one or two veins are visible in 50 to 100 metres long cuttings.

The veins are most obvious when the intrusive material remains in position in sandstone. In such cases the vein material may be more weathered than, or as equally preserved as, the host rock. Occasionally it is more durable, but is generally softer than its sandstone host. At a site at Wallsend Borehole Colliery near Minmi the dyke material has, over a period of seven years, weathered back about three to four metres from the vertical face of the old open cut, and the fissure is wide enough for the vein material to be sampled by entering the cavity which is 400-450 mm wide. The fissure extends to the top of the sandstone face with an estimated height of ten metres.

The vein material observed at the many sites varies from hard grey rock to soft plastic clay. Most samples contain a sandy component, the percentage of which varies considerably. Colours range from light to dark grey, frequently of a leaden hue, which contrasts distinctly with fresh sandstone surfaces. The less weathered specimens frequently exhibit a distinctive irregular network of thin light coloured veins (0.1-0.2 mm) on a fresh surface. The network units are of the order of two or three to several millimetres across. A "hackly" fracture is also a common feature.

At some sites the only evidence of the intrusive is to be found on exposed joint surfaces where it forms a thin remnant coating.

In vertical veins the grey colour and the texture mostly provide fairly positive identification. When the material occurs as an injection along bedding planes field identification can be difficult due to the similarity to the sedimentary units, unless there are distinguishing features. Some veins are affected by varying degrees of iron oxide impregnation with resulting colour changes.

IRON OXIDE REPLACEMENT OF VEINS

In some localities iron oxide seems to be a common replacement of the vein material. At a location near Wheeny Creek, in a road cut, normal grey veins have been found to change to reddish brown in an upward vertical distance of 1.5 to 2.0 metres as they approach the ground surface. At other localities, remnant patches of unaltered grey joint filling have been found in iron oxide filled joints.

These observations suggest that some of the many iron oxide filled joints in the Hawkesbury, Narrabeen and Permian sandstones may be altered grey intrusive material and that the clastic intrusions may have been much more common at one stage.

LITHOLOGICAL CONTROL OF INTRUSION MODE

The grain size of the host rock strongly influences the form of the intrusive. This may be due to the fact that the jointing modes are related to the grain size of the host rock and that the established joints provided planes of weakness exploited by the injection mechanism.

(a) Conglomerate

Field observations in the study area show that joints are widely spaced in the conglomerates. In the Teralba aggregate quarry very few joints are visible and no intrusives were observed. Spacing of vertical and near-vertical joints is as much as 40 m. At other conglomerate outcrops joint spacings of many metres have been noted. At a site near Gretley Colliery intrusives invade joints which are spaced in the order of metres apart. The presence of large pebbles in the conglomerate prevents a clear and well defined joint development, as they do not cut pebbles, but deviate around them. Consequently, the thin veins of intrusive, up to 30 mm thickness, are also not clearly defined by straight margins, but appear to be rather irregular.

(b) Sandstone

Sandstone has the best defined and more continuous sets of joints among the various rock types in the study area. Most sites exhibit joint spacings ranging from a few metres or less and rarely exceeding one metre.

The strength of sandstone and its joint spacing normally prevent even mild forms of ductile deformation or formation of many new failure planes. It will fail along existing joint planes, and only in extreme cases along newly created fracture surfaces. In both cases the vein material intrudes in sharply defined surfaces.

Two excellent examples of the lithology of the hostrock controlling the mode of emplacement occur in the Wyong district, near Mardi, in the first road cut west of the freeway overpass; a 200 mm wide vertical dyke of clastic intrusive in sandstone crops out at road level on the southern side of the road. Several metres above, a silty bed overlies the sandstone. The wide dyke no longer exists in this weaker rock, and the intrusion has changed its form and is represented by a number of thin veins radiating outwards from the top of the dyke.

At Scadden's Quarry, the massive sandstone cap on the hilltop is either steeply or vertically dissected by two orthogonal joint main sets. Some joints are not penetrative, and are filled with plastic grey clay to thicknesses of approximately 200 mm, occasionally wider. Some of these veins terminate suddenly at the base of the sandstone but other cross veins extend to lower levels. Such a face would indicate that some veins occur isolated in one bed with no downward

connection, although the feeder vein is situated in a cross joint not visible on the face. Such situations are common in the near vertical faces of many road cuts.

(c) Siltstone and claystone

Jointing surfaces and bedding planes in these fine grained sedimentary rocks are often very closely spaced, ranging from a few millimetres to 200 or 300 mm. Injection of material into these rocks can result in some distortion by the formation of several thin veins, either along joints or the numerous bedding planes. Thus individual intrusions in these rocks tend to be of much smaller dimensions than those in sandstone and as a result are less obvious. In addition, the intrusive weathers to grey clay, and is often of similar appearance to the host rocks.

INTRUSION MORPHOLOGY

The intrusives display a variety of forms which are predominantly governed by the strength of the host rock and its physical discontinuities.

(a) Dykes and joint veins

The intrusives most commonly occur in the normal joints of the host rock and thus are generally reasonably straight, vertical or steeply dipping and continuous for several metres. Owing to the limited size of outcrops it has generally not been possible to estimate the order of maximum length. At Scadden's Quarry at Wyong, dykes up to 200 mm wide extend for at least 50 m. Veins in curviplanar configuration are not uncommon. The width of these dykes and joint veins varies from thin films of sub-millimetre size to approximately 450 mm. Widths of more than 200 mm have been measured at four sites, and widths of 100 mm are quite common, whereas the most common width is less than 50 mm.

At many locations subsidiary joints, as well as the main joint set, have been invaded, producing a roughly rectangular or rhomboidal pattern.

As most veins weather readily, and are usually quite narrow with exposures of limited size, the maximum observable length, in most cases, is only several metres. Sets of veins have been observed over much greater distances, but continuity of individual veins cannot yet be demonstrated. The veins certainly lack the continuity of the igneous dykes, both vertically and horizontally, which exist in the same area.

The vertical extent of individual veins is most probably limited by the thickness of the sandstone bed in which they occur. As described earlier, the intrusion is liable to change its direction or mode of emplacement at a lithological boundary. The maximum

vertical extent observed for a continuous dyke or vein has been approximately ten metres.

(b) Irregular fracture veins

The veins in this group follow irregular fractures which are not associated with normal joints. These veins emanate from the joint veins and penetrate into rock which became irregularly fractured during or immediately before the injection process. Many taper rapidly and terminate in intact rock with no sign of jointing or fracturing. Some of the wider veins in this category contain angular inclusions of country rock.

(c) Polygonal pattern veins

Such patterns occur where irregular blocks of sandstone have been engulfed by the intrusive material. Some sites with sub-circular sandstone blocks up to 2 m have been noted.

(d) Bedding plane and sill-like intrusions

These forms are often more difficult to identify with certainty than any of the other categories and are probably more common than the data indicate. As the intrusive material is generally grey, fine grained, weak or soft when weathered, it closely resembles siltstone or claystone when it occurs in thin veins along bedding planes. These horizontal features occasionally thin rapidly with irregular boundaries, in which cases the identification can be made with more certainty.

When the intrusives occur in silty sandstone it is more visible, particularly if it is present as elongated blebs parallel to the bedding and connected to a vertical feeder vein. Thin beds or films along the bedding planes are often very difficult to identify as they blend with the host rock.

(e) Isolated veins

Some isolated veins have been observed on vertical sandstone faces. In these cases the veins taper to a termination at each end with no visible connection to other veins. Obviously these veins must have a lateral connection.

FIELD EVIDENCE FOR SUBTERRANEAN INJECTION OF VEINS

(a) Vertical veins of intrusive have been observed thinning to a film on joint surfaces which then continue upwards and finally fade into sound rock. Wide veins which taper upwards are common. The former Wallsend Borehole Colliery open cut site (Grid ref. 722599, Wallsend 1:25000 sheet) is the best example of these features.

(b) Some vertical veins have both upper and lower tapering terminations and appear to be unconnected with any pre-existing joint.

In these cases the material could have been injected laterally under pressure during or after brittle deformation of the rockmass.

(c) The vein material does not resemble any possible source material at the surface, either in the rocks above the veins or in close proximity below the veins.

(d) Intact rock has apparently been fractured in a random pattern, unassociated with any pre-existing joint sets and then injected with the intrusive.

AGE OF THE INTRUSIONS

Upper Hawkesbury Sandstone is the youngest sedimentary rock known to be intruded by the clastic intrusives. No search has yet been made in Wianamatta Group rocks. The only evidence of younger age is an intrusion into a basalt dyke near Jewelstown, a Newcastle suburb. Embleton et al. (1985) quote two basalt dyke samples from this vicinity with ages of 90.1 and 92.7 Ma.

It seems improbable that all these intrusions were formed contemporaneously. At present no indications have been found to indicate the period of time during which the activity took place.

From the present field evidence there appears to be no relationship between the diatremes and the clastic intrusives. Clastic intrusives have been located close to three diatremes, namely Hornsby, Oxford Falls and the Basin, in the headwaters of Wollombi Brook. These intrusives sites showed no unusual features and there was no increase in number of the veins despite the proximity of the diatremes. In addition, the clastic intrusions are numerous in the north-eastern part of the Sydney Basin where diatremes and other larger volcanic bodies have not been recorded.

Basaltic dykes are present throughout the area invaded by the clastic intrusives, but no connection between these features has been indicated. At the Terry Hills garbage tip a weathered basaltic dyke is located a few metres from clastic intrusions with no apparent influence of one upon the other.

RESULTS OF EMPLACEMENT OF VEINS

The emplacement of the intrusive materials into the vertical and sub-vertical joint sets of sandstone, with expansions of up to 450 mm for individual veins, would set up horizontal stresses or increase existing stresses in the host rocks. As sandstone is more favoured as a host for vertical intrusion than the finer grained rocks, the sandstones are more likely to be horizontally stressed than other strata above or below. This has resulted in the development of horizontal shear planes at the strata interfaces.

BRECCIA OCCURRENCES

Whereas the veins are very common, only two definite sites with brecciation and one site of breccia formation have been identified in an area near Killingworth, in the Newcastle district.

SUMMARY

The intrusives appear to have been forcefully emplaced in existing discontinuities developed in sandstones and to a lesser extent in finer grained sedimentary rocks.

Three distinct sources for the veins have so far been distinguished, namely shale/mudstone, basaltic and tuffaceous. The sediment derived veins as well as those of tuffaceous material have probably been formed by emplacement of material from layers below a regional compressive event, or events, whereas the basaltic veins have probably intruded when their "jost" joints experienced dilation.

As the occurrence of these veins is widespread, attempts will be made to link this phenomenon to other indicators of tectonic processes that have affected the Permian and Triassic successions of the Sydney Basin.

ACKNOWLEDGEMENTS

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B. Franklin examined the first thin section of the material and provided helpful discussions during the preparation of the paper.

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AEROMAGNETICS OVER THE SOUTHERN COALFIELDS

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An aeromagnetic survey was flown by BHP, Elcom and Kembla Coal and Coke over a section of the Southern Coalfields to try to delineate small scale features significant to mining. Of most importance were the position of dykes and the extent of sills.

BHP Engineering was commissioned to interpret this survey.

A high degree of success was achieved despite large semi-regional gradients caused by basement relief. Image processing successfully removed the gradients and highlighted features down to the noise level of the survey estimated to be below 0.5nT.

Flight lines were flown northeast-southwest at a nominal spacing of 200m and terrain clearance of 70m. Tie lines were flown perpendicularly every 1000m. The results were reduced, gridded and contoured and the grid was also put into an image processor.

The total field residual was quite striking in its large amplitude, semi-regional variations evident on Figures 1 to 3. When colour enhanced these variations showed long linear boundaries between levels in the magnetics. These have been interpreted as due to relief in the basement and could give quantitative data regarding basement structure.

Large dykes and sills were clearly evident through the gradient (see Figures 1 and 2). However, the presence of large scale features are often known, but the aim of this survey was to also detect smaller features. To achieve this, the gradient would first need to be removed.

A gradient filter was tried in the northwest-southeast orientation. Since this orientation was across flight lines it accentuated the small heading errors evident as corrugations in the data (see Figure 3). Although these were only about 2nT, analysis of small features was severely disrupted.

By applying the gradient filter along the flight lines, the line-to-line mis-ties were not evident and a more detailed data set was available for interpretation.

Another approach was to apply a box filter along the flight lines and view the residual. This operator was sensitive enough to highlight features down to the noise level estimated to be less than 0.5nT. Hence it was now possible to delineate 1nT features within a relief of over 250nT.

One problem of effectively amplifying the small scale variations was that the near surface and cultural features such as basalt (see Figure 4) and culture (see Figure 5) were also enhanced. To overcome that problem, an optical illusion was employed in the colouring of the data. By making the subtle variations appear largely as one colour, the culture and basalt with their very large variations showed up as dark, speckled areas. The eye could then be easily trained to ignore these areas.

A process known as 'artificial sun' was also useful in delineating small scale features. It can be thought of as considering the data as a three-dimensional surface. It was then 'illuminated' by an artificial sun from various angles. As the angles changed, different features became apparent.

Many features were detected by the above processes. Probably the most significant benefit was in delineating the margins of sills at depth. Also dykes with only small magnetic relief were detected.

It can be concluded that this aeromagnetic survey and the associated image processing located the margins of sills and the position of dykes with only small magnetic relief. As a result substantial exploration costs have been saved and the survey and processing have proven cost effective.

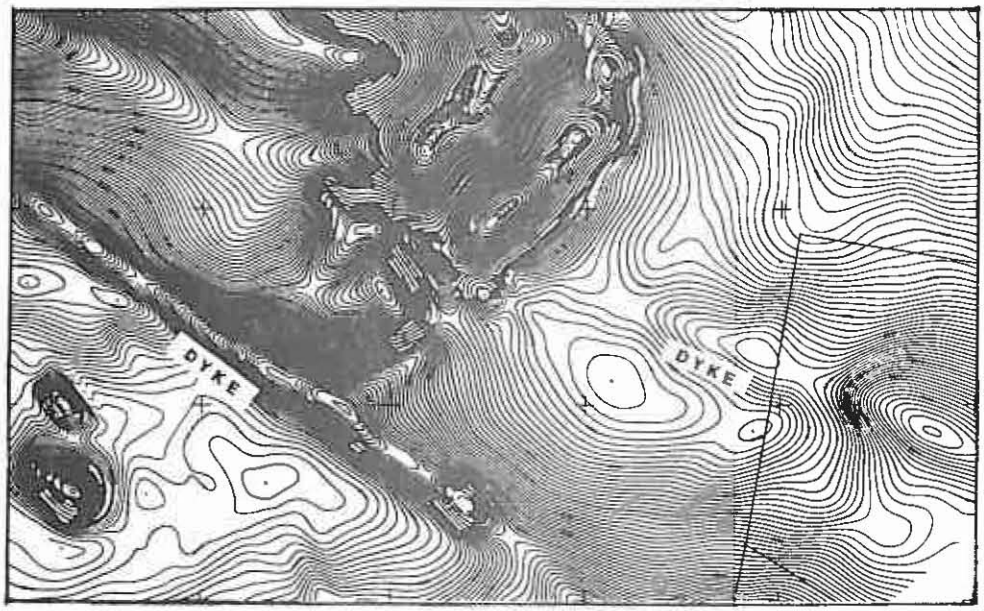

Figure 1 Dykes

Figure 2 Sill

Contour Interval = 1nT - All figures

Tick Marks = 1km - All figures

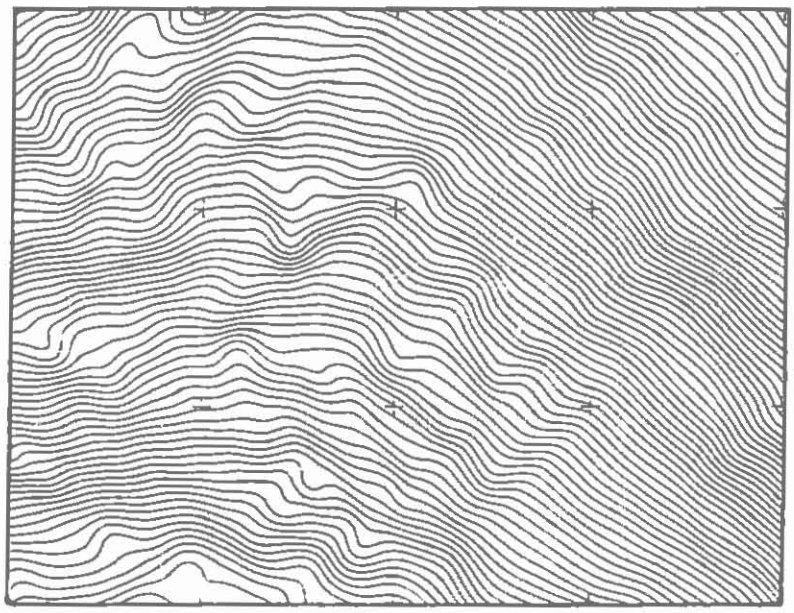

Figure 3 Heading Errors

Figure 4 Basalt

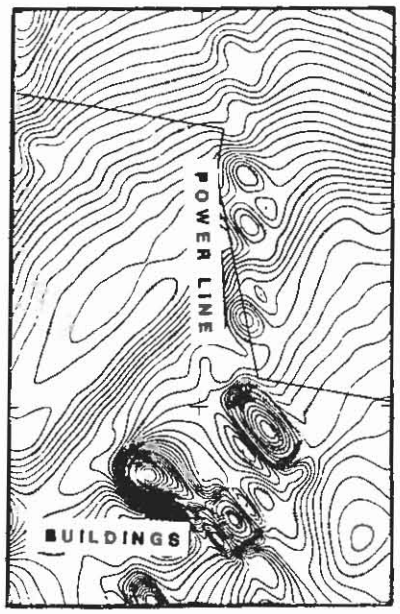

Figure 5 Culture

A CHAR MORPHOLOGY CLASSIFICATION WITH APPLICATIONS TO COAL COMBUSTION

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CHAR PROPERTIES AND COAL REACTIVITY ON COMBUSTION

Experiments have shown (Shibaoka et al., 1985) that coal combustion occurs in two main steps - devolatilization to produce char, followed by char combustion. Devolatilization takes place in less than 50 milliseconds, while char combustion may require several seconds and is the rate-determining step. For this reason, it is important to investigate the morphology and rate of combustion of char from various coals, in order to determine the features which prevent some coals from burning to completion during their normal residence time in the furnace of a power station.

Until recently, mathematical modelling of coal combustion assumed p.f. particles to be composed of homogeneous material which burned with constant density as shrinking spheres. However, observation of char and partly combusted coal shows that just as coal is heterogeneous, p.f. and char of 40-200 microns is also composed of heterogeneous particles of different maceral composition, varying shape, porosity and internal surface area, and different optical anisotropy.

The char burning rate may be calculated by considering a two step combustion process. The first step involves diffusion of oxygen to the surface, and the second step involves the chemical reaction at the surface of the char particle.

The measurable parameters of char which can contribute to the interpretation of reactivity equations are:

a) The external dimensions of a particle which determine the rate of diffusion of reactant gas toward it and can be estimated or measured by optical or electron microscopy.

b) The porosity and pore distribution of char particles which can determine the extent of diffusion of oxygen into the particles, and will influence the extent of internal burning taking place inside the char. For most coals, internal burning constitutes by far the most important type of burning (Simons,1983). The porosity of char particles may be estimated visually by optical microscopy, or measured in two dimensions by an imaging process using QEM (Quantitative Electron Microscopy).

c) The surface reactivity of char may be related to the optical texture or coke texture of the char, and the degree of anisotropy developed. Anisotropy represents the degree of re-ordering of 'micelles' or basic aromatic units which occurs in a coal as it is heated through its plastic stage. As aromatic groups coalesce, and graphitic lamellae increase in extent, there are less plate-edge carbon atoms available to react with oxygen, and the developing aromatic frameworks become increasingly stable. The char appears to become less reactive with increasing anisotropy as a result of this changing structure.

Therefore, a char classification aimed at contributing to char combustion models should be based on the following parameters:

* estimated macroporosity (pores >1 micron)
* distribution of macropore sizes
* wall thickness of particle or of internal partitions
* presence of anisotropy of particle walls
* bireflectance or coke domain size (extent of anisotropy)

CHAR PREPARATION AND CLASSIFICATION SYSTEM

Sample Preparation

Samples are prepared by first making solid cylindrical moulds of polyester resin with a cylindrical cavity of 5mm depth and 12mm diameter recessed in the centre top. Since only small quantities of some chars are available, 0.1 to 0.2g of representative char is mixed with the same type of resin within the cavity and allowed to set. The sample surface is then polished and examined microscopically in reflected light in oil immersion. Placing the small amounts of char available in a recessed cavity allows sufficient concentration of particles to enable examination of the sample by point counting using a mechanical stage.

Simplified Char Classification

At low temperatures most char types may exist in isotropic or anisotropic form, and so the classification must provide for a large number of char categories. However, chars pyrolysed at higher temperature (i.e. 1500°), and burnout residues tend to have more exclusively anisotropic particles, and so require fewer categories for description. For combustion studies, some char types having similar characteristics but simply a different vesicle shape, for example, because of their origin from coals of different rank may be conveniently grouped together. A condensed system of char morphologies, presented in Table 1, has been established so that high temperature particles can be classified in only ten categories.

Table 1: CONDENSED CHAR MORPHOLOGY SYSTEM FOR HIGH TEMPERATURE CHAR

CHAR CATEGORY NAME	DESCRIPTION	VESICLE DISTRIBUTION
tenuisphere	hollow, spherical, thin-walled, anisotropic	>80% porosity, 1-3 large central vesicles ± secondary vesicles
isocrassisphere	hollow, spherical, thick-walled, isotropic	>50% porosity, 1-3 large central vesicles ± secondary vesicles
anisocrassisphere	hollow, spherical, thick-walled, anisotropic	as above
network	thin-walled, high internal surface area	>60% porosity, > 5 vesicles, walls <10μm
dense network	thick-walled, high internal surface area, anisotropic	>40% porosity, > 5 vesicles, walls >10μm
inertoid	thick-walled, low internal surface area, isotropic	5-40% porosity, walls >10μm thick
unfused	isotropic, no degassing vesicles	<5% porosity
anisoinertoid	thick-walled, low internal surface area, anisotropic, may have ribbon anisotropy.	<40% porosity, walls >10μm thick
mixtoid	50% unfused, 50% fused	variable porosity
mineroid	over 50% mineral matter	none

CHAR POPULATIONS FROM PARTICULAR COALS

Raw Data

Four coals which have been combusted at pilot and laboratory scale have been examined. Of the coals, Collie was found to burn out most efficiently, followed by Tarong, Bayswater and Curragh (Bailey et al, 1988). In the case of these four coals the order of burnout coincides with order of increasing rank, but the work of Field (1970), Oka (1987) and the author show that this is not always the case. When considering coals of similar rank, petrographic properties and char types produced help to predict burnout performance. The same properties and char types can be used to predict burnout order for these coals regardless of rank.

Char produced at 1500°C most closely represents fully devolatilized p.f., so these results along with counts of combustion residues generated at 1200°C are presented in Tables 2 and 3. Significant groups of char particles have been summed for comparison at the base of each table.

Table 2: CHAR TYPES AT 1500°.

COAL	COLLIE	TARONG	BAYSWATER	CURRAGH
RANK (R_{or})%	0.38	0.57	0.70	1.14
CHAR TYPES.				
Unaltered coal	0.0	0.0	0.0	2.1
Tenuisphere	4.1	1.3	16.9	5.5
Anisocrassisphere	1.5	5.4	24.9	25.6
Network	49.9	32.2	3.8	4.5
Inertoid	13.0	37.2	19.8	3.9
Unfused	24.4	20.6	12.7	7.0
Anisoinertoid	0.2	1.9	20.0	41.3
Mixtoid	7.0	1.3	2.0	10.0
TOTAL	100.1	99.9	100.1	99.9
Special Categories for Comparison.				
Thick-walled anisotropic	0.9	2.3	22.2	62.3
Thick-walled	14.1	35.4	52.9	66.5
Thick-walled + Unfused	38.3	51.9	62.9	78.7
Anisotropic	4.9	7.1	25.0	72.1
Low Density	57.5	34.2	21.7	15.0

APPLICATION TO COMBUSTION PERFORMANCE

Burnout

A comparison may be made of the trends in the proportions of certain char categories with the burnout ranking. The percentage of high density char residue (thick-walled + unfused) produced by pyrolysis at 1500°C does indicate correct burnout order. The proportion of unfused chars becomes an unreliable burnout estimator in the coking coal range (i.e. Curragh char) in optical density. Anisotropic char appears in these experiments and in those of Oka et al. (1987) to be less reactive than isotropic high density char and to reduce burnout performance considerably. Although anisotropic char may develop an enhanced microporosity, this does not appear to increase its reactivity to oxygen.

Residues prepared at 1500°C are shown to be suitable for classifying chars for combustion applications whereas those prepared at lower temperatures (<1000°C) are not. During the initial study the burnout ranking of four coals may be predicted by:

* Increasing order of thick-walled char
* Increasing order of thick-walled plus unfused char
* Increasing order of anisotropic char
* Increasing order of thick-walled anisotropic char
* Decreasing order of low density char

Table 3 : BURNOUT RESIDUE POPULATIONS AT 1200°C

Char Types	COLLIE	TARONG	BAYSWATER	CURRAGH
Tenuisphere	17.4	15.0	0.8	16.4
Anisocrassisphere	2.3	0.4	0.3	8.2
Network	23.7	7.2	10.1	18.8
Dense Network	4.3	0.4	1.1	6.3
Inertoid	10.1	23.8	23.9	15.3
Unfused	15.6	18.9	30.9	7.4
Anisoinertoid	5.6	2.4	0.2	5.1
Micro-disrupted : anisotropic	6.3	13.4	7.3	7.4
isotropic	5.7	17.4	20.3	2.9
Mixtoid	9.3	0.9	5.0	12.2
TOTAL	100.3	99.8	99.8	100.2
Special Categories for Comparison				
Anisotropic thick-walled	12.2	3.2	1.6	19.6
Thick-walled	21.4	25.1	27.8	34.9
Thick-walled + Unfused	42.6	46.4	58.9	48.4
Low Density	57.8	53.5	41.0	51.6

The percentage of high density combustion residue (thick-walled + unfused) produced by burnout at 1200°C places the four coals in burnout order except for Curragh coal. The lower amount of thick-walled and unfused char counted in Curragh coal indicates that the coal should perform better than Bayswater coal, but this fails to take into account the proportion of anisotropic thick-walled char present. A better estimate of burnout performance based on combustion residue populations would be obtained by considering not only the amount of high density residue produced, but also the proportion of this residue with discernible coke anisotropy. Predictions from combustion residue should also take into account the amount of very reactive material which has already been burnt out by 1200°C.

For the burnout residue produced at 1200°C, burnout order may be predicted by:

* Increasing order of thick-walled char

Further testing on a wider variety of coals is needed, but the burnout order appears to be adequately predicted by rank when the coal ranks are significantly different. However, in order to predict burnout performance for coals of similar rank, but varying chemistry and petrology, high temperature chars and burnout residues offer scope as a qualitative ranking tool.

Flyash character

The particle size analysis of pyrolysed char from the same coals was obtained using a laser particle size analyser. Table 4 shows the mean p.f. size, mean char sizes at 900, 1000 and 1100°C and percentage of char below 10 microns in size for each coal at each of these temperatures. Deviations from a char particle size distribution directly related to p.f. size occur in coals for two main reasons:

* Char particles from swelling coals may expand during pyrolysis or combustion producing a coarser size distribution than predicted.
* Alternatively, skeletal or swollen chars may fragment, causing the production of many fine char particles.

Comparison of the char sizes and char types of the four coals gives some indication of the likelihood of a coal to produce large quantities of fine ash. In particular, Curragh coal which lies in the range of prime coking coals, produces a significant quantity of char cenospheres which have swollen to over twice the original p.f. size. This is evident from Table 4, with the char size being drastically reduced by ultrasonic treatment of Curragh char. The original character of the char is confirmed by the extent of thin-walled low density char observed microscopically. These particles can be seen to have fragmented to very fine splinters of char material at a temperature of 1000°C.

Consequently Curragh coal will produce large quantities of fine ash, and this property has been described quantitatively in Wall et al.(1988). Power utilities confirm that Curragh coal does produce a large percentage of very fine ash.

On the other hand, Bayswater coal which has no tendency to swell, does not produce thin-walled cenospheres, but thick-walled isotropic spheres which burn out without significant fragmentation. Similarly, Tarong char does not swell, and its top char sizes are composed of unreactive mineral-rich inertinite. Collie coal does not swell but because of its low rank, and so very high porosity, has a tendency to fragment as the char devolatilizes. Thus, the quantity of fines increases slightly with temperature.

Table 4 : CHAR PARTICLES SIZES AT 900, 1000 and 1100°C

	COAL			
	COLLIE	TARONG	BAYSWATER	CURRAGH
	microns/%	microns/%	microns/%	microns/%
Mean Size p.f./ %<10um	90/1	83/1.5	80/3.5	99/5.5
Mean Size Char at 900°/ %<10um	80/4	68/4	64/5	72/12
Mean Size Char at 1000°/ %<10um	78/3	82/1.5	77/4.5	81/5
Mean Size Char at 1100°/ %<10um	55/6.5	62/4	60/4	58/6
				150/4*

* no ultrasonic treatment of sample.

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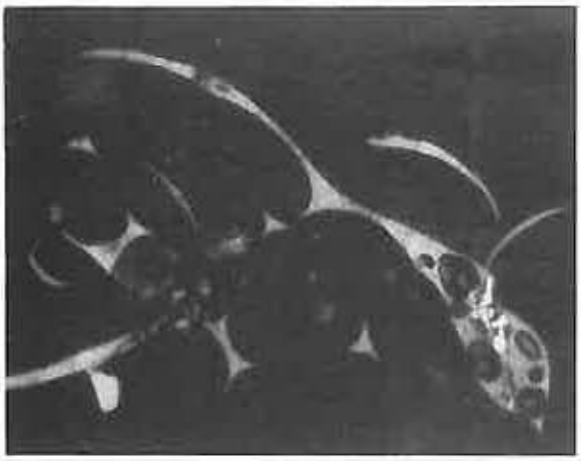

Plate 1. Fragmented anisotenuisphere

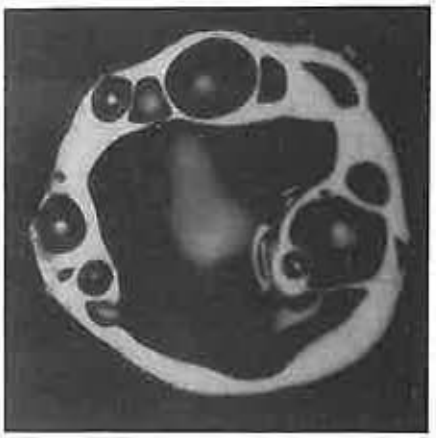

Plate 2. Isocrassisphere

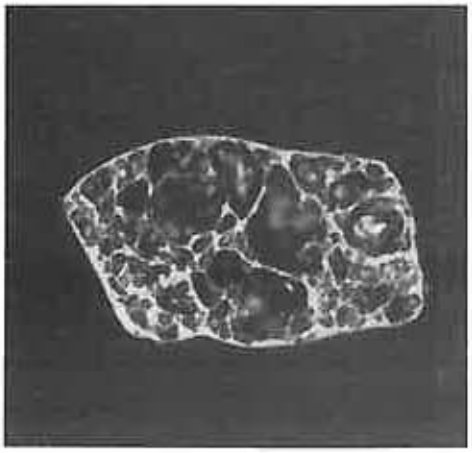

Plate 3. Network

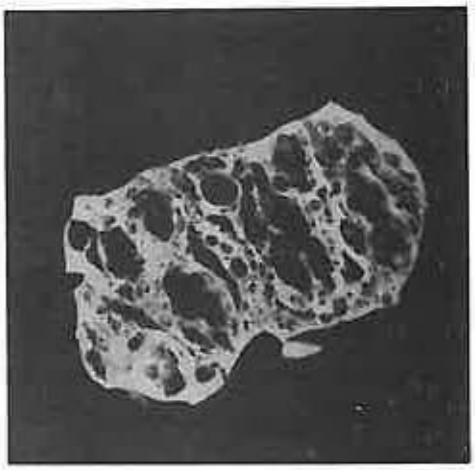

Plate 4. Dense Network

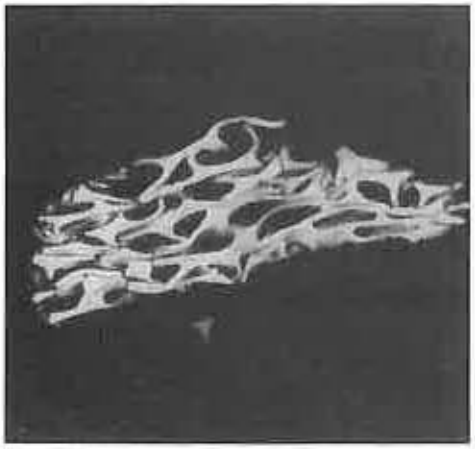

Plate 5. Fusinoid (Unfused)

Plate 6. Macrinoid (Unfused)

PETROGRAPHY OF CERTAIN GONDWANA COALS OF AUSTRALIA AND INDIA

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ABSTRACT

The Permian coals of Australia and India are often referred to as Gondwana coals, which are of increasing economic importance to both countries of the former Gondwanaland. The coals have been deposited under a set of geological, biological and chemical environments that show similarity in petrography and the distribution of mineral matter.

INTRODUCTION

The Early to Late Permian coals of Australia and India along with those of South Africa, South America and Antarctica are often referred to as Gondwana coals. The Gondwana coal deposits have been formed under similar geological, biological and geochemical environments. The similarities in coal have significant importance in exploration, preparation and utilization in respective countries.

The comparative petrographic studies of Australian and Indian coals by Marshall (1959, 1964) have demonstrated close affinities in physical constitution and distribution of mineral matter which impact on utilization. Relatively high proportion of ash in both coals is largely due to dispersed mineral matter associated with lithotypes and macerals of vitrinite and inertinite groups. The presence of mineral matter is relatively more in 'dull' lithotypes than the 'bright' lithotypes of coal. The intimate association of finely dispersed mineral matter with inertinite group of macerals creates problems in washing processes.

Coal is the most important and readily available source of energy in Australia and India. In both countries it has played an important role in economic development and industrialisation.

It provides metallurgical coke for iron and steel manufacture, gaseous fuel, a wide range of organic chemicals and a source of energy for electricity. The Australian overseas shipment of coal has increased dramatically over the last ten years, and it has boosted Australian export earnings and assisted in maintaining a favourable trade balance. In 1987 Australia was the world's second largest exporter of coal. The Australian continent has about 4.0% of the world's insitu demonstrated coal reserves for a population of 16 million people, in contrast to the Indian coal reserves of 1.1% for a population of approximately 800 million people.

REGIONAL GEOLOGY

The Early Permian to Late Triassic sediments of the Indian Peninsula are commonly referred in literature as the Gondwana Supergroup (Casshyap and Tewari 1984). The Gondwana Supergroup consists of a 7000 m thick clastic sequence with associated coal. The distribution of Gondwana sediments in the Indian Peninsula consists of three separate elongate basins, namely :

(i) The Koel Domodar Valley, eastern India.

(ii) The Son-Mahanadi Valley, east-central India.

(iii) The Pranhita-Godavari and Satpura, south-central and central India.

Similar to India, the Australian black coal deposits are mainly of Permian and early Mesozoic age. The geo-tectonic settings of the Permian coal basins of Australia are characterised as fore deeps associated with orogenic belts (Sydney and Bowen Basins), and intra-cratonic basins described as grabens (Collie Basin) and half grabens (Perth Basin). The characteristic flora which contributed to the formation of Australian and Indian coals has similarities and it is described as glossopteris flora. The coal bearing sequences of both countries are mainly of fluvial and deltaic origin, and they are characterised by the absence of marine sequences. Brief comments on geology of important Australian and Indian Permian basins are described in this paper.

Sydney Basin

There were at least two periods of widespread coal formations in the Sydney Basin. One in the Early Permian consisting of the Greta Coal Measures in the northern part and the equivalent Clyde Coal Measures in the southern part of the basin, the second in the Late Permian consisting of the Illawarra Coal Measures in the southern part and the Singleton Supergroup in the northern part

of the basin. 65% of the measured coal resources in the Sydney Basin have coking properties, and the rest are steaming coals (Traves et al. 1975).

Bowen Basin

Bowen Basin coal measures occur in four stratigraphically distinct groups. The Early Permian (Group I) coals occur in the Reids Dome Beds, the Middle Permian (Group II) coals occur in the Collinsville and Blair Athol Coal Measures and Alderbaran Sandstone. The Late Permian includes (Group III), the Blackwater Group and (Group IV) the Baralaba Coal Measures. The Late Permian coal measures are the most extensive in distribution within the basin. The Bowen Basin is a major source of high quality coking coal and steaming coal for export (King 1976).

Collie Basin

The two half grabens of the Collie Basin in Western Australia contain about 1300 m of Early to Late Permian Coal Measures. The coal is non-coking and suitable for steam generation (Sappal 1986).

Other significant and yet to be explored basins of Australia are - Perth Basin, Carnarvon Basin, Canning Basin, Bonaparte Gulf Basin and the Cooper Basin.

Domodar East Basin

The Domodar East Basin consists of Karharbari, Barakar and Raniganj Formations with inter-bedded sequence of sandstone, shale and coal. The basin contains twenty five seams of more than 1.2 m thickness, which occur in the Raniganj coalfield in West Bengal, and the Jharia coalfield in Bihar. The coal is of high-volatile bituminous rank, generally with high ash and low sulphur content. The Jharia coal reserves represent the major coking coal resources of India.

Godavari Basin

The age of the coal measures in the basin is Early to Late Permian, and these have been identified over a large area of Andhra Pradesh. The coal measures contain four main seams which range in thickness from 1 to 4 m, and the coal is of high volatile bituminous rank.

PETROGRAPHY

Coal is a mixture of combustible metamorphosed plant remains that vary in both physical and chemical composition. Differences

in the kinds of plant remains (type) and the degree of metamorphism (rank), and in the range of impurities present (mineral matter) are characteristic of coal. The physical variations due to kind of plant material are manifested in coal as lithotypes (macroscopic), macerals and microlithotypes (microscopic). Brief comments on lithotypes, macerals and mineral matter, and their practical importance for Australian and Indian coals are described.

Lithotypes

Macroscopically the northern hemisphere coals have been described on the basis of Stopes (1919) terminology - Vitrain, Clarain, Durain and Fusain. However, these terms are not easily applicable to coals of Australia and India, because these coals are finely banded, and vitrain bands are usually less than 10 mm thick, and dull and non banded component is higher. Due to finer laminations, a smaller limit of a minimum of 5 mm is used, and the terms commonly used to describe lithotypes are - dull, dull banded, banded, bright banded, bright and fusain for fibrous coal (Diessel 1965).

The lithotypes with brightest lustre in banded coals show moreover homogeneous maceral composition in contrast to lithotypes with dull lustre. The physical and chemical properties of lithotypes differ considerably along with the distribution of mineral matter which largely accounts for ash content in coals. Table 1 shows the range of ash contents of the selected lithotypes of Australian and Indian coals (Marshall 1964).

TABLE 1 - Comparison of range of ash content of the lithotypes from selected coals

Lithotypes	Australian coals, range of ash yield %	Indian coals, range of ash yield %
Vitrains (Bright coals)	< 2 - 14	< 2 - 14
Clarains and duroclarains (Bright banded, banded and dull banded coals)	2 - 22	2 - 22
Durains (Dull coals)	6 - 32	4 - 42
Fusains	6 - 32	n.a.

The variation in ash content of different lithotypes is significant in the utilization of coal. The range of ash content for Australian coals is lower than those of Indian counterparts.

Macerals

Macerals are considered analogous to minerals of rocks, and on the basis of the similarity of petrographic characters, the macerals are grouped into vitrinite, exinite and inertinite. Table 2 describes the maceral group composition of selected Australian and Indian coals. Vitrinite is an important maceral group of Australian and Indian coals. The Australian coals shows slightly higher vitrinite content than those of Indian coals. Vitrinite is relatively rich in oxygen, tends to concentrate in particle sizes smaller than 1 mm in crushing, and contributes to coking ability due to high swelling properties and good plasticity. In low rank coals vitrinite is readily hydrogenated, and it represents a large proportion of mine dust during mining. Vitrinite reflectance for Indian Permian coals is slightly higher than that of Australian coals, and the coals from both countries fall into sub-bituminous to bituminous rank.

Exinite group of macerals result from the accumulation of specific parts of plants such as spores, cuticles, resins and waxes and algae. The exinite content in Australian coals is lower in comparison to Indian coals (Table 2). Exinites are rich in hydrogen, and the presence of exinite in coal increases the strength of bands in which it occurs. On carbonization exinite produces highest yield of by products, and due to high hydrogen content the coals rich in exinite are suitable for hydrogenation. Owing to their toughness, exinite group of macerals restrict dust formation in mining operations.

Inertinite group of macerals originate from similar plant remains as vitrinite, but severe bio-chemical alteration has occurred to a far greater extent than in case of vitrinite. The inertinite content of Australian coals is slightly higher than Indian coals (Table 2). Inertinites are rich in carbon and oxygen in comparison with vitrinites, but lower in volatile matter. The presence of inertinites increases the strength of bands in coal, and during carbonization it is generally inert in coking coals, and hydrogenation of inertinites is not possible due to low hydrogen content.

TABLE 2 : Petrography of selected Australian and Indian Permian coals, data from Babu (1968), Pareek (1985), Sappal (1986) and Ward (1984).

Country Basin Seam	Vitrinite %	Exinite %	Inertinite %	Minerals %	Vitrinite Reflectance RO_{max}%
AUSTRALIA					
SYDNEY BASIN					
Bore hole	74	5	16	5	0.85
Greta	70	11	17	2	0.63
Bulli	45	-	49	6	1.24
Wongawilli	49	1	39	11	n.a.
BOWEN BASIN					
Black water	51	2	42	5	1.11
Blair Athol	35	4	54	7	0.74
Callide	29	1	59	11	0.51
COLLIE BASIN					
Bellona	54	4	38	4	0.43
Hebe (A)	54	4	39	3	0.44
Wyvern	53	4	40	3	0.47
INDIA					
DAMODAR EAST BASIN					
Dishergarh	64	6	25	5	0.69
Jharia SI	47	9	36	8	1.35
Samla	60	2	34	4	1.06
Laikidih	43	16	39	2	0.92
GODAVARI BASIN					
Queen (B)	54	9	14	23	0.69
Queen (M)	35	24	21	20	0.62
King (M)	32	6	54	8	0.65
Green (M)	23	9	63	5	0.57

Mineral Matter

In addition to the organic components (macerals), coal invariably contains smaller or larger amounts of inorganic constituents. Two groups of inorganic constituents can be distinguished dependent on their origin. The first group is of inherent mineral matter, which is present in coal forming plants and common constituents of this group are compounds of Ca, Mg, Fe, Al, Na, K, Mn, Ti, S, Si, Cl and P. Some of these elements like Na, K, Mg and Cl are removed during the bio-chemical stage of coalification. The contribution made by the inherent mineral content of coal is relatively small, and the second group of inorganic constituents called adventitious make bulk of the mineral matter in coal.

The adventitious mineral matter in Australian and Indian coals has similarities to its origin and type, and the dominant groups are; clay minerals (kaolinite, montmorillonite, illite, gibbsite etc) carbonate minerals (calcite, dolomite, ankerite and siderite), pyrite minerals (pyrites, and marcasite) and quartz grains impregnated in vitrinite and inertinite. The durains of Australia and India are commonly characterised by higher proportions of mineral matter in comparison to clarains and vitrains (Table 1). The mineral matter associated with maceral groups in Indian coals is higher than the one associated with the Australian coals (Table 2).

CONCLUSIONS

The variations in petrographic composition and mineral matter distribution of Australian and Indian coals have far reaching effects on the quality of coal and its technological behaviour. The petrographic characterisation of coals from both countries also impacts on preparation, selective marketing and utilization. The character, proportions, distributions and associations of mineral matter with lithotypes and macerals has been a matter of particular concern to both producer and consumers of Australian and Indian coals.

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