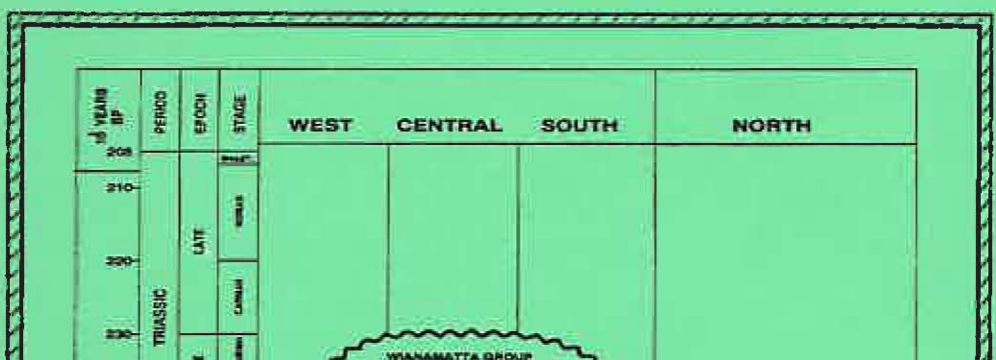
THIRTY SECOND NEWCASTLE SYMPOSIUM

on

ADVANCES IN THE STUDY OF THE SYDNEY BASIN

April 3-5, 1998

NEWCASTLE NSW AUSTRALIA



DEPARTMENT OF GEOLOGY, THE UNIVERSITY OF NEWCASTLE, NSW 2308

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PROCEEDINGS OF THE
THIRTY SECOND NEWCASTLE SYMPOSIUM

on

"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

edited by R L Boyd and J Winwood-Smith
The University of Newcastle

April 3-5, 1998
NEWCASTLE NSW 2308 AUSTRALIA

R L BOYD
CONVENER

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Note: Acceptance of abstracts and presentation of papers does not necessarily imply acceptance of the ideas and concepts by the organisers of the Newcastle Symposium or The University of Newcastle.

PREFACE

Welcome to the thirty-second Newcastle Symposium. We have received around twenty presentations for this year's meeting, as well as posters and trade displays. We have a program of sessions on Saturday morning, afternoon and Sunday morning. In addition we have a full day excursion on Friday, and social events on Friday and Saturday evening. We hope you will enjoy and appreciate this variety of material.

In this Thirty Second year, the Symposium has reverted to a general theme, after two years of specialising in historical themes associated with the Bicentenary of Newcastle (1997) and celebrating the 30^{th} (Diessel) Symposium by honouring its founder Professor Claus Diessel (1996). In recognition of our long association with research at the University of Newcastle, we are pleased that the Pro Vice-Chancellor for Research, Professor Ron MacDonald, will be officially opening our Symposium. In addition, our Keynote Address will be given by David Williams from CSIRO on the topical subject of greenhouse gas emissions and their relationship to the mining industry. An invited talk by Dave Alder, Brad Mullard and Ray Shaw from the NSWDMR will begin our Symposium by describing a new model for Sydney Basin evolution and its implications for offshore hydrocarbon exploration. A second invited talk by Michael Creech from Power Coal will present a very interesting theory on the origin of coal. Finally, a third invited talk by David Brewer, the general manager of Port Waratah Coal Services will review the development of the Port of Newcastle and its role in the coal industry.

In keeping with our normal program, we have sessions that will examine regional geology, coal geology, engineering geology, and environmental geology. The Department of Geology undergraduates will be actively involved with running this year's symposium and will also co-sponsor the Friday evening sheep roast. I would like to thank the innumerable helpers that make it possible to stage this event each year. In particular, I would like to acknowledge the efforts of our Departmental staff, who have played a central role in organisation and preparation for the 1998 Symposium. Judi Winwood-Smith (our new Departmental administrative assistant) and Sharon Francis have done a great job of organising the Proceedings and all other activities. Major contributions have also come from Richard Bale, Phil Seccombe, and Eddie Krupic and the students of the Geology Department. We have managed to maintain costings at last year's levels for all events except for a $5 increase in dinner costs. Our aim remains to present a quality scientific meeting at a reasonable cost.

As always, we hope to provide a forum for the exchange of ideas in a friendly and convivial atmosphere. I welcome you to the 32^{nd} Newcastle Symposium, and hope that you will have an enjoyable weekend.

Ron Boyd
Convener

FOREWORD

Welcome to Newcastle! It is customary for the Head of the Geology Department to use these pages of the Newcastle Symposium to report on the happenings within the Department over the last twelve months. The opportunity is useful - it allows us to keep our supporters up to date with the major events, successes and transitions of the year.

1997 saw considerable change. After a little over two years at the helm as Professor of Geology, Stephen Cox resigned late in the year, to return to the Australian National University, where he took up a Professorial Fellowship jointly between the Research School of Earth Sciences and the Department of Geology. Steve did an excellent job within our department, during difficult times - we wish that he had remained with us longer, but thank him for his leadership and wish him well in his new endeavours. On a personal note, I wish that Steve was still with us, since I have re-acquired the administration of the Department! I look forward to the arrival of a successor!

Mid-way through 1997, Robin Offler 'retired' after 30 years service to the Department. I use the term 'retirement' cautiously since Robin appears busier than ever, with a number of recent publications, numerous periods of fieldwork in the New England, Adelaide and Lachlan fold belts, collaborative projects with many colleagues (Latrobe, Monash and Ballarat universities), a current visiting colleague (Prof Shigesuki Suzuki from Japan) and four Honours students! Robin has the title of Conjoint Associate Professor, which (for punishment) allows him to teach the third-year metamorphic course for the next five years! We are particularly pleased to see two further conjoint appointments (Prof Ron Vernon and Dr Chris Mawer) both of whom will link into and strengthen our research programs, particularly in the fields of structure, metamorphism and tectonics.

Two other staff appointments have been especially important for the Department. Bill Landenberger, who has made such a great contribution to our first-year and second-year teaching programs, was appointed Lecturer at the start of 1998. We hope that this will be an on-going position. Second, we are very pleased to have Judi Winwood-Smith join our ranks as Administrative Assistant, following the resignation of our long-time Department Secretary, Geraldene Mackenzie. One of Judi's first major tasks has been to help organise this symposium. We hope she is not dismayed by the workload!

A highlight and major social occasion late in 1997 was the marriage of two of our academics - Drs Tim Rolph and Jennifer Wadsworth. Tim and Jennifer kindly scheduled their ceremony after academic business was complete for the year, allowing them time for a brief honeymoon before returning to their work. Jennifer is a Postdoctoral Fellow, working with Ron Boyd on a sequence stratigraphic project funded by the ARC and oil companies, using Canadian and Sydney Basin data. Tim is busy working up teaching programs in geophysics and environmental geology and has RMC New Staff grants to continue his research into the geomagnetic field (particularly the Permo-Carboniferous Reverse Superchron) and to fund a project aimed at establishing the magnetic signature of atmospheric pollution.

Judy Bailey continues her involvement with the Black Coal CRC, focussing on projects to assess unburnt carbon during gasification and a collaborative study with the University of NSW and a US steel company to test pulversised coal injection in blast furnaces. Judy was Keynote Speaker on the topic 'Coal characterisation - the future' at the seventh NZ Coal Science Conference last

October.

Bill Collins gave a paper on the origin of granite-greenstone belts to the combined annual meeting of the geological and mineralogical associations of Canada in Ottawa during May 1997. Bill is involved in three major research grants, namely an on-going ARC Large Grant to study crustal evolution of the Lachlan Fold Belt, an ARC Collaborative Grant (with Phil Seccombe) and industry partner (Lynas Gold) to understand the causes of gold mineralisation in the Pilbara and Bill is also co-chief investigator of an NSERC (Canada) grant looking at magma transfer processes in the crust. If all that isn't enough and to ensure he keeps out of mischief, Bill is supervising four Honours students this year and has just completed a new Rb/Sr and Sm/Nd isotope preparation laboratory in the Geology building.

Our Convenor, Ron Boyd has also been on the meeting circuit, firstly to the April 1997 AAPG meeting in Dallas, where he taught a short course on sequence stratigraphy, then in October to the annual meeting of COGS in Adelaide and recently, the APEA conference in Canberra. Ron is heavily involved in major grant activity, sharing in two ARC Large Grants with Claus Diessel. Both projects are concerned with non-marine sequence stratigraphy and coal geology and provide support for the graduate research group in sedimentology and coal. Ron also maintains his interests in Quaternary incised valleys and seismic surveying of the Hunter River.

Apart from pushing paper, Phil Seccombe has just completed a two-year position as Regional Vice-President of the Society of Geology Applied to Mineral Deposits and is busying himself with ore geology research in the Lachlan and the Pilbara. An up-coming GAC/MAC meeting in Quebec this May dangles like an enticing carrot!

All this productivity is not without it's downside. Workloads are high and staff numbers are depleted. Despite a freeze in university growth at Newcastle, undergraduate student numbers in geology are on the increase and include an all-time high in the number of students enrolled in our BSc Honours program. We look forward to growth in our resources to meet these demands.

I wish you an enjoyable weekend in Newcastle!

Phil Seccombe
Head of Department

NEWCASTLE SYMPOSIUM PROGRAM

"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

FRIDAY	**3 APRIL 1998**	
09:30 - 17:30 **EXCURSION**	**A NEW LOOK AT THE NEWCASTLE COAL MEASURES - TWO CONTRASTING APPROACHES TO THEIR SEQUENCE STRATIGRAPHY AND FORMATION** ***LEADERS :*** Ron Boyd, Murray Little and Chris Herbert The excursion will examine classic exposures of the Newcastle Coal Measures along the coastline and at Black Hill Quarry as well as subsurface correlations. Chris Herbert and Ron Boyd/Murray Little will present contrasting models for NCM formation, and attempt to convince the participants as to their relative merit. Lunch will be provided. In the event of heavy rain, the excursion will be cancelled.	
18.30-23.00	**UNIVERSITY OF NEWCASTLE GEOLOGY GRADUATES' SOCIETY SHEEP ROAST - UNIVERSITY UNION**	
SATURDAY	**4 APRIL 1998**	
08:30 - 09:00	**REGISTRATION** - Second Floor, Foyer of the General Purpose Building	
09:00 - 09:05 **Lecture Theatre GP 2-1**	**WELCOME** by the Head of the Geology Department, Associate Professor Philip Seccombe	
09:05 - 09:10	**OPENING** of the 32nd NEWCASTLE SYMPOSIUM by the Pro-Vice Chancellor of Research, University of Newcastle, Professor Ron MacDonald	
TECHNICAL SESSION 1	**LECTURE THEATRE GP2-1** **Chair** David Branagan	
09:10 - 09:40 **Invited Lecture**	*D Alder, S Hawley, B Mullard & R Shaw* *NSWDMR*	Origin of the Sydney Basin: A New Structural Model
09:40 - 10:05	*E Leitch, G Caprarelli & D Och* *University of Technology*	Late Triassic deformation in the hinterland of the Sydney Basin
10:05 - 10:30	*P Odins & N Hanson* *Maptek*	Don't close your pit, Optimise It!
10:30 - 11:00	**MORNING TEA in the FOYER OF THE GENERAL PURPOSE BUILDING**	
11:00 - 11:30 **Invited Lecture**	*M Creech* *Power Coal*	So where are all the trees - implications for the origin of coal
11:30 - 12.00 **Invited Lecture**	*D Brewer* *General Manager, PWCS*	The Port of Newcastle and its Future Development
12.00 - 12:40	***D Williams*** ***Group Manager Urban & Industrial Air Quality, CSIRO Div of Coal & Energy Technology***	**KEYNOTE ADDRESS** Keeping Track of Greenhouse Gas Emissions from Australian Coal Mining.
12:40 - 12:45	*CHAIR*	VOTE OF THANKS
12:45 - 13:50	**LUNCH in the UNIVERSITY SHORTLAND UNION**	

SATURDAY	**4 APRIL 1998**	
TECHNICAL SESSION 2	**LECTURE THEATRE GP2-1** **Chair** Tim Rolph	
13:50 - 14:15	*M Creech* *PowerCoal*	The Rogue Bore
14:15 - 14:45	*G Hawkins & A Schuch* *Douglas Partners* *E George Formally Daracon Eng*	Belford Deviation Construction Problems due to subterranean gases
14:45 - 15:15	*G McNally* *University of New South Wales* *J Whitehead* *University of Newcastle*	The environmental and engineering geology of former, current and future waste disposal sites in the Hunter
15:15 - 15:45	**AFTERNOON TEA in the** Foyer **of the GENERAL PURPOSE BUILDING**	
15:45 - 16:15	*J Whitehouse* *Dept of Mineral Resources, NSW* *D Branagan* *University of Sydney*	Geology at the Kimbriki Waste Disposal Depot
16:15 - 16:45	*A Jurkiw, G Birch & S Taylor* *University of Sydney*	Heavy metal contamination in sediments of the North Shore Lagoons, Sydney NSW
16:45 - 17:15	*G Birch, E Robertson & S. Taylor* *University of Sydney*	Sedimentary contaminants in the Upper Parramatta River, New South Wales
17.15 - 17:20	*CHAIR*	VOTE OF THANKS
19:00 FOR 19:30	**SYMPOSIUM DINNER in the UNIVERSITY SHORTLAND UNION**	
SUNDAY	**5 APRIL 1998**	
TECHNICAL SESSION 3	**LECTURE THEATRE GP2-1** **Chair** Phil Seccombe	
09:05 - 09:30	*M Newton & J Whitehead* *University of Newcastle*	Vegetational response to native seed treatment and biosolids application in the rehabilitation of a spoilpile at Cooranbong Colliery
09:30 - 09.55	*S Thomson* *CoalBed Concepts* *S Finch* *Valley Longwall Drilling P/L*	Tool loss due to geology in directional drilling - recovery or bust!
09:55 - 10:20	*P McClelland* *Ultramag Geophysics*	High resolution ground magnetics and dyke delineation in the Hunter Valley.
10:20 - 10:45	*J Wadsworth et al.* *University of Newcastle*	The role of accommodation space in non-marine stratigraphy: contrasting examples from Western Canada and Australia
10:45 - 11:15	**MORNING TEA in the** Foyer **of the GENERAL PURPOSE BUILDING**	
11:15 - 11:45	*A Hodson* *Wootmac Consulting*	Recent coal exploration in the northern Newcastle Coalfields
11:45 - 12:15	*I Roche & A Hutton* *University of Wollongong*	Distribution of the Sydney subgroup, southwestern margin of the Sydney Basin.
12:15 - 12:45	*B Ross* *Oceanic Coal*	The sedimentology, palaeontology & geomechanical behaviour of sediments from a Permian lake
12.45 - 12.55	*CHAIR*	VOTE OF THANKS
12:55 - 14:00	**LUNCH in the UNIVERSITY SHORTLAND UNION**	
14.00-16.00	**Standards Association MN/1/5/1 Coal Petrography Working Group Meeting. GP2-1**	

ORIGIN OF THE SYDNEY BASIN: A NEW STRUCTURAL MODEL

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NSW Department of Mineral Resources, 29-57 Christie Street, St Leonards NSW 2065

INTRODUCTION

The Sydney Basin covers a total area of approximately 52,000 km^2 comprising 37,000 km^2 onshore and 15,000 km^2 offshore. In the absence of any direct control the stratigraphy of the Offshore Sydney Basin is based on that of the adjacent onshore. Onshore Sydney Basin sediments range in age from earliest Permian to Middle Triassic and attain a thickness, based on gravity and magnetics estimates of 9,000m. Offshore, sediment thicknesses attain a maximum of at least 5,000m. Excluding a relatively thin veneer of Cainozoic cover these sediments are also anticipated to range in age from earliest Permian to Middle Triassic. Onshore Early Permian sediments are dominantly marine, Late Permian sediments are marginal marine to non-marine and Triassic sediments are dominantly fluvial. Sydney Basin sediments unconformably overlie Lower to Middle Palaeozoic magmatics and meta-sediments of the Lachlan Fold Belt, to the south and west, and Late Carboniferous volcanics and volcanoclastics to the north and offshore.

Offshore Sydney Basin is located between latitudes 32° 30'S and 34° 30'S, roughly extending between the coastal cities of Newcastle in the north and Wollongong in the south. The structural framework of the offshore portion of the Sydney Basin comprises four principal elements; the "Offshore Syncline", an offshore extension of the Newcastle Syncline, an offshore extension of the New England Fold Belt, and the "Offshore Uplift" - portion of the Currarong Orogen (Figure 1). The present easterly extent of the Basin was imposed following Cretaceous rifting and commencement of seafloor spreading in the adjacent Tasman Sea (Shaw, 1990). Following dispersal, fragments of the Sydney Basin are now interpreted to lie on the Dampier Ridge and perhaps the western flank of the Lord Howe Rise. However, across the continental shelf offshore Sydney Basin exhibits no obvious preserved syn-rift development.

The Sydney Basin, together with the Bowen and Gunnedah basins, form a major longitudinal Permo-Triassic basinal complex stretching 2500km down the eastern margin of Australia. The onset of this basinal development may have been extensional, and previous authors have emphasised the role of extension in the development of the Sydney Basin. However, a reinterpretation of seismic and other geophysical data highlight the potential role played in the early development of the Sydney Basin by easterly directed compression. A compressional style is to be contrasted with the dominantly extensional style interpreted for the adjacent onshore areas. The most conspicuous structural element in the offshore, the Offshore Uplift, is interpreted to represent the western overthrust edge of the Currarong Orogen. Its Early Permian structural growth may have provided a load to the eastern edge of the Lachlan Fold Belt. Much of the Early Permian development of the Sydney Basin therefore could have resulted as a consequence of foreland loading. This is consistent with depositional trends including the overall westerly directed marine transgression which dominated the sedimentary record of the Early Permian. Alternatively, this marine transgression may represent the sag phase induced along a segment of the Bowen-Sydney rift system that had been offset along the Hunter River Transverse Zone from the Gunnedah Basin to a site coincident with the Offshore Syncline.

Previous interpretations identified structural development of the Currarong Orogen as either a Cretaceous (Tasman Sea rift related) or Middle to Late Permian phenomena. Early Permian structural growth of the Offshore Uplift has important implications for petroleum exploration. The emerging Uplift provided a major sediment provenance area and represented a barrier behind which restricted anoxic conditions flourished, conditions favouring the preservation of organic matter. Late Permian and Triassic sequences are absent across the crestal portions of the Uplift. However, the emerging, sea-ward facing flank of the Uplift would have been subject to marginal and shallow marine, wave-base, barrier and strand bar deposition during the Lower Permian, conditions known in the onshore to favour better reservoir development. Cretaceous, Tasman Sea rift related, structuring is subordinate to that of the earlier compressional and wrench related features.

BASINAL SETTING

The Sydney Basin, together with the Bowen and Gunnedah basins, comprise a major longitudinal basinal system, stretching over 2500 km from northern Queensland southwards to the coastline off southern New South Wales (Figure 2). This basinal system skirts the western margin of the New England Fold Belt with respect to which, the basinal system it is considered a Late Permian and Triassic foredeep. However, the tectonic setting of the developing basins during the Early Permian is less clear. The popular view is that the Sydney Basin commenced as a tensional volcanic rift between the Lachlan and the New England Fold Belts (eg. Murray, 1990; Schneiber, 1993; Veevers & Powell 1994). On the basis that the rift coincides with the Meandarra Gravity Ridge, it is interpreted to traverse the onshore Sydney Basin west of the Lapstone Monocline (Schneiber, 1993).

According to Veevers & Powell (1994; *at p.21*) rifting and associated volcanism in the Sydney Basin began in the Late Carboniferous above the former fore-arc portion of an

Andean-type magmatic arc which had originally developed in response to westerly dipping subduction beneath the approaching Lachlan Fold Belt. At the time this subduction was facilitating convergence of the New England Orogen. With the cessation of subduction this margin developed into a foredeep depression across which subsequent Permian sedimentation was initially focused. It was during another foredeep loading episode in the Late Permian that the economically significant and regionally extensive coal bearing facies of the Tomago, Newcastle and Illawarra Coal Measures were deposited (Figure 3). Whereas the Early Permian was dominated by marine deposition, Late Permian deposition was characterised by regressive clastic fill derived from the arc-related, acid-intermediate to basic-intermediate lithologies comprising the New England Fold Belt, then undergoing episodic uplift. By contrast deposition during intervening periods, of structural quiescence and foreland bulging, were marked by quartz-rich sands shed from the Lachlan Fold Belt to the west. Extensive uplift at the end of the Permian culminated in the subsequent Triassic being dominated by fluvial sedimentation and an overall marine retreat to the east.

Onshore, the youngest Sydney Basin sediments preserved beneath a major surficial unconformity are the Middle Triassic Wianamatta Group (233 Ma) (Figure 3). Maturity trends and burial history analyses imply that a substantial thickness (1.5 - 3km) of younger rocks were deposited during the Jurassic and Cretaceous, following a Late Triassic hiatus (Mayne et al, 1974; Sullivan et al, 1995). Jurassic-Cretaceous sequences were probably subject to minor erosion from the Early Cretaceous to the Middle Cretaceous (~100 Ma), after which time rapid uplift, in response to the commencement of rifting prior to seafloor spreading in the Tasman Sea, led to a period of more severe erosion that resulted in its subsequent denudation.

STRUCTURAL FRAMEWORK

Four principal structural elements are recognised in the offshore largely on the basis of seismic and magnetic data.

Offshore Uplift

The most conspicuous structural element, the Offshore Uplift, is bound on its western side by a zone of transpressional wrenching characterised by low angle thrust and high angle reverse faulting. Seismic interpretation and magnetic lineations imply that the Uplift is extensively partitioned by reverse, thrust and normal faults, the latter presumably representing overprinting during rifting that preceded break up and the formation of the oceanic Tasman Sea Basin. The Offshore Uplift plunges below the Newcastle Syncline to the north, whereas its southern limit is poorly defined; it can be tracked as far as Wollongong beyond which seismic imaging is impeded by structural complexity and the presence of shallow volcanics.

There are a number of similarities between the Offshore Uplift and a major structural feature, the Lochinvar Anticline, located in the northern onshore Sydney Basin. Both are cored by Late Carboniferous Volcanics, both are bound by reverse and/or thrust faults on their western flanks, both experienced Early Permian structural growth and both have similar total magnetic intensity responses (Grybowski, 1992 *his Figure 10*). Both the Offshore Uplift and Lochinvar Anticline lie within the precincts of the Panthassalan margin (Veevers & Powell, 1994), a globally scaled convergent margin which extended down eastern Gondwana, around the southern edge of the New England Block and then southwards beyond the present coastline off southeastern Australia, outboard of the Transantarctic Basin, across the southern tip of Africa and along the western margin of South America. The Offshore Uplift, like the Lochinvar Anticline, is interpreted to be cored by Late Carboniferous volcanics. In tectonic parlance the Offshore Uplift forms the western margin of an Upper Palaeozoic terrane, the Currarong Orogen (Jones et al., 1984). This orogen acted not only as a provenance for epi-clastics but also as a centre for latite extrusives (Shaw et al., 1991). More importantly however, we interpret the Currarong Orogen as most likely having provided a thrust load onto the eastern margin of the Lachlan Fold Belt, thereby controlling deposition and overall development of the Sydney Basin from earliest Permian times (Figure 4).

Newcastle Syncline

Covering an area of approximately 650 km^2 between the Offshore Uplift and the New England Fold Belt, this is an offshore extension of the onshore Newcastle Syncline. Seismic data show significant erosional truncation of the sediments at the top of the section, indicating that the syncline was once much more extensive covering offshore extensions of the New England Block. Its present synclinal nature was superimposed, or exacerbated, following uplift of the adjacent offshore extension of the New England Fold Belt in the Late Permian or Triassic. The contained basal sediments are considered to be of Early Permian age, offshore equivalents of the Lower Dalwood Group, unconformably overlying volcanoclastics of Upper Carboniferous age.

Onshore the Newcastle Syncline represents an overthrust foredeep with respect to the southern New England Fold Belt. However, interpreted seismic data reveal no evidence that this structural relationship continues into the offshore (Figure 5). Moreover the overall synclinal geometry is inconsistent with foreland loading insofar as the synclinal axis lies in a mid-basinal position rather than in an asymmetrical position. If the southern New England Fold Belt were providing a thrust load in the offshore then the fold axis would be expected to be adjacent to, and parallel with, offshore extensions of this fold belt. The origin of the Newcastle Syncline in the offshore remains conjectural. One theory proposes that the syncline represents the site formerly occupied by the Hastings Block, prior to its rotation in Namurian or Stephanian times (Schmidt et al., 1994); but this is difficult to reconcile with the syncline containing a thickened Early Permian stratigraphy.

Offshore Syncline

The Offshore Syncline is a well defined north-northeast trending syncline, of 15-25 km width, lying in-board of the Offshore Uplift and flanking the coastline. Its fold axis parallels major onshore structural fold axes including the Macquarie Syncline. At its deepest point, near the intersection of the western segment of the Newcastle Syncline, the top Carboniferous volcanics lie at approximately 3.0 seconds (TWT) or ~6000m. The syncline exhibits no obvious thickening towards the synclinal axis, although, and based on an Macquarie Syncline analogue, synclinal growth is anticipated in the Late Permian section. A gradual steepening of westerly dips towards the Syncline's eastern margin reflects an increasing intensity of compressional deformation towards the boundary with the Offshore Uplift.

The two most likely origins for the proto-Offshore Syncline are that it either represented a foreland deep with respect to the adjacent Offshore Uplift, or it coincided with a segment of the Bowen-Sydney basinal rift system, offset along the Hunter River Transverse Zone from the Gunnedah Basin. Like the Newcastle Syncline, the present day geometry of the Offshore Syncline is interpreted to have been largely acquired during Late Permian to Triassic times as a result of westerly directed compression and overthrusting along the western edge of the Currarong Orogen – the Offshore Uplift. Seismic interpretation indicates that the syncline was subjected to considerable strike oriented transpressional wrenching as well as to later northeast trending extensional faulting.

New England Fold Belt

Although the bulk of the southern New England Fold Belt lies onshore and bounds the Sydney Basin to the north of the Hunter- Mooki Fault, aeromagnetic and seismic data indicate that it also extends offshore where it coincides with shallow "basement" overlain by a thin, easterly prograding sequence of Cainozoic sediments. This basement is anticipated to include Late Carboniferous volcanics equivalents of the onshore Patterson and Seaham formations. Seismic data indicates that these offshore portions were previously covered with at least Early Permian sediments. In contrast to the adjacent onshore, there is no evidence of the New England Fold Belt overthrusting the adjacent Sydney Basin sediments, however, there is minor evidence of southerly directed underthrusting of Late Carboniferous volcanics beneath the adjacent offshore Newcastle Syncline sediments.

Onshore Areas

Gravity and magnetic data reveal a major depocentre located between the Lapstone Monocline and the present coastline beneath the Cumberland Plain. In turn this is separated by a relative structural high from the Offshore Syncline. Normal faulting is the dominant fault style mapped in the southern and western portions of the offshore Basin. Faults are typically oriented northwest to north-northwest or broadly north-south. Several of the northwest trending faults have been intruded by dykes. It was the extensional style of structuring in the onshore, coupled with the setting of the Sydney Basin on an Atlantic-type, passive, continental margin, that influenced earlier workers to presume that the dominant structural style of the Basin was extensional. Whereas compression is well recognised as the dominant structural style in the onshore northern

Sydney Basin in the Late Permian, compression both during the Early Permian and in the offshore, has not been previously suggested although Evans & Migliccui (1991) deduced that foreland loading from the east must have been operative at this time, on the basis of the observed sedimentary patterns.

Extensive mapping associated with exploitation of coal resources in the onshore region of the northern Sydney Basin has long confirmed that compression dominated during the Late Permian. Major thrusts, which sole-out at depths of 3 km or more either at the boundary between the Seaham Formation and Patterson Volcanics or within underlying volcanics have been mapped around the margin of the New England Fold Belt (Glen & Beckett, 1997; Hawley et al., 1995) with anticlines preferentially developed in the hanging wall. One of the largest of these structures is the Lochinvar Anticline, which covers an area of 900 km^2, or approximately one-third the area of the Offshore Uplift. The Lochinvar Anticline is thrust bound in the north by the Hunter Thrust system. Across the axis of the structure erosion has exposed a core comprising Gyarran Volcanics overlain by Greta Coal Measures, the latter of which thin across the flanks. Glen & Beckett (1997) suggested that the Lochinvar Anticline grew as a hanging wall anticline over a blind splay thrust and they recognise a major zone along across differential shortening may have occurred - the Hunter River Transverse Fault. Overall there appears to have been a westward migration of thrusting in the northern onshore Sydney Basin, growth on the Loder and Muswellbrook anticlines occurring after the inception of the Lochinvar Anticline. If an analogy with the Offshore Uplift is valid, then corresponding movements of the offshore Uplift presumably accompanied and/or preceded those of the Lochinvar Anticline. Measured outcrop sections establish that the Lochinvar Anticline underwent structural development during Tomago Coal Measures time, between Tomago and Newcastle Coal Measures time, and again before deposition of the Triassic Narrabeen Group (Glen & Beckett, 1997). Further, we contend that this deformational history is not comprehensive, but limited by the identification of datable geological markers exposed in outcrop. These identified markers do not preclude the occurrence of earlier pre-Greta movements that would be expected to have occurred in association with east-west compression.

In a more regional context, major onshore structural features such as the Lapstone Monocline, Kulnura Anticline - Lochinvar Anticline, previously interpreted as extensional, may be near surface expressions of hanging wall anticlines and thrust ramps, and merely surface extensional manifestations of otherwise compressional structuring dating back to the Early Permian.

CONCLUSIONS

A review of the seismic coverage integrated with onshore geological control confirms that the Offshore Sydney Basin is a region of structural complexity. It is one dominated by the development of the western edge of the Currarong Orogen - the Offshore Uplift rather than an extensive rift system traversing the basin along the Meandarra Gravity Ridge. Depositional trends, being dominated by westerly directed transgression, indicate the source of basin subsidence to have been located in the east, in what is now the offshore (Figure 6). Conceivably, the Bowen-Sydney rift system may have been offset along the Hunter River Transverse Zone from the Gunnedah Basin into a site coincident with the Offshore Syncline. Alternatively, the Currarong Orogen may have provided a thrust load so that the Offshore Syncline developed by foreland loading.

In either case the Offshore Uplift, representing the western edge of the Currarong Orogen, provided the most conspicuous structural element in the offshore. Depositional thinning across the eastern flank of the Offshore Uplift attests to its palaeo-relief from the earliest Permian. The Offshore Syncline, located in-board of the Offshore Uplift, is interpreted to have been the site for anoxic conditions which favoured the preservation of organic matter and the development of coal seams, whereas best reservoir development at this time would have been along the sea-ward facing flank of the Uplift where sediments would have been subjected to shallow marine and wave-base conditions.

The interpreted structural history of the Offshore Uplift is one dominated by compression. During the Early Permian the direction of tectonic transport was to the west. This is to be contrasted with southwest direction compression of the southern margin of the New England Fold Belt across the northern onshore Sydney Basin during the Late Permian. Uplift and erosional truncation at these times, and subsequently, resulted in the preservation of mainly an Early Permian stratigraphy across structural highs in the Offshore Sydney Basin. Although Triassic and Late Permian reservoir objectives are largely absent, several prospective leads are recognised along a number of structural fairways. Volumetrically they have the potential to contain significant gas reserves, of considerable economic significance.

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ORIGIN OF THE SYDNEY BASIN

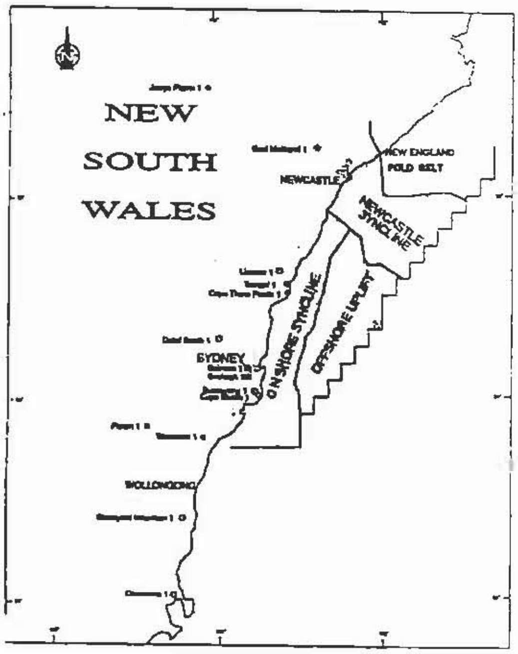

Figure 1. Structural elements map

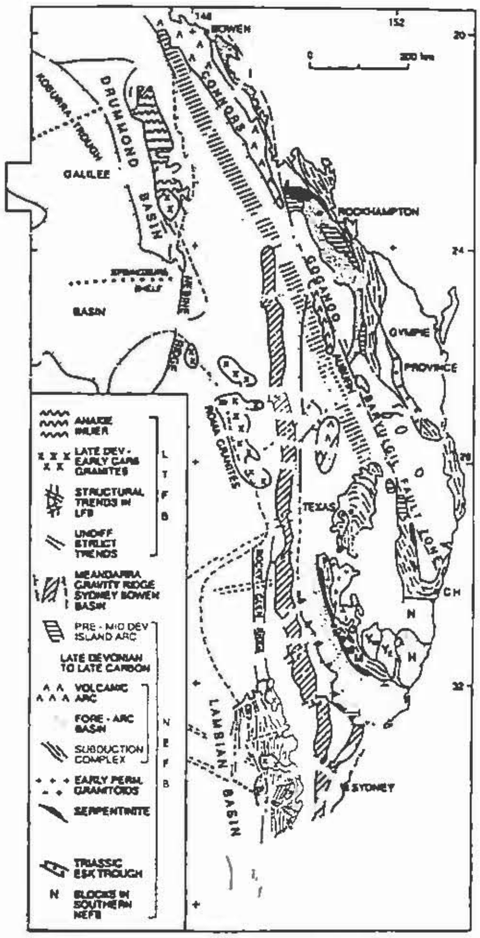

Figure 2. Sydney - Bowen Basin Complex, Structural setting (after Veevers and Powell, 1994)

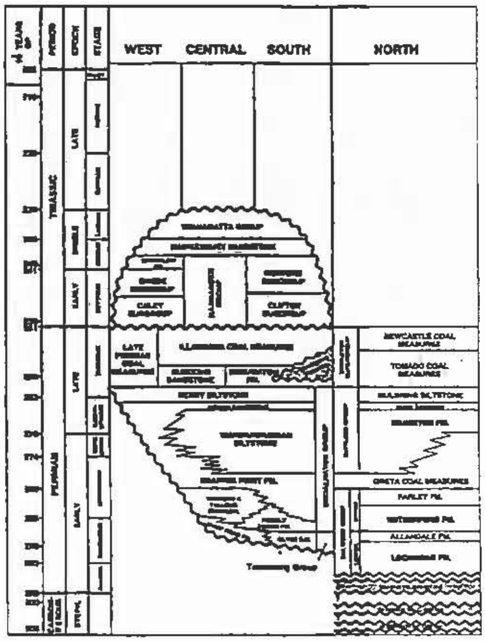

Figure 3. Generalised stratigraphy

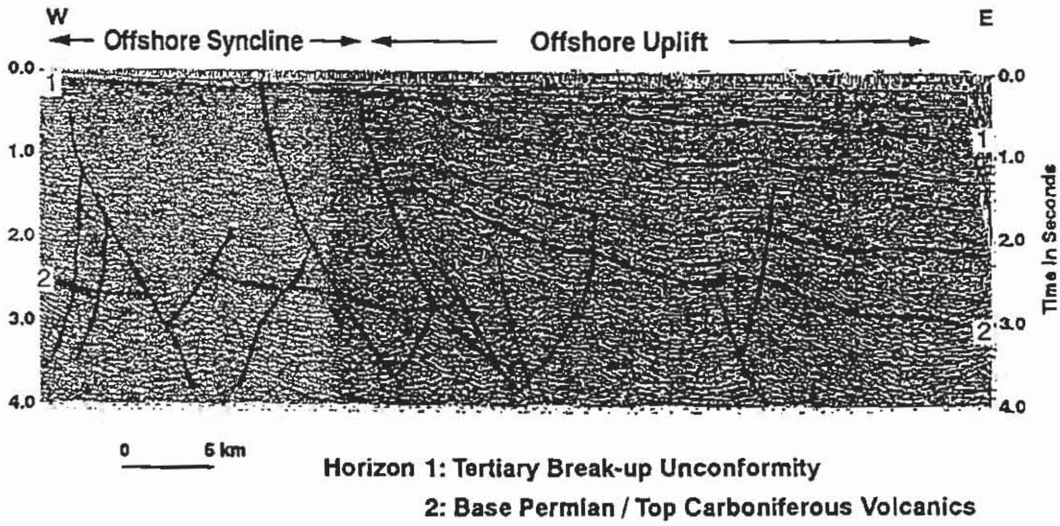

Figure 4. Portion of interpreted line SY91-14

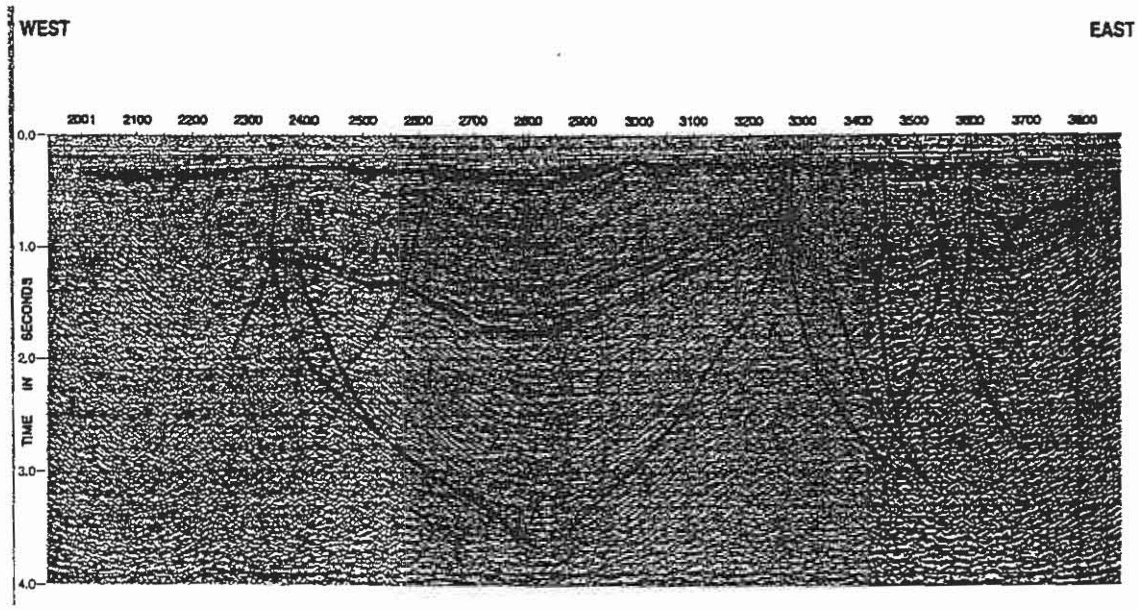

Figure 5. Portion of interpreted line SY91-04

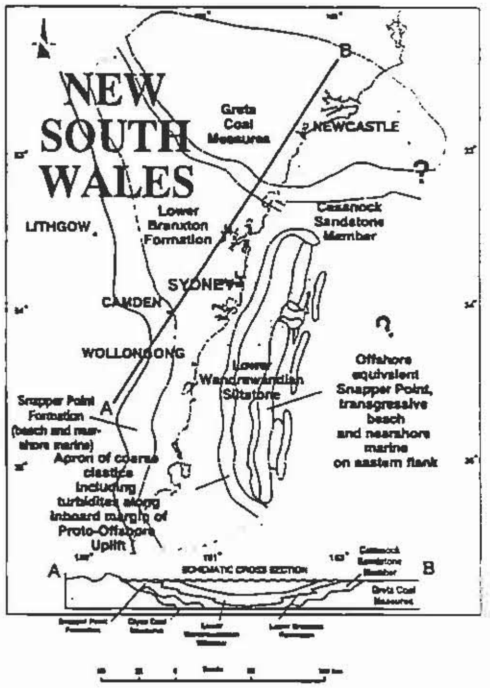

Figure 6. Palaeogeographic reconstruction at the time of Snapper Point deposition (Early Permian).

LATE TRIASSIC DEFORMATION IN THE HINTERLAND OF THE SYDNEY BASIN

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INTRODUCTION

A major change of tectonic regime, from extensional to compressional, took place in northeastern Australia towards the end of the Early Permian, with compressive stresses dominating this region until late in the Triassic (eg. Veevers *et al.*, 1994). The change was marked in the major depositional realm, the Sydney - Gunnedah - Bowen Basin, by a shift from extensional to foreland (compressional) basin tectonics, and in the basin hinterland, the New England Fold Belt, by the onset of stratal shortening and metamorphism and the emplacement of granites.

Much of the deformation in the New England Fold Belt is considered to have occurred during the earlier part of the interval, for widespread latest Permian granites appear unaffected but Triassic foreland basin rocks have been folded and thrust. However, post-Permian deformation has been documented in the eastern New England Fold Belt. The Demon Fault, with horizontal offset of 23 km, has displaced igneous rocks as young as about 234 Ma (McPhie and Fergusson, 1983; Veevers *et al.*, 1994), and Early Triassic rocks of the Camden Haven Group have been folded and faulted (Leitch and Bocking, 1980). There are few unequivocal constraints on the minimum ages of these structures.

Recent work on granites and associated thermally metamorphosed rocks in the eastern New England Fold Belt have allowed us to establish that some deformation took place before complete cooling had occurred, and hence soon after the age of emplacement of these rocks as determined by radiometric dating. In this paper we summarise results of our investigations of the northern margin of the Triassic Carrai Granodiorite (Figure 1) where we have documented the presence of mylonites, both in the pluton and in nearby hornfels.

CARRAI GRANODIORITE

The Carrai Granodiorite is an epizonal calc-alkaline pluton that outcrops over an area of about 150 square kilometres in the SW part of the Nambucca Slate Belt about 250 km N of Newcastle (Figure 1). Most of the pluton is composed of medium

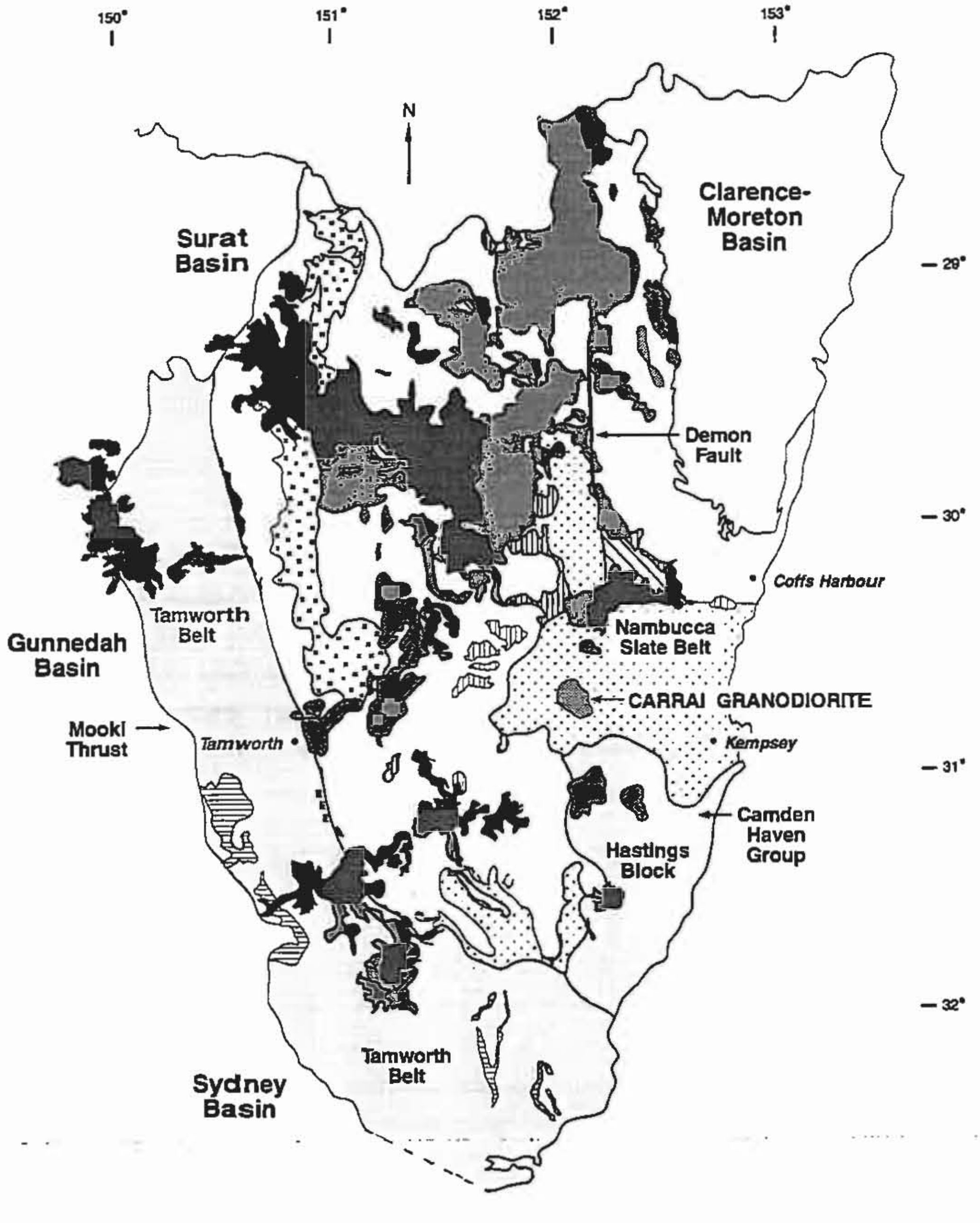


Figure 1. Location of Carrai Granodiorite. In New England Fold Belt: dark grey - Tertiary basalt; grey - I-type silicic masses; crosses and horizontal lines - earlier S-type granites; dots - Early Permian strata; pale grey and colourless - mainly Devonian and Carboniferous rocks.

grained mafic hornblende-biotite granodiorite that contains scattered feldspar phenocrysts. A small granite mass occurs towards the SE corner of the body and aplite dykes and irregular leucogranite segregations occur widely, as do dioritic enclaves. The pluton is one of several igneous masses emplaced in a NNW-trending belt in the eastern part of the New England Fold Belt late in the history of the New England Batholith. It is an I-type body, intermediate in composition between the Uralla and Clarence River suites of Shaw and Flood (1981), but younger than both. K/Ar and Rb/Sr dates on hornblende and biotite indicate an age of 225 ± 4 Ma (Leitch and McDougall, 1979; Shaw, 1994).

CONTACT AUREOLE

The country rocks surrounding the Carrai Granodiorite are Early Permian siltstone, sandstone and diamictite that were penetratively deformed and subject to regional prehnite - pumpellyite facies metamorphism at about 255 Ma (Leitch and McDougall 1979; Fukui, 1991). Deformation produced a near vertical E-W striking slaty cleavage that has been overprinted by a zonally developed north dipping crenulation cleavage that is axial plane to rounded subhorizontal mesoscopic folds. These structures are overprinted by minerals produced during contact metamorphism which, at the northern margin of the pluton, gave rise to assemblages that allow the recognition of three mineral isograds. A biotite - in isograd occurs about 1200 m from the edge of the body. At 600 m the cordierite - in isograd appears, and the start of the cordierite - K-feldspar isograd is found at about 100 m (Och, 1997). The last indicates a contact temperature of 600-650℃ and a pressure of less than 0.29 GPa (Bucher and Frey, 1994).

MYLONITES IN THE CARRAI GRANODIORITE

A belt of shearing at least 20 m wide is found in fresh water-washed outcrops of Carrai Granodiorite adjacent to its NE contact beside the Macleay River (Figure 2) (gr 24409725 Carrai 1:25000 sheet). The outcrops are transected by narrow (< 150 mm) zones of mylonitic rock that range from dark ultramylonite seams with a single foliation parallel to the shear zone boundaries, to wider mylonites with well developed C/S fabrics. The nature of individual zones changes markedly along strike, with narrow seams bifurcating or dividing into three or more discrete seams and isolating lower strain lenses within which S planes are preserved (Figure 3). Some zones bulge abruptly producing mylonite knots of lensoidal or less regular shape.

Microscopically the mylonites show porphyroclasts of bent orthoclase and biotite and fractured hornblende and plagioclase with the hornblende especially commonly showing mortar texture. Quartz shows little sign of strain, forming aggregates with straight grain boundaries and numerous triple junctions indicative of static recrystallisation. New formed biotite has crystallised parallel to S and forms trails at opposite ends of magmatic relics producing mica fish structure. The ultramylonites comprise fine equigranular aggregates of quartz and feldspar with foliation defined by aligned small biotite flakes.

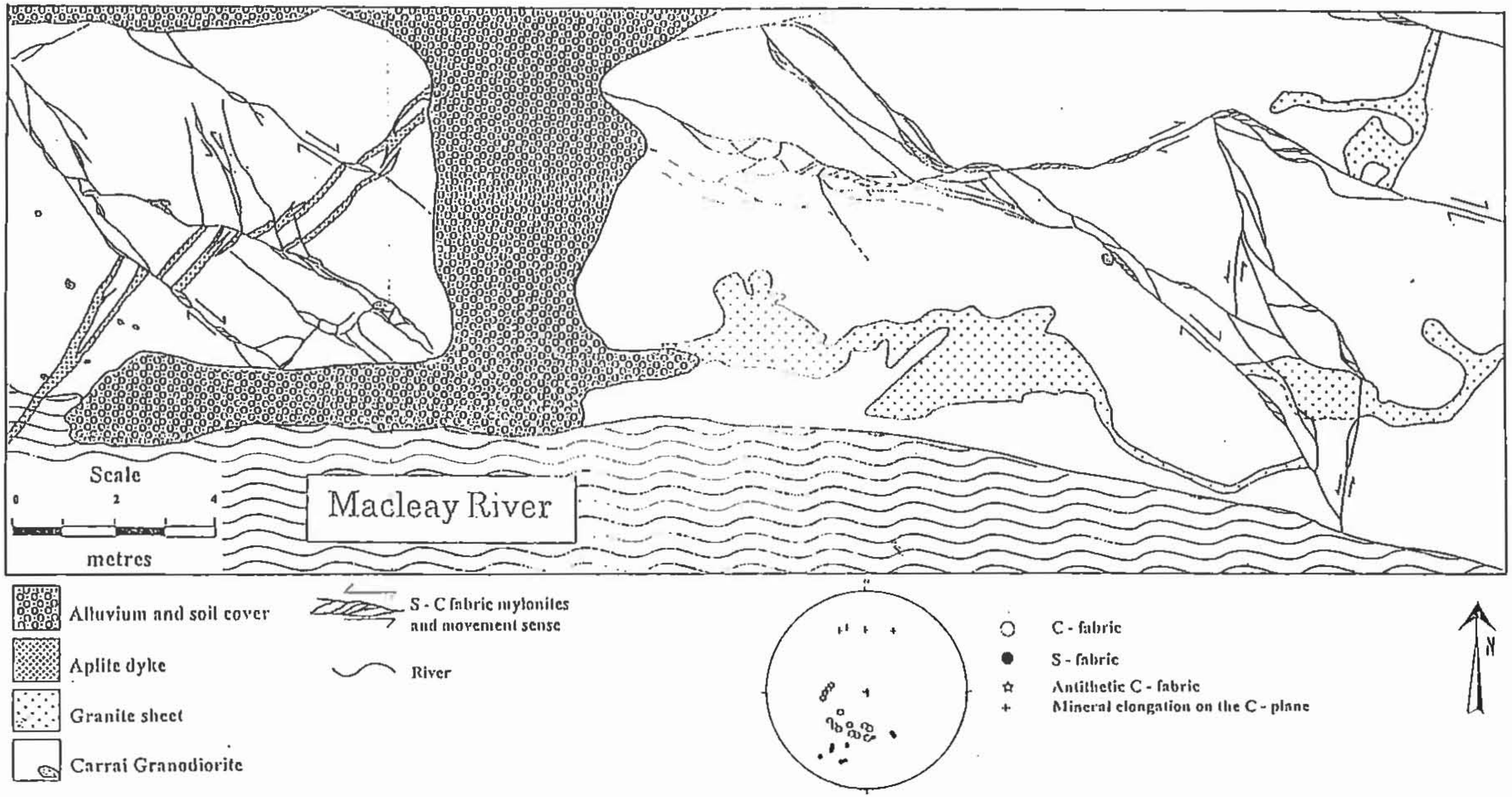
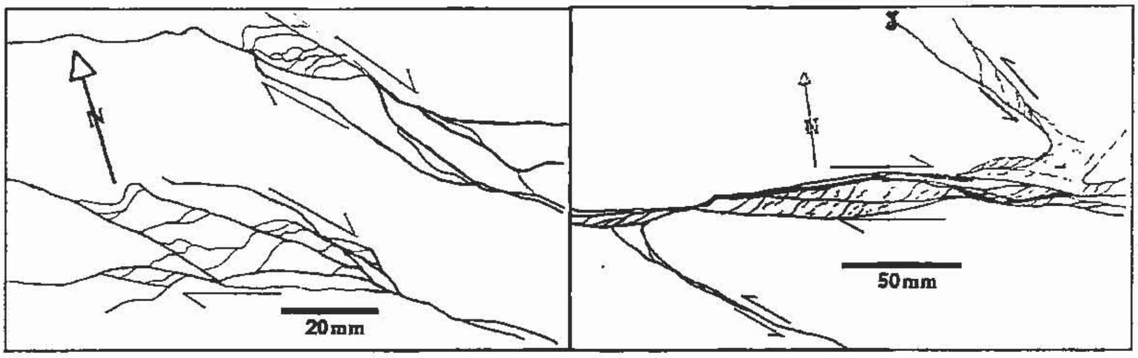


Figure 2. Detailed map of mylonites and associated rocks, NE corner of Carrai Granodiorite (gr.24409725, Carrai 1:25000 sheet)



(a) (b)

Figure 3. Details of mylonite fabrics: (a) Mylonite knots, C fabric long thicker continuous lines and S fabric short thinner lines, (b) Typical C\S mylonite zone with antithetic shears.

The movement sense across the mylonite zones has been determined from C/S fabrics, mica fish, rotated porphyroclasts and the offset of aplite dykes (Figure 2) and rarely enclaves. The orientation of C was measured in outcrop but S and the mineral elongation lineation on C was mostly determined in the laboratory, using samples cut to reveal these elements clearly and mounted in their original position in a non-magnetic three-axis frame. Most zones show dextral movement in map view, with the mineral elongation showing the actual direction of movement plunging about 25°to the N, and with oblique dextral reverse slip indicated. Total movement on the three zones disrupting the bifurcating aplite dyke in the western outcrop (Figure 2) totals 2.5 m. The apparent sinistral offset of the granite sheet in the eastern outcrop is an artefact, produced by the irregular character and very gentle north dip of the body.

Most dextral zones strike about 125° and dip at about 35° NE. The few mylonite zones that show sinistral movement strike N and dip about 45° E. Neither set of zones consistently overprints the other and essentially synchronous movement is indicated.

MYLONITES IN THE CONTACT AUREOLE

Ultramylonites have also been discovered within the cordierite zone of the Carrai aureole at gr 27009742 (Carrai 1:25000 sheet). These form discrete sharply bound planar zones up to 10 mm wide and at least 20 m long transecting polyclinally folded hornfels. The ultramylonites lack porphyroclasts and consist largely of very fine-grained quartz, feldspar and biotite. A weak compositional layering is defined by concentrations of biotite. The zones strike E-W and dip about 60° N. An elongation lineation is absent so the movement direction could not be determined, but a dextral horizontal component is indicated by small antithetic and synthetic fractures.

AGE OF MYLONITES

The mylonites must be younger than the crystallisation of the Carrai Granodiorite which they transect. Microstructures, the static recystallisation of quartz, and the new growth of biotite in the mylonites, indicate that deformation took place under relatively low grade conditions. The presence of feldspars with bent twins, deformation bands and undulatory extinction suggests a temperature of 300° to 400°C (Pryer, 1993; Passchier and Trouw, 1996); biotite crystallisation is consistent with formation of the mylonites around 400°C as is the static recrystallisation of quartz. This temperature is considerably greater than that attained by the country rocks beyond the thermal aureole (about 300°C as indicated by the grade of regional metamorphism), and hence the deformation occurred during cooling of the pluton and soon after emplacement. A temperature of 400°C is close to the temperature below which the isotope systems involved in the dating of the Carrai Granodiorite are set. Thus the K/Ar and Rb/Sr age of about 225 Ma indicated for the pluton will be close to that of mylonite formation.

DISCUSSION

The mylonitic rocks associated with Carrai Granodiorite indicate that compressive deformation occurred in the SE part of the New England Fold Belt in the Late Triassic, around the Carnian - Norian boundary (Young and Laurie, 1996). This post-dates the youngest preserved strata of the Sydney and Gunnedah basins but was possibly of similar age to structures that have affected their Triassic fill. Thus Herbert (1989) suggested that Late Triassic transpressional deformation produced the Lapstone Monocline-Nepean Fault system, and contractional structures have been recorded by other workers (eg. Moelle and Sutherland, 1977; Mills *et al.*, 1989). Etheridge (1987) interpreted seismic data from the northern Gunnedah Basin as indicating that compressive structures preserved in Triassic rocks were absent from unconformably overlying Jurassic strata of the Surat Basin. Hamilton *et al.* (1988) also found evidence of Late Triassic compression and uplift in the Gunnedah Basin, especially close to the Boggabri Ridge and the Mooki Thrust.

Transcurrent movement on the N striking Demon Fault, may be of similar age to the movements recorded by the Carrai mylonites, although Veevers *et al.* (1994) have argued, on the basis of an extrapolation of the former structure into southeast Queensland, that movement on this structure predated the 228 Ma Hogback Granite. While it is tempting to correlate folding and faulting of the Camden Haven Group with the Carrai deformation they lack younger age constraints.

Widespread Late-Permian compressive deformation is widely recognised in NE New South Wales, but opinions differ as to whether compressive stresses characterised the whole of the Late Permian-Late Triassic interval as portrayed by Veevers *et al.* (1994) and implied by a foreland basin interpretation of the post-Early Permian Sydney and Gunnedah basins, or whether there was one or more episodes of extension during this 40 my. period (Collins *et al.*, 1993). Only by mapping and dating structures formed during this time will such differences in interpretation be resolved.

LATE TRIASSIC DEFORMATION

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DON'T CLOSE YOUR PIT, OPTIMISE IT!

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ABSTRACT

The combination of tightening economic margins and the need to consider more geologically complex deposits has led to many coal mining operations throughout Australia finding it more difficult to operate economically. This has resulted in reduced profits and in extreme cases pit closures.

The aim of this paper is to illustrate that in some instances the use of block modelling and pit optimisation techniques can provide a new perspective on how to economically mine an uneconomic deposit or show the most profitable way to exploit a new resource. These techniques are used to great effect in the 'hard rock' mining industry and have resulted in some spectacular turnarounds for previously uneconomic deposits.

Recent advances in computer hardware and mine planning software such as Vulcan allow full stratigraphic and geostatistical block modelling capabilities to be applied to coal deposits. In this way a detailed stratigraphic geological model can then be block modelled with sufficient resolution to allow meaningful data to be used in an advanced pit optimisation package such as Whittle 4D. With careful selection of optimisation parameters the optimised pit shell output will then provide the basis for detailed pit design and allow mine planning to be carried out with a degree of surety previously unobtainable in the coal mining industry.

INTRODUCTION

Traditionally coal miners have been conservative in their approach to some aspects of geological modelling and mine planning. This has not been without good reason; up until recently, the adage 'if it ain't broke don't fix it!' has been applicable to the vast majority of mining operations. Recent changes in the profitability of many coal mines has led several mining operations to look at the applicability of pit optimisation techniques, the most successful being those utilising the Lerch-Grossman (1965) algorithm.

Currently this methodology has not enjoyed wide acceptance in the Australian coal mining industry Mastoris & Topuz (1995). This could be for a number of reasons:

- The inability of many other 'coal' mine planning packages to produce block models of sufficient resolution

- The lack of an interface to a recognised pit optimisation package such as Whittle 4D,a lack of knowledge and hence confidence in the applicability of the technique, and
- The previous inability of reasonably priced hardware to deal with the computation required to block model a coal deposit.

Pit optimisation is standard procedure for the majority of 'hard rock' mining operations in Australia and around the world and it is only a matter of time before the benefits of this technique are adopted by the coal mining industry. This will occur through either necessity or the fear of competitors gaining an advantage. For many mining operations the benefits of pit optimisation from a financial and resource exploitation point of view far outweigh the additional expenditure initially required.

Who should consider Block Modelling/Pit Optimisation?

All open cut mining operations can benefit from pit optimisation - indeed all pits are already 'optimised' to some extent. This has traditionally been achieved by the mine planner using stripping ratios, coal quality models, ROM models etc. These techniques are still valid and should be used in conjunction with pit optimisation. What the combination of block modelling and pit optimisation will do is ensure that no coal is mined uneconomically, based on geological, mining and financial parameters. A series of optimal shells is output, ranging from the most economic to 'break even'. This gives the mine planner a sound economic basis from which the optimal balance of revenue versus resource exploitation can be achieved. Of course the other major advantage is the ability to quickly recalculate optimal designs based on a range of input parameters and to delineate areas of greatest or least profit sensitivity which can be taken into account during mine design.

Two types of open cut coal deposit are currently recognised by the authors as being ideally suited to block modelling/pit optimisation. These reside at both ends of the geological complexity spectrum.

- Type 1 - 'simple' geology and structure, one or two thick horizon(s), e.g. a Victorian Brown coal mine.
- Type 2 – 'complex' geology and structure, many coal seams ranging in thickness, many seam splits and coalescences, e.g. a typical Hunter Valley coal mine.

BLOCK MODELLING – the advantages

Block modelling at its simplest is a three dimensional grid which forms a framework for the estimation of a range of geological and analytical parameters. Using a sophisticated geological and mine planning package such as Vulcan, block models can be created over any geographical area at a specified bearing, dip and plunge and with a user defined range of blocking sizes.

The ability to orient a block model is important in coal deposits as the user can cater to dipping, plunging or even folded strata. Sub-blocking or the ability to automatically vary the size of blocks generated based on horizons or analytical constraints is crucial in coal deposits because of the generally large size of the 'orebodies' and their tabular nature. Without the ability to 'sub-block' the user is always fighting a losing battle between achieving sufficient resolution in areas of interest and keeping the overall block model size down to a manageable level. Surprisingly this still is a major constraint for many mine planning packages.

Another previous limitation of block modelling now overcome by Vulcan is the ability to use triangulated surfaces or solids defining horizons, structures such as faults, and mining blocks. All volumetric calculations are carried out using the exact limits of the triangulations, using a 'proportional cell evaluation' method. Using this technique volumetrics are not compromised by the cell resolution of the block model. The advantages of the block modelling technique in certain geological situations are detailed below.

Type 1 deposits (thick seams, few in number)

A grid-based method of estimating quality parameters for this type of geology will result in a single quality parameter being calculated for any particular X, Y location throughout the seam, irrespective of the actual number of individual quality samples available. In some cases this single quality is representative of a coal seam intersection in excess of 100 metres thick! If the geologist can correlate individual plies from logging or geophysics this may improve results, but this is not always feasible.

Using Block modelling to estimate quality into a thick coal seam allows the roof and floor of the seam to be determined in the usual grid based fashion and used as a constraint to quality estimation techniques. The advantage comes in the way block modelling also breaks the seam up in the vertical axis and can much more accurately represent downhole quality samples in their true X, Y, Z location. Using a range of available geostatistical methods from the simple (linear, inverse distance) to the highly sophisticated (kriging etc), block modelling can provide accurate estimations of quality and allow detailed geological interpretation and reserving to be carried out. Of course some comparisons should be made between geostatistical options and with 'conventional' grid based techniques to ensure the best method is used.

Type 2 deposits (many splits, thinner seams, and complex structure)

Although conventional grid based stratigraphic modelling will model the location of quality samples quite well, block modelling is an essential step to the Whittle Pit optimisation process and also provides a way of modelling extremely complex structural regimes and/or complex coal seam shapes. By using Vulcan's comprehensive stratigraphic modelling capabilities to model seam splitting, faulting, washouts, depth of weathering etc and then using the solid triangulation modelling options to build up models of features such as sills and dykes a truly representative block model of the deposit can be constructed. Into this model the quality information (including composited or raw data) can be estimated. Once more the utilisation of coal seam surfaces for volumetric calculations ensures that no accuracy is lost due to the resolution of the block model itself.

Methodology

A detailed description of the steps involved in Block modelling is beyond the scope of this paper, however the process is basically simple and has been included to demystify the process and show where the differences lie between conventional grid based modelling techniques and those based on block modelling.

The initial stages of modelling are identical, including the database construction, correlation, and surface modelling. In the case of Vulcan an integrated stratigraphic modelling utility is commonly used to enable multiple horizons to be modelled with associated seam splits and any masks (inclusion or exclusion) or non-conformable horizons - such as topography, depth of weathering or basement. The advantage of the integrated approach is that crossing horizons are avoided and the software handles general stratigraphic 'bookkeeping'.

At this stage of modelling the two techniques diverge. Conventional stratigraphic modelling would then involve the creation of a series of composited surfaces representing the variations in quality parameters across each modelled horizon. Estimation methods such as triangulation, inverse distances, trend surfaces, least squares and kriging are available. Once created, these quality surfaces are incorporated with the structural surfaces for reserve calculation.

For block modelling the next step is to create a database of regular composited geological and analytical intervals directly from the drillhole database. There are several available options to allow the user to best match the sampling regime. This database is then used for the construction of the block model. The model is then defined in terms of extent, orientation (bearing, dip and plunge), parent (largest) and sub-blocking (smallest) block dimensions. Once the basic framework for the block model is established, parameters such as geological horizon, structural block and rock type may then be loaded on the basis of surface or solid triangulations, geographical extent, tags in the drillhole database or calculated fields. It is at this stage the sub-blocking routine is used to guide the block model construction around the user defined areas of interest.

Once the detailed construction of the block model is complete the quality information is estimated into the blocks. A properly defined search ellipse and estimation method will ensure quality estimation accurately reflects the true distribution. At this stage the user can calculate mining reserves directly from the block model using mining horizons and blocks and report them on a user defined basis. Alternatively the output can be read directly into a scheduling package such as Chronos - Vulcan's fully interactive scheduler and be optimised from a mining availability point of view.

Alternatively the block model can be exported directly to the Whittle Pit Optimiser using the customised Vulcan interface which greatly improves the speed and user friendliness of the transferal process as well as automatically regularising the Vulcan block model.

PIT OPTIMISATION

Pit optimisation is a tool that can be used during open pit design to help the user design pits which have high values and which are very stable in the face of economic change.

The Whittle Pit Optimiser was established in 1984 and since that time has become an industry standard. The 'Four - D' product was used in this example but the newly released Four X product will add to the applicability of pit optimisation to the coal industry. Many detailed texts are available outlining the Lerch-Grossman algorithm and a full description of the Whittle products can be found in their documentation Whittle (1997). A simplified explanation of the concepts behind pit optimisation with special reference to those aspects relevant to coal pit optimisation is included below.

The Whittle Pit Optimiser forbids any block in the model being mined unless it is paid for by the overlying blocks, in this way uneconomic pit designs are scrapped early on in the calculations Hanson (1996). The value of product in an individual block is represented by a single variable in Whittle Four-D and this value incorporates all the available quality criteria both positive (carbon content, specific energy, CSN) and negative (ash content, sulphur content, moisture). A limitation of Four-D is it only optimises for one product, this has been addressed the new Four-X package, therefore mines producing more than one product can be successfully optimised. The block value is calculated by Vulcan from the original quality data and exported to Whittle. Similarly costs are estimated based on criteria such as depth, rock type, seam name, distance from stockpile etc. These costs are also calculated from various fields in the block model and exported into Whittle.

There are three basic rules to apply in the calculation of a block value.

- The value must be calculated on the assumption that the block has already been uncovered. In other words, no allowance should be made for the cost of the stripping required to access the block, because this is precisely what the optimiser calculates, we don't want the stripping to be paid for twice.

- The value should be calculated on the assumption that the block will be mined. So, if the block contains some coal that could profitably be mined as well as some waste, the value of the coal should be added in even if the resulting total value of the block is still negative. The optimiser will not choose to mine such a block, but if it still has to mine it to get at something more valuable, the coal value will help to pay for the stripping, as it should in practice.
- Any cost that would stop if mining stopped must be included in either the cost of mining or the cost of processing. Conversely, any cost that would not stop if mining stopped must be excluded.

Basic pit design constraints such as batter angle are inputted into the optimisation process and a range of optimised 'pit shells' are exported back to Vulcan. Obviously, the mine designer cannot always accommodate the optimal pit design exactly. Generally, graphing a range of pit designs against their value results in a graph similar to that shown in figure 1.

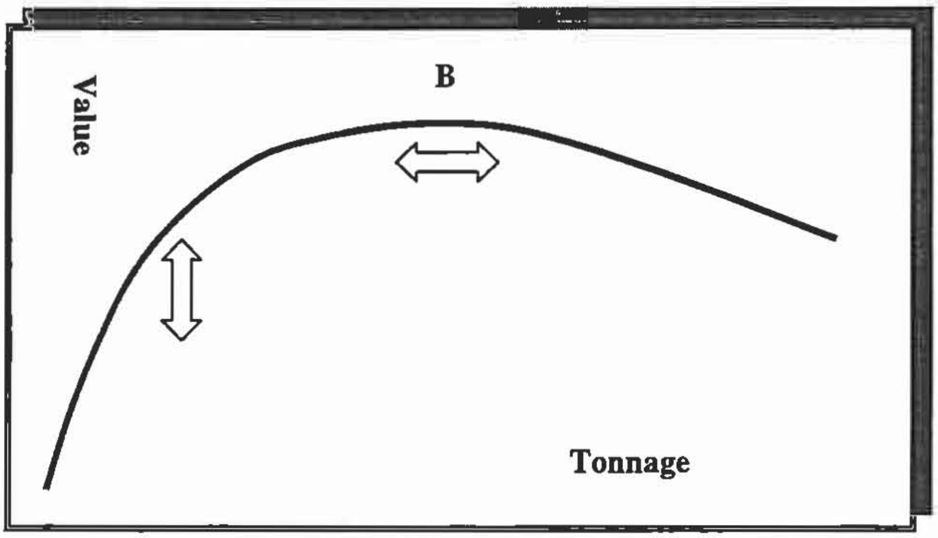

Figure 1. Value – Tonnage curve, A non-optimal, B optimal

Although this is stylised curve, such a smooth maximum is normal for real deposits. If the mine planner has chosen an optimal pit at point (A) on the curve, small deviations in pit size can have significant effects on the pit value; i.e. the pit is non-optimal. However if the optimiser has suggested pits about point (B) then small deviations have a negligible effect on the value of the pit. Therefore the value of the pit design selected is near the maximum possible and it becomes insensitive to minor changes in the pit outline. This is one of the major goals in optimal pit design.

RESERVING & SCHEDULING

Once the mine planner selects the optimal pit shell or shells, the usual Vulcan pit design tools can be utilised to create mineable pits including ramps, access roads and dumps. At any time the designed pit can be graphically compared with the optimal pit and the raw stratigraphic data to ensure the result makes 'sense'. Detailed reserving is then carried out in the normal manner and these results combined with the NPV and other financial results can then be directly input into an interactive mine scheduler such as Chronos for short and long term mine scheduling.

CONCLUSIONS

- Block Modelling and Pit Optimisation is a well-established technique employed routinely by the metalliferous and industrial minerals industry.
- Coal clients are gradually adopting the techniques.
- Software packages such as Maptek's Vulcan and Whittle's Four-D & Four-X have eliminated all the previous limitations incurred when applying pit optimisation to a large-scale open pit coal deposit.
- Hardware requirements (using efficient software) are no more onerous than those used in conventional stratigraphic mine planing – modest Unix or high-end PC NT platforms are suitable.
- Run times are in the order of hours for initial construction and optimisation and minutes for updates, they can be batched. Running several different scenarios simultaneously is common.
- History has shown that initial outlay is quickly recouped. Or work may be performed on a consultancy basis.

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SO WHERE ARE ALL THE TREES? IMPLICATIONS FOR THE ORIGIN OF COAL

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ABSTRACT

The ubiquitous claystone bands or tonsteins within the seams of the Newcastle Coal Measures (NCM) enable some unique observations to be made concerning the environment of coal formation. Their preservation over 1000's of square kilometres across the entire coalfield and beyond (?) is not only indicative of a subaerial origin but also of deposition underwater, on a surface devoid of topographic relief and protected from redistribution by rainfall and surface runoff. Their ability to accurately preserve their depositional surface renders the lack of preserved trees in these intraseam bands an enigma requiring an explanation. Evidence is presented that these bands preserve the normal seam environment, being a shallow brackish lake system with trees restricted to the margins or when falls in sea level begin to expose the seam. The only autocthonous (in-situ) plants in this environment grow underwater, their overall structure and root systems not sufficient enough to remain preserved by these bands.

THESE ASH FALLS

The seams of the NCM are unique in that they include many claystone bands which are generally accepted to be ash fall tuffs or tonsteins. This notion is consistent with their remarkable continuity across the coalfield which has enabled them to be used as effective correlation tools in an environment of seam splitting and coalescing, between overlapping coarse clastic channels. Their general petrology and the identification of contained glass shards (Diessel 1992) also confirm their pyroclastic origin, and as such these bands represent a series of internal time lines within the host seam. Some propose that these bands are the result of peat fires however there is no supportive evidence for this proposition. Sharp lower contacts, fine internal layering, common preservation of coal wisps, rare tree preservation at seam roof level and their wider occurrence in non coal strata are inconsistent with a peat fire origin.

The remarkable continuity of the claystone/coal relationship is amply illustrated by the Fassifern Seam (Figure 1) which contains approximately 15 claystone bands within a 6 metre seam. This banding is maintained even as the seam is split internally by conglomerate/sandstone channels up to 50 metres thick. Each coal ply divided by these bands is laterally uniform both in thickness and ash across the coalfield (Figure 2). This uniformity of claystone bands and coal plies renders the model proposed by Warbrooke (1981 - Figure 3) unsustainable as any time line (such as an ash fall) would crosscut the entire seam over tens of kilometres, as indicated.

These intraseam claystone bands also preserve a coal forming environment almost devoid of topographic relief. Bands FAR, FCR and FER overlie coal plies of varying ash contents (refer Fig. 1) and 90% of thickness data is restricted to a range of 7, 11 and 8cm respectively (Figure 2). At a compaction ratio of say 5 to 1, topographic relief totals generally less than 0.5m over the 1500 sq kilometres of the Newcastle Coalfield. To illustrate the uniformity of these bands, claystone FAR has been modelled across the coalfield using 5mm contour intervals (Figure 4). Several conglomerate/sandstone channel systems bisect the model where this band and associated coal plies are absent. The clastic load of these fluvial systems is likely confined by high gravel banks and compaction of underlying peat. This model is bound by outcrop/subcrop to the north-west and north-east and by lack of data to the south (>650m depth) and east (beyond the coastline). As such all features modelled and statistics referred to regarding this seam are open ended and may extend beyond the Newcastle Coalfield.

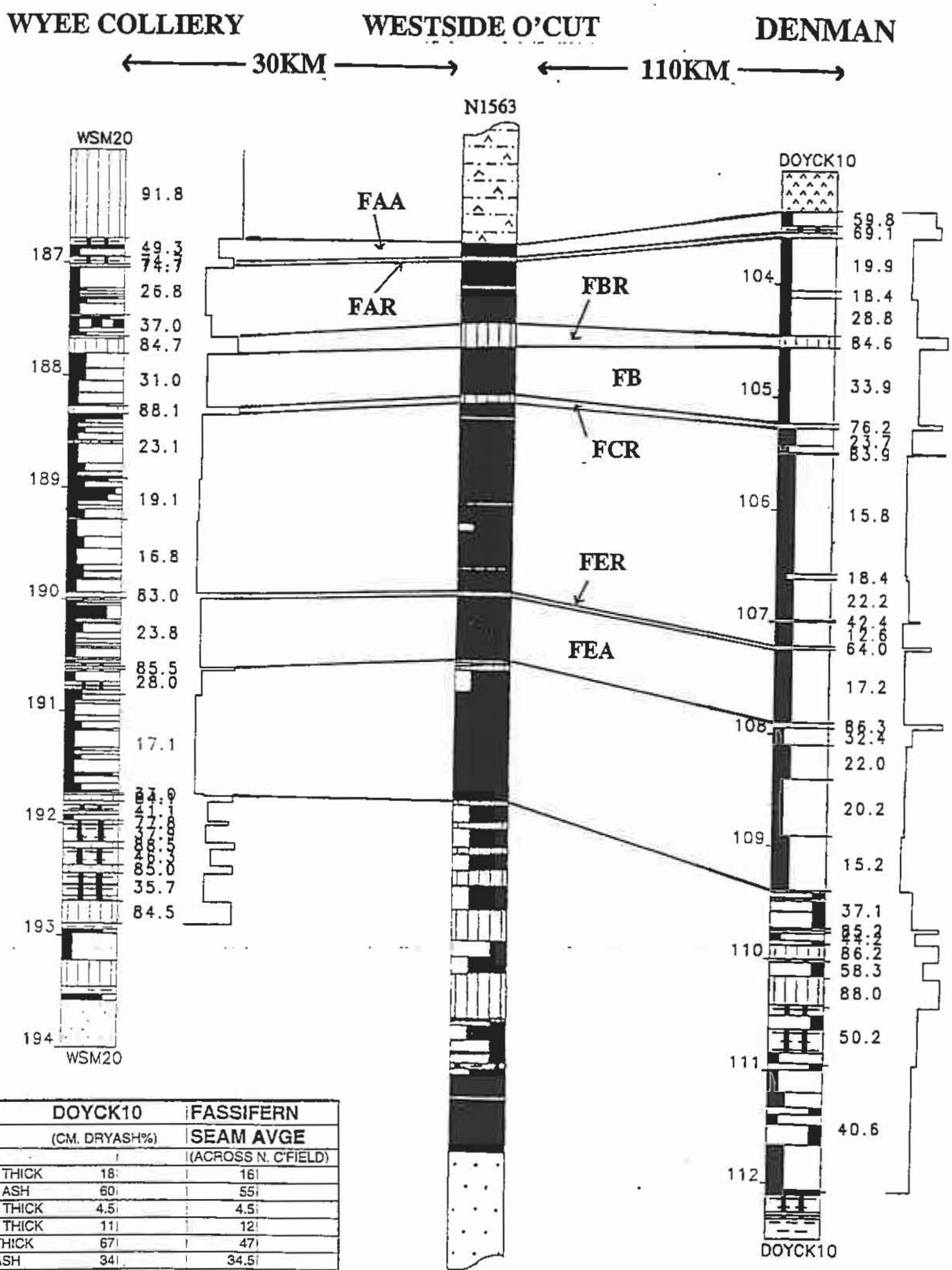
Recent drilling at Broke (40km NW of Westside O'cut) by the DMR intersected the upper split of the Hobden Gully Seam of the Wollombi Coal Measures, which is very similar to the upper plies of the Fassifern Seam. Doyles Ck 11 a further 30km NW near Mt Thorley, has intersected the lower split of the H.Gully seam which has plies and bands very similar to ply FEA and down from the Fassifern Seam. Doyles Ck 10 near Denman (Figure 1) over 110km NW from the Newcastle Coalfield has intersected the full H.Gully seam with all bands and plies conforming to the Fassifern Seam (see table in Figure 1). Profiles of dryash confirm the similarity of these seams, which are both overlain by a thick tuff unit and a thick relatively unbanded coal seam (Wallarah/Gt. Northern).

If the Hobden Gully seam is indeed the Fassifern Seam, then the above observations may be extended over many more 1000's of square kilometres. The only geological province where thin banding possesses similar remarkable continuity is the Banded Iron Formation (BIF) environment of the Hamersley Ranges in WA, which are assumed to be formed in a shallow water environment. Such an environment is also consistent with negligible topographic relief and preservation of thin ash fall tuffs.

HOW DOES YOUR PEAT GROW?

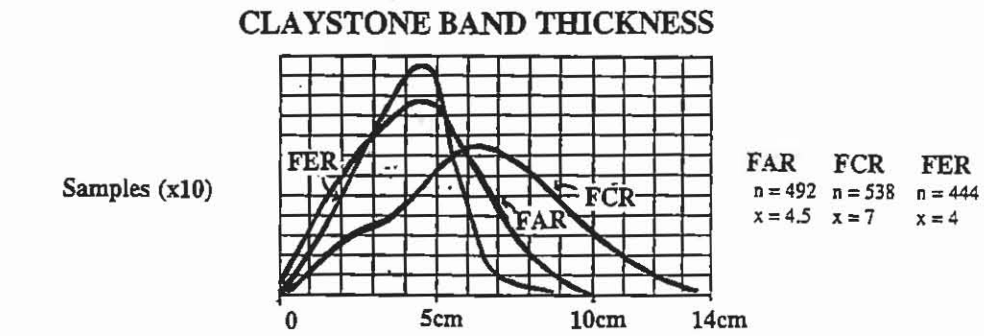
A further inconsistency with Warbrooke's model (Figure 3) is the lack of preservation of any large plant growth by these intraseam claystone bands. Not only would there be an irregular local distribution caused by the canopies of trees and bushes, but more importantly there are virtually no trunks or large root systems preserved as sharp breaks in

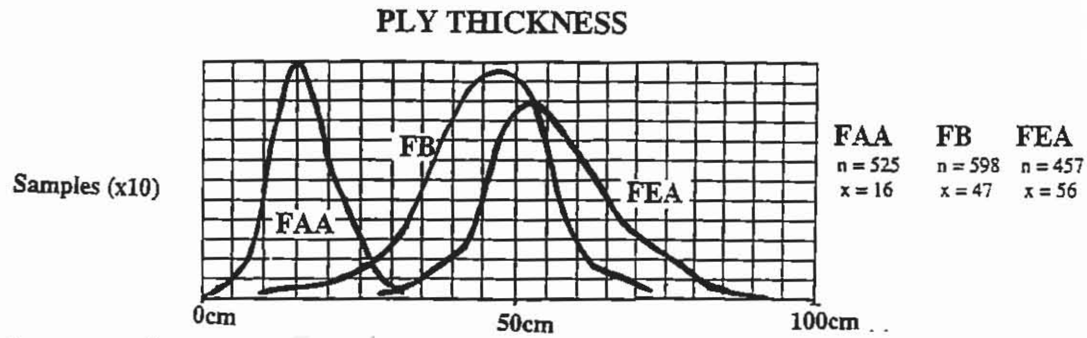
FIGURE 1. FASSIFERN SEAM ACROSS THE NEWCASTLE COALFIELD AND BEYOND (?)

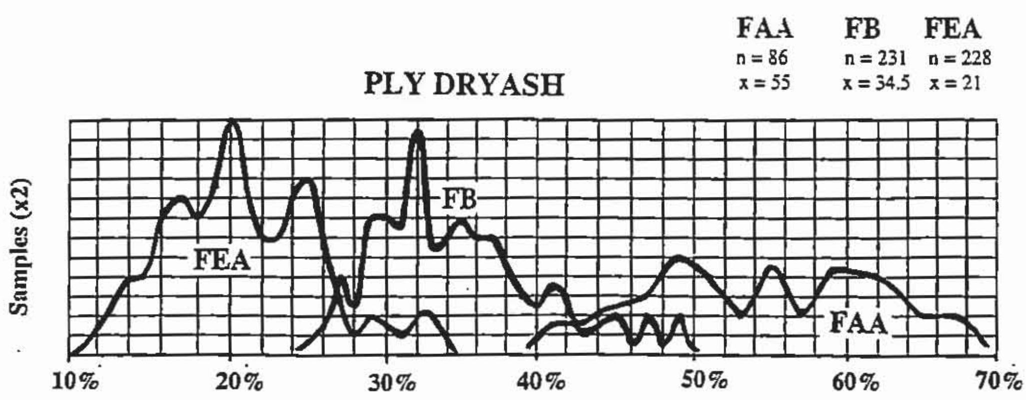


	DOYCK10 (CM. DRYASH%)	FASSIFERN SEAM AVGE (ACROSS N. C'FIELD)
FAA THICK	18	16
FAA ASH	60	55
FAR THICK	4.5	4.5
FBR THICK	11	12
FB THICK	67	47
FB ASH	34	34.5
FCR THICK	4.5	7
FER THICK	3	4
FEA THICK	65	56
FEA ASH	17	21

FIGURE 2 SELECTED PLY AND BAND CHARACTERISTICS OF THE FASSIFERN SEAM ACROSS THE NEWCASTLE COALFIELD (see Fig. 1 for ply and band identification).







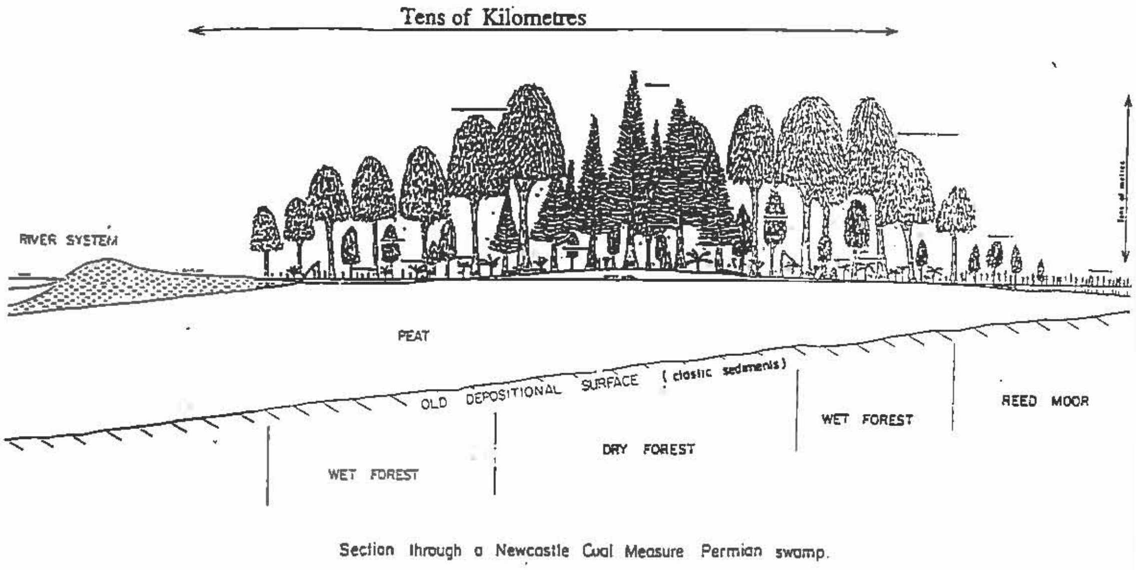


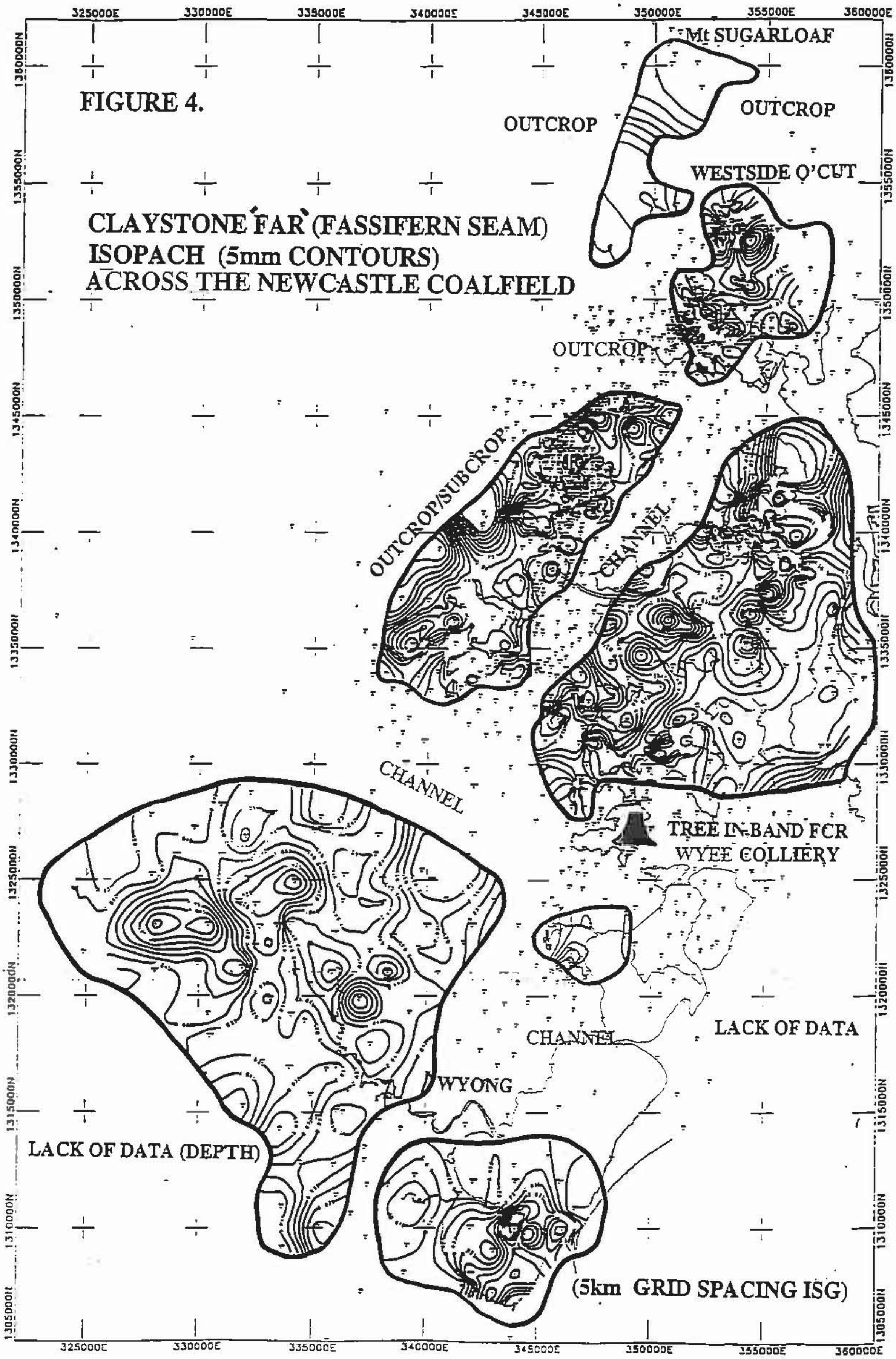
FIGURE 3. COAL FORMATION MODEL
(after Warbrooke 1981)

TABLE 1: QUESTIONNAIRE RESPONSES

MAN YEARS OF OBSERVATIONS

	RECOLLECTIVE*	ACTIVE*	COMMENTS
AUTHOR	2	6	4 FOUND AT 1 LOCALITY
RESP1	15	3	UNDULATIONS BASE OF CB AT ONE LOCALITY
RESP2	1	30	NO, ROOF & CLASTICS ONLY
RESP3	15	3	UNCERTAIN, RARE IF ANY
RESP4	17	1	NO
RESP5	20	1	NO
RESP6	20	1	NO, RARE VERTABRARIA
RESP7	24	1	NO
RESP8	27	1	NO
RESP9	10	0	NO
RESP10	17	0	NO, CLASTICS ONLY
RESP11	5	1	NO
RESP12	33	0	NO
RESP13	24	2	NO, IN THE ROOF THOUGH
RESP14	18	1	NO
RESP15	14	1	NO
RESP16	31	6	NO
RESP17	10	3	NO
RESP18	30	3	NO
RESP19	18	0	NO
	351	64	
* RECOLLECTIVE OBSERVATION IS NOT AN ACTIVE SEARCH			
TOTAL MAN YEARS OF OBSERVATION		415	

M.CREECH - SNR GEOLOGIST POWERCOAL



these bands. This is in contrast to the preservation of fine coal wisps and layers, rare vertabraria and at some localities tree trunks at seam roof and interseam levels (Plate 1). The lack of any evidence for trees is most striking at longwall face exposures (Plate 2) and opencut highwalls. The best series of surface exposures in the Newcastle Coalfield has been at Westside opencut where the Fassifern seam with all it's internal bands and the Awaba Tuff as it's roof, has failed to produce any evidence of trees in it's 5 year operation. So where are all the trees within the seams?:

- The author has not observed enough exposures - Table 1 records replies to a questionnaire sent to 19 local geologists, which combined represent 415 man years of observations in the NCM. These replies confirm that rare trees are preserved in clastics between seams and at seam roof level but not within coal seams themselves. These observations include considerable vertical exposures as well as lateral exposures where benches are cut on claystone bands.

- These intraseam bands are not capable of preserving trees - This argument is not consistent with the preservation of a sharp lower contact, rare vertabraria, fine coal wisps and mineralogical layering. In addition the author has identified 4 trees protruding through an internal band at one location during a 6 year search, proving such preservation is indeed possible though obviously rare.

- These bands preserve rare flooding events when peat deposition ceased - This argument fails to address the lack of tree roots protruding from above. There is also no evidence from maceral or ply analysis for such a proposition that the author is aware. The ubiquitous nature of these bands in the NCM (more than 15 such bands in the 6 metre Fassifern Seam for instance) argues against their preserving an uncommon peat forming environment, particularly with the absence of any highly irregular bands which would preserve the more traditional coal forming environment, of partially submerged peat with trees. Raised bogs with their hummocky surface would also be incapable of preserving regular ash falls without considerable localised redistribution.

BORON GEOCHEMISTRY

In order to further explore this last point the author sampled coal adjacent to these bands in order to compare boron levels with those found generally within the seam. Warbrooke (1981) found boron levels indicative of a brackish environment throughout the NCM, with values ranging from fluvial to marine (10 to 100ppm). The author assumed that any flooding event may be identifiable as anomalous boron adjacent to the claystone bands particularly if in response to rising sea levels. The unstable nature of sulphur during diagenesis led the author to believe that at the scales of sampling required a result may not be achieved. In contrast boron appears stable even during magmatic cycles (pers comm I Plimer 10/8/97).

The general boron levels of terrestrial trees range between 10-30ppm with grasses around 10ppm (Reuter and Robinson 1997). If grown in fertiliser, the same plants can exceed 200ppm boron. So the environment in which plants grow affect their boron uptake. The author analysed Casuarina and Mangroves growing on the shores of L. Macquarie and

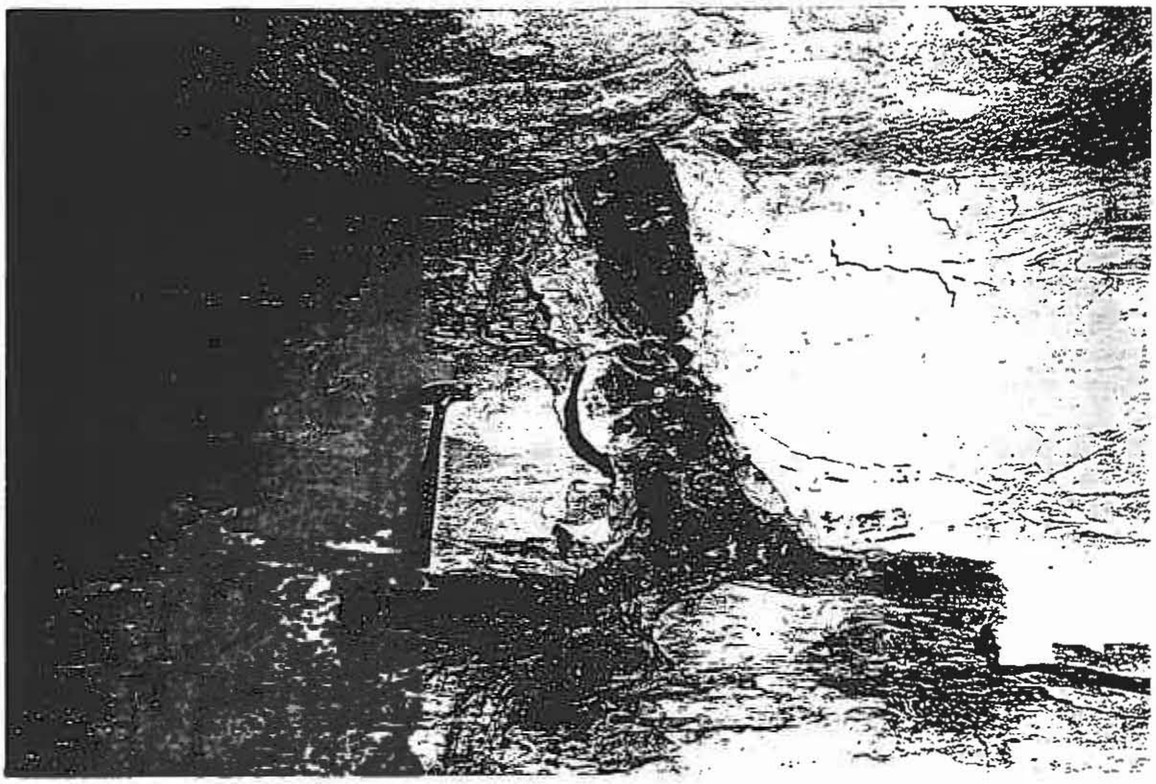


PLATE 1 PRESERVED TREE IN CLAYSTONE ROOF
MUNMORAH COLLIERY

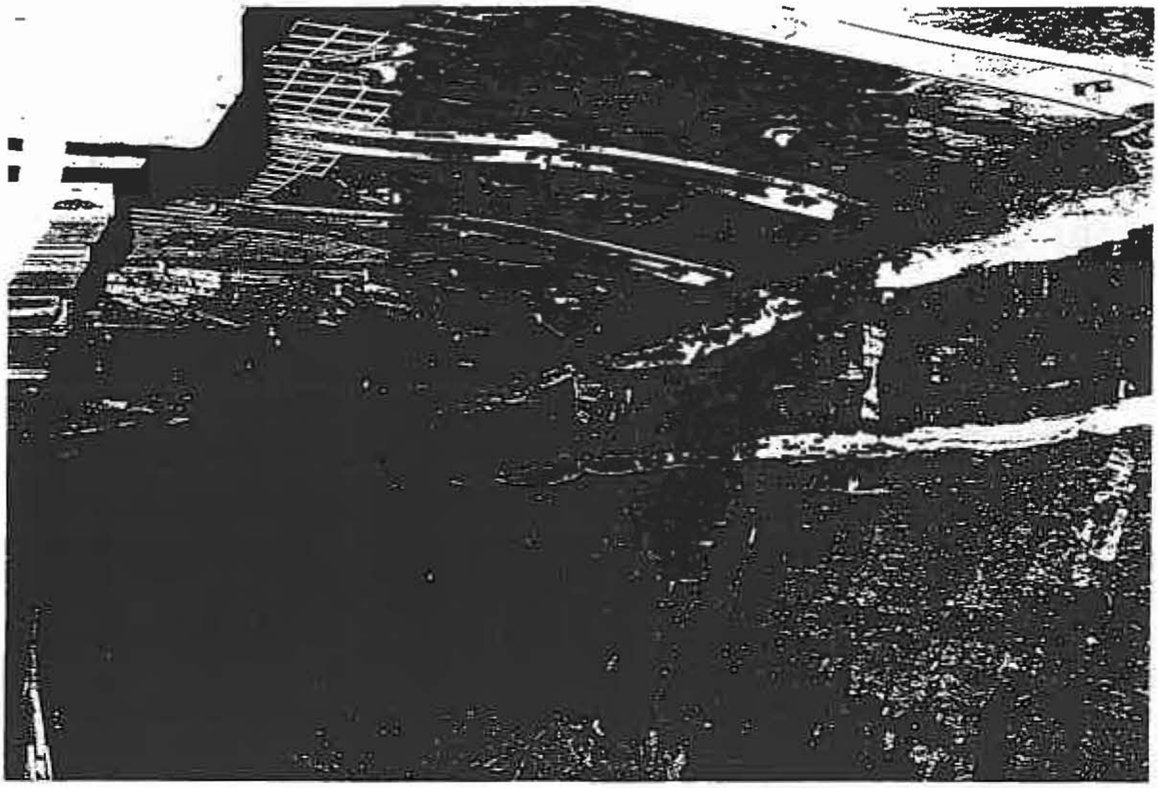


PLATE 2 INTRASEAM CLAYSTONE BANDS - LW14
WYEE COLLIERY - FASSIFERN SEAM

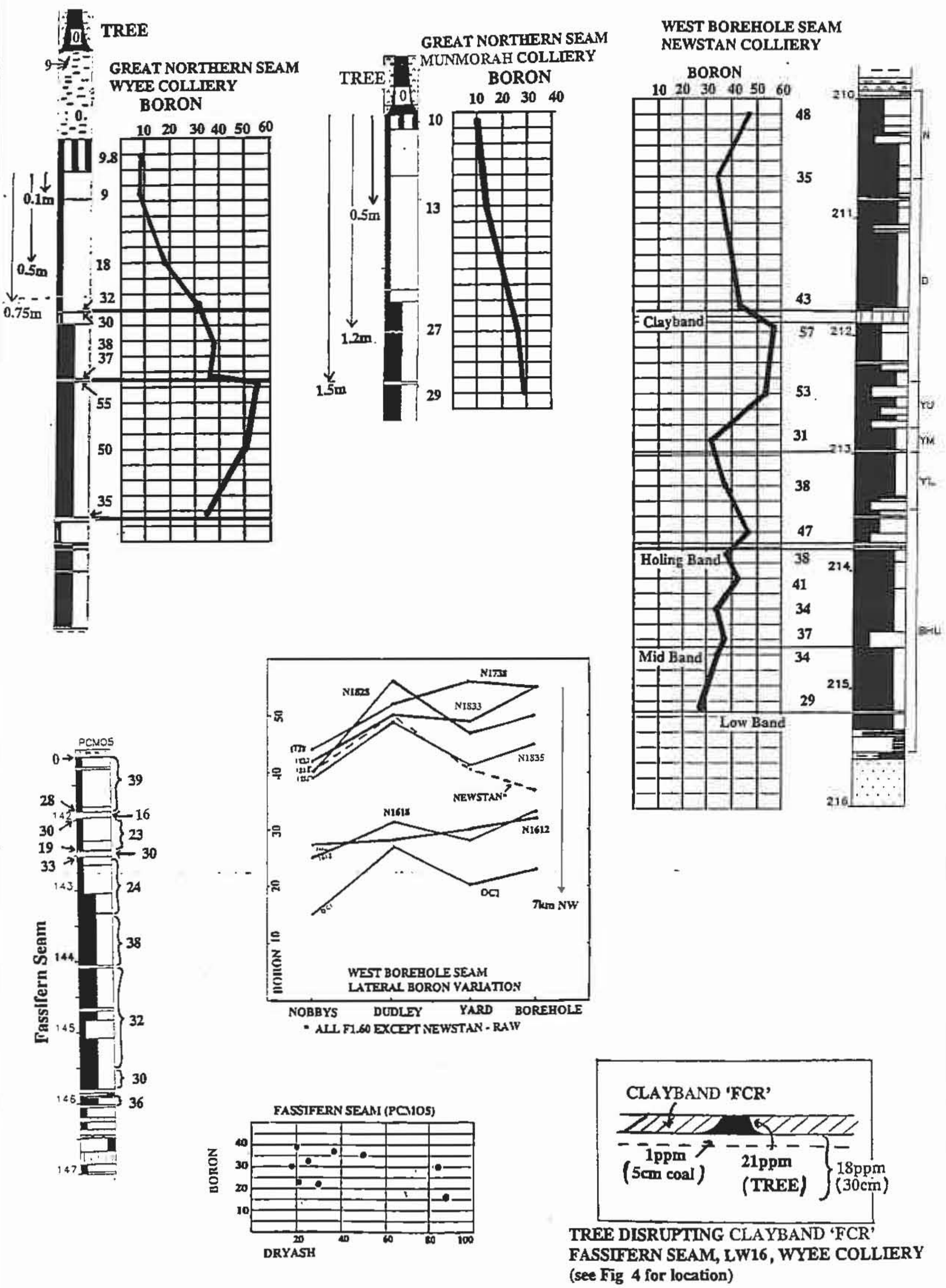
found they contained 15 to 50ppm boron (the highest concentration in mangrove leaves). Fluvial water contains .01ppm boron whereas sea water contains 4.6ppm, so even coal at 45ppm has involved a 10 fold increase in boron. Diagenesis would only roughly double the inherent peat values, therefore these values imply biological accumulation, and plant growth is the obvious contender. For additional information on boron geochemistry refer Swain (1962b, 1971), Goodarzi & Swain (1994) and Harrington et al (1989).

Two profiles were initially sampled from the Great Northern Seam at Wyee Colliery and at Munmorah Colliery (5.5 km apart) with both locations including preserved trees at or near the seam roof (Figure 5). Coal immediately adjacent to claystone bands contained boron levels in concordance with broad seam levels however at both localities the upper metre of the seam displayed a gradual depletion in boron. There is no sympathetic pattern of maceral or ash distribution that the author is aware. Subsequent profiles of the Fassifern and West Borehole Seams (Figure 5) confirmed normal boron levels adjacent to bands but did not reproduce a pattern of depletion towards the seam roof. In contrast to the GN seam there is no evidence of trees at seam roof level at these locations. There is also no relationship between ash and boron content evident (refer again Figure 5). The trees the author found exposed in an internal band in the Fassifern Seam at Wyee Colliery were also growing in a boron depleted environment, (Figure 5) 500m north of a major fluvial channel which begins replacing the entire seam only 1 km away (Figure 4). Although the environment in which the tree was growing was depleted in boron the tree itself contained reasonable levels. Not only does this indicate plant growth is responsible for enhanced boron levels in coal seams, but that boron appears stable during diagenesis reflecting a primary pattern of distribution. The sharp changes in boron either side of some claystone bands may reflect changes in currents following volcanic events and subsequent transport/redistribution of ash fall material within fluvial systems.

It would appear the argument regarding trees in the coal forming environment can now be reversed. Trees are actually growing in a boron depleted environment and the intraseam ash bands, deposited underwater in an environment devoid of trees, are deposited in coal bearing normal seam boron levels. This pattern is very suggestive that trees are restricted to the margins of a brackish lake system in shallow water depths (intertidal?) and proximal to active river systems. The gradual depletion in boron towards the roof of the Great Northern Seam in Powercoal Central Coast Collieries may represent a gradual fall in sea level culminating in a tree growth horizon.

The lateral decrease in boron levels towards the Lochinvar Anticline (Figure 5) in all component seams of the West Borehole Seam (WBH) are also consistent with the likely shallowing of a brackish lake system to the northwest. The high boron levels (up to 100ppm) recorded by Warbrooke (1981) are from samples taken from John Darling and Burwood Collieries, on the eastern side of L. Macquarie (pers. comm. 10/2/98 P.W.) confirming a trend towards a more brackish environment to the east. The consistent relationship of boron in each component of the combined WBH Seam implies slight environmental variations superimposed on the lateral variations of each seam. This suggests a primary distribution for boron as does the fine scale variations in seam profiles.

FIGURE 5. BORON PROFILES (all results in ppm)



TREE DISRUPTING CLAYBAND 'FCR'
FASSIFERN SEAM, LW16, WYEE COLLIERY
(see Fig 4 for location)

SO WHERE ARE ALL THE TREES? IMPLICATIONS FOR THE ORIGIN OF COAL

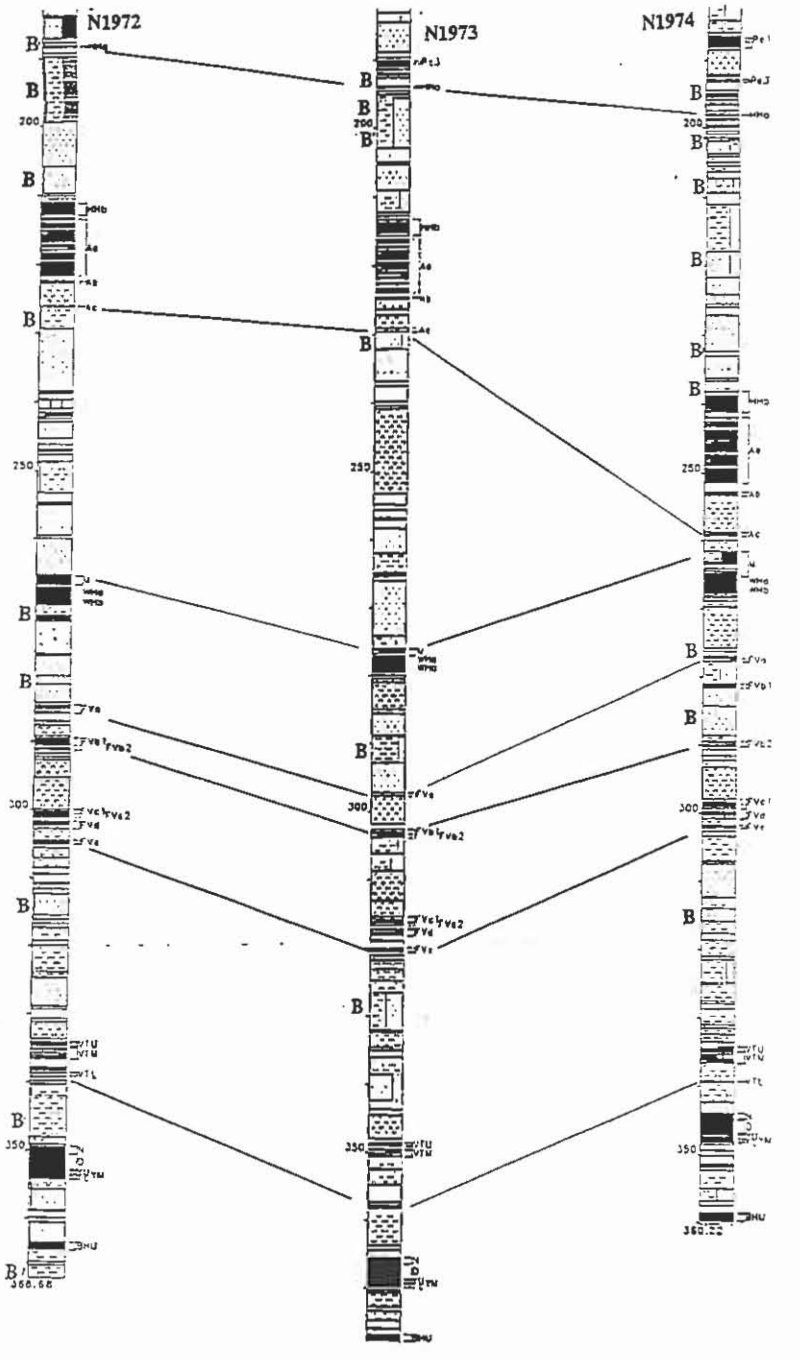
It is therefore proposed that the coal forming environment is a shallow brackish lake system and any component of the seams derived from trees is allocthonous, being derived from growth sites at lake margins (up to 10km distant - see Figure 4) and redistributed by wind and tidal currents. In-situ plant growth (autocthonous) grows under permanent water and must involve a general structure and root system not significant enough to be preserved by the internal ash fall bands. The uniform ply thicknesses and qualities of the Fassifern seam imply that the majority of the seam is derived from autocthonous growth, as allocthonous material must be redistributed very efficiently across such a large lake system.

SUPPORTIVE EVIDENCE

Supportive evidence for the site of coal formation in the NCM being a shallow lake system largely devoid of trees includes:

- Seat earths are uncommon features of NCM seams.
- Correlatable horizons of bioturbation are common throughout the NCM, found by the author (Figure 6) and others such as Peter Doyle while logging core from Cooranbong Extended near Morisset. (If you don't look for it, it isn't there).
- Dropstones up to 15cm in diameter have been identified in the Wallarah Seam at two localities at Coal Pt by separate researchers. At Laycock St (M. Fahey 1979), and at Skye Pt Rd (K. Brown pers. comm. 10/97). Dropstones have also been observed in drillcore in the Tomagos (K Brown 6/3/98). The author suspects these stones may have been dropped from floating tree root systems rather than the traditional iceberg scenario as the pebbles are not striated.
- Large fish fossils have been recovered by B.Ross from near the roof of the Borehole Seam at West Wallsend Colliery, currently held at Aust. Museum for identification. Beryl Nash also reports that Dana found fish in "The Guide to the Hunter Valley".
- Tiny freshwater (?) arthropods have been found near the roof of the VT Seam at John Darling Colliery (B. Ross) and in tuffaceous shales from Belmont and Warners Bay (Mitchell Collection- held at Aust. Museum).
- Acritarchs have been identified throughout the NCM (Evans 1967, McMinn 1982 & 1984)
- The non erosional contact of conglomerates above coal seams (such as the Great Northern Seam exposed at Catherine Hill Bay) suggest deposition underwater.
- No significant ash flow has preserved large log jams which were a feature of the recent Mt St Helen's eruption.

FIGURE 6 BIOTURBATION (B) IN THREE BOREHOLES THROUGH THE NCM



SO WHERE ARE ALL THE TREES? IMPLICATIONS FOR THE ORIGIN OF COAL

- The author has been told of trees found within coal (Lithgow Seam - J. Martin of ACIRL pers. comm. 6/96) and the Borehole Seam - Burwood Colliery - (G Carney pers. comm. 20/1/98). Horizontal trees were also uncommon to rare in the Borehole Seam at John Darling Colliery (F. Stoddart - 4/3/98). All were sideritised and generally horizontal. Why, in a peat supposedly consisting of predominantly tree parts, are these individuals isolated and preserved by sideritisation?

Individually each of these observations can be countered assuming a standard peat bog environment, however some of these features are to be anticipated in a brackish lake environment, and collectively they are difficult to reconcile with a forest setting.

DISCUSSION

There is no present day environment capable of producing thick coal seams bearing claystone bands with the features outlined in this paper. However it is these large scale field relationships which must be first reconciled with any model of coal formation. The lack of tree preservation intraseam and the coal ply/band continuity across 1000's of square kilometres directly refute models like that proposed by Warbrooke 1981. Any proposed coal forming environment must also incorporate negligible relief (both large and small scale) and the preservation of thin ash falls.

If the notion that coal forms in a shallow lake system is correct the constituents of coal, being a combination of lower plant life (the autocthonous component) and drifted wood tissue and leaves (the allocthonous component) add many new dimensions to maceral and chemical analysis of coals. For instance sea level fluctuations may be responsible for some ply and chemical variations as lake edges dry out. How many maceral and chemical properties can be linked to laterally consistent horizons reflecting sea level fluctuations within coal seams, along the lines of those found in the brown coal deposits of Victoria (Holdgate 1995). Apparently the trees evident in these brown coals grow on specific horizons, away from marine influences.(pers. comm. G Holdgate 3/2/98). The author wonders what a boron profile would reveal across these tree horizons.

The speed of coal formation may also be more variable than currently accepted being dependant on the supply of tree derived material (how deciduous was glossopteris) and the growth rate of any proposed submerged autocthonous growth. Proximity to an extensive brackish lake systems may not have merely provided the habitat for some plant growth but also incorporated efficient methods of redistribution of plant material such as wind and weak tidal currents. This answers what the author sees as the main argument against allocthonous origins of coal that river currents, previously required to distribute plant material would incorporate too much detritus to produce low ash coals. The close proximity of the ocean to most coal basins may be more critical than realised at present, particularly for the Palaeozoic coal basins, which incorporate plant species now extinct. The author collated the tonnes of 'accessible coal' through geological time using " The Concise Guide to World Coalfialds - IEA Coal Research (1983)" to illustrate the anomalous concentration of coal deposited during the Permian/Carboniferous (Figure 7). Is a large portion of Palaeozoic coal partially composed of plant life yet to be identified and/or how deciduous were these large spore bearing plants. The author has no personal experience in maceral analysis however some researchers have indicated that a large proportion of the original components of black coals cannot be directly identified, and there is scope for the inclusion of some form of submerged plantlife.

Seaweed cannot be ruled out as a component of coal (though the author does not want the readers imagination to be restricted to present day seaweed, though this plant growth is highly variable in form). Of 135 seaweed samples taken from around the world their boron contents ranged from 0 to 300ppm boron drywt, averaging 41ppm (Swain 1962a).

Some estimate of water depths can also be made by reference to present day environments. Glossopteris has a similar root system to a mangrove tree and such trees grow on the intertidal zone, unlikely to be in permanent water. Seagrasses grow to 2m depth in L. Macquarie and Botany Bay (dependant on water clarity and nutrient supply) and it is therefore estimated that water depths may be restricted to several metres only. Wants, an uncommon hazard in coal mines in the Newcastle Coalfield, may be areas where water depth has exceeded that capable of any autocthonous plant growth.

The argument between allocthonous and autocthonous coal formation has been in progress for over 100 years and it may be possible that boron analysis of coal and in particular tree growth horizons may begin to resolve this issue, and suggest a compromise between both modes of plant supply.

ACKNOWLEDGMENTS

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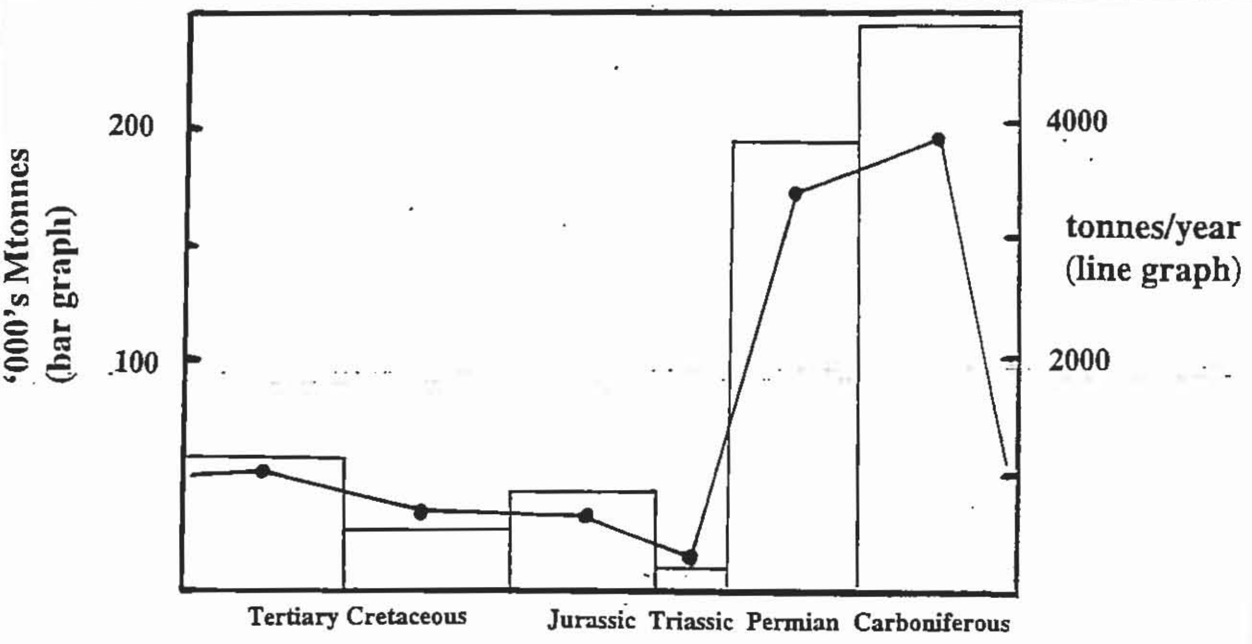

FIGURE 7. COAL FORMATION OVER GEOLOGICAL TIME

(based on collating data from "The Concise Guide To World Coalfelds - IEA Coal Research 1983. Data presented is dry 'accessable tonnes' as defined in this publication.)

KEEPING TRACK OF GREENHOUSE GAS EMISSIONS FROM AUSTRALIAN COAL MINING

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Australia, along with over 150 other countries, signed the United Nations Framework Convention on Climate Change at the United Nations Conference on the Environment and Development in June 1992.

Australia has recognised that an effective national greenhouse response requires action by Governments in partnerships with industry and the broader community. Energy market reforms and the Greenhouse Challenge are part of this response. The Australian Coal Association (ACA) has recently decided to participate in the Greenhouse Challenge Program. As a result The ACA recognises that more quantitative knowledge of greenhouse gas emissions (GHGE) from coal mining activities is required, in order to prioritise its mitigation and management strategies designed to reduce GHGE.

This paper details some of the background as to how previous estimates of coal-related GHGE were derived, mostly related to methane emissions and summarise the current position, as developed on behalf of the ACA, in which oxidation of waste coal and other carbonaceous material is included. A brief outline of potential key performance indicators is presented.

THE ROGUE BORE

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It came to Powercoal's attention on the 21/8/97 that a borehole was being drilled (since late July) within Munmorah Colliery's Mining Lease and that it had passed within 150 metres of active workings. Existing core was found laid out in the ground, including the economic seam. The Disrict Inspector ordered the drilling operation to cease that afternoon, however after 3 weeks of negotiations Powercoal allowed the hole to continue under our supervision. Canadel Pty Ltd (of Indonesian parentage) had applied for a Mineral Lease over their industrial site near Lake Haven Shopping Centre. However before the Dept. had responded to their claim, drilling had commenced. Powercoal was told that under the direction of the Aust. Drilling Ind. Training Comm. (ADITC) they were training Indonesian nationals as offsiders, and testing drillrigs they planned to purchase off the contractor, McDermott Drilling.

However a target depth of 1000m (--- target??) took on a mystical feel as drilling progressed, through the Newcastle Coal Measures, the Upper Tomagos and into the Kulnura Marine Tongue at 935m. At the target depth, the only objects of interest amongst monotonous black shales, were sparse glendonites of which those at 1000 metres mysteriously vanished from the core box. The decision was taken to drill to 1200 metres as the target may be deeper --- target?? The hole produced another 200 metres of black shales.

Why was the target not intersected — target?? Geophysics found that the hole had deviated 12 metres, and a redrill was organised. The driller had indeed missed the target — target? A downhole motor was used after wedging off at 600 metres, with the aim of keeping the hole straight (er) however the driller missed again, more black shale. After 7 months and $200,000 (my estimate) the hole was cemented on the 10/2/98, Munmorah workings due to undermine the site within 2 weeks.

Powercoal have subsequently corresponded with the Inspector requesting that contactors be required to contact the Dept. prior to spudding a hole. Although not full proof and adding further red-tape the company could see no other way to minimise the chances of such a danger recurring within it's leases. And the target ?? — see you at the symposium!!

BELFORD DEVIATION CONSTRUCTION PROBLEMS DUE TO SUBTERRANEAN GASES

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1. INTRODUCTION

During the construction of the Belford Bends Deviation, Daracon Engineering Pty Ltd (Daracon) encountered blasting difficulties at the 28 km cutting (Cut 5). Douglas Partners Pty Ltd (DP) was engaged to undertake geotechnical investigations to assess the cause and the impact of these difficulties on the proposed works.

2. GEOLOGICAL SETTING

Reference to the Newcastle Coalfield Regional Geology 1:100,000 Sheet indicates that the Belford Deviation is within the 'Belford Dome'. The surface outcrop in this area is the Branxton Formation, which is the basal member of the Maitland Group and comprises conglomerate sandstone and siltstone. Hawley & Brunton (1995) summarise bore data from AOG Belford DDH1 and Belford Dome Belford DDH2, which were drilled about 1 km to the north and south of the site respectively . These bores indicate a depth in excess of 400 m to the base of the Maitland Group.

The location of the site within the Belford Dome is indicated on Figure 1.

3. CONSTRUCTION DIFFICULTIES

After the completion of general excavation to subgrade level, the excavation of a 2 m deep longitudinal drainage trench was required between the formation and the batter of the cutting. This excavation was undertaken using the drill and blast method. The blast design had been previously used for this purpose in Cut 2.

Between Chainages 28050 and 28125 (approximately) fragmentation was not achieved in the trench area and jacking of the strata under the formation was observed for about 8 m laterally from the trench. Based on comparison of design subgrade level and levels taken after the blast, the formation had been jacked by an amount which ranged from 100 mm to 600 mm. A second blast to achieve fragmentation resulted in up to 160 mm additional jacking.

After the blast the shotfirer and an overseer heard noises emanating from the shot holes which they believed represented rock falling into a void. The overseer had previously worked on the Swansea Deviation and hence was familiar with the sound of rock falling into a mining void.

4. INVESTIGATION

4.1 Investigation Method

DP was engaged by Daracon to investigate the cause of the blasting difficulties and to advise on a construction methodology for the affected area.

Following an initial desk study, discussions with the Mine Subsidence Board and site inspection, DP concluded that it was unlikely that the site was underlain by a mining void at shallow depth. As bedding plane shears were observed in a nearby trench it was suspected that the observed jacking may have been associated with similar features.

To investigate subsurface conditions nine percussion bores were drilled to depths ranging from 5.35 m to 15.5 m. The cuttings were logged and the upper sections of the hole spoon tested by a DP Geotechnical Engineer. After completion, geophysical logging and CCTV inspection of the bores was undertaken.

The relatively deep depth of investigation was adopted to eliminate the possibility of previously unidentified shallow workings under the site. As discussed above, the presence of such workings was assessed to be most unlikely. Nevertheless the potential consequences of such workings were such that the relatively deep investigation was considered appropriate.

4.2 Investigation Results

The subsurface investigation revealed sandstone of variable strength with sub-horizontal fracture / shear seams and partings. A spatial correlation between these features and the area in which jacking was most severe was apparent.

The bores near the area of maximum heave indicated that much of the jacking movement occurred towards the base of the trench. In bores more remote from the trench the jacking movement appears to have been restricted to bores at higher elevation.

An apparent anomaly was the detection of a small cavity in Bore 1 at a depth of 14.5 m. The cavity was present over a borehole length of about 0.5 m. At a depth of 14.5 m, this cavity is beyond the zone of influence of the blasting activity. An odour of H_2S was detected at the bore collar when the bore had been advanced to about 15 m depth.

Following the subsurface investigation, Daracon arranged for gas testing of the bores to be undertaken by HLA-Envirosciences Pty Ltd. This testing indicated:

- toxic Levels of H_2S
- potentially explosive mixtures of methane
- depletion of oxygen to levels which, in a confined space, would be unsuitable for entry.

5. ASSESSMENT

When the presence of gasses was considered in conjunction with the considerable radius of propagation of blast damage, it was concluded that the partings, joints and shears within the rock mass were filled with gasses which were detonated during blasting, increasing the apparent powder factor and allowing the explosion to affect a considerably larger volume of rock than would normally be anticipated.

6. REMEDIAL MEASURES

As significant heave had occurred beneath the formation, the integrity of the subgrade had been severely compromised. The remedial options considered were:

- grouting
- over excavation and replacement of damaged subgrade.

The latter option was selected by Daracon in conjunction with the Roads & Traffic Authority. The excavation work was undertaken without blasting. Gas levels were monitored during the work.

As it was apparent that the overexcavated area could not be entirely drained, free draining granular rock fill was adopted for use below the invert of the subsoil drains. This rock fill was to be separated from the overlying general embankment filling by a geotextile fabric blanket to prevent the intrusion of fines into the rock fill.

To minimise the risk associated with methane and H_2S accumulation in the subsoil drainage system:

- venting was provided for subsoil drainage line
- manholes, pits and outlets were labelled as confined spaces containing potentially toxic and explosive gases. Appropriate 'confined space entry procedures' should be adopted for all future work requiring access to the drainage pits.

7. POINTS TO PONDER

- Information subsequently made available to Daracon by contacts in the coal mining industry suggests that the presence of gas in the Belford Dome was detected circa 1928 and that blasting restrictions have been applied to coal mining activity in this area. A system is needed to ensure that such information is available to the general engineering industry.
- In retrospect the presence of gas in the Belford Dome is not overly surprising as the dome has the form of a classic stratigraphic trap. The presence of gas near surface is surprising considering the overburden thickness over the Greta Coal Measures apparently exceed 400 m.
- A brief perusal of the Hunter Coalfield and Newcastle Coalfields 1:100,000 Sheets suggests the potential for other stratigraphic traps within the Hunter Valley. This raises the question of whether the testing for toxic / explosive gasses should be a normal requirement for shallow site investigation drilling within the Hunter Valley?

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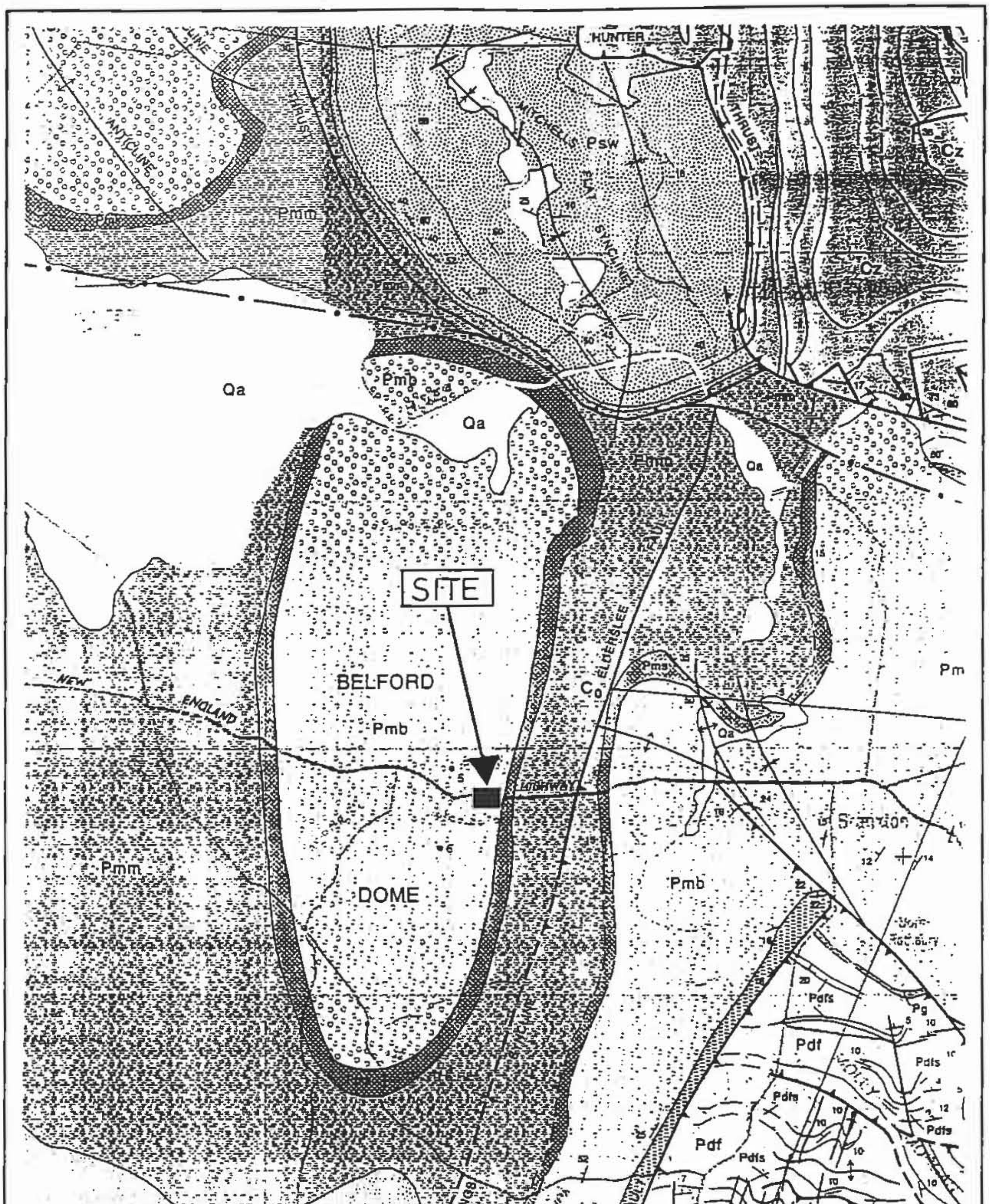

FIGURE 1: LOCATION & SITE WITHIN BELFORD DOME

THE ENVIRONMENTAL AND ENGINEERING GEOLOGY OF FORMER, CURRENT AND FUTURE WASTE DISPOSAL SITES IN THE HUNTER

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INTRODUCTION

The Hunter Region boasts a number of waste disposal sites which illustrate interesting aspects of environmental and engineering geology. Historically there has been little geological input into the siting, design and management of waste disposal sites but with increasing environmental awareness, tightening legislation and the opportunity to respond to significant commercial opportunity, in particular the disposal of waste from Sydney, there has been increased interest in the Hunter Region as a potential location for future major waste disposal facilities. This creates added interest and opportunity for those with expertise in environmental and engineering geology. This paper reviews some aspects of the environmental and engineering geology of a number of former, current and prospective waste disposal sites within the Hunter Region.

TYPES OF FORMER, CURRENT AND FUTURE WASTE DISPOSAL SITES

Within the Hunter Region are a significant number of former waste disposal sites, many of which were relatively small by modern day standards. These commonly occupied areas of low lying ground, thought at the time to be suitable for filling as they were otherwise waterlogged, pits and quarries resulting from various extractive operations or the heads of valleys which could be conveniently infilled and remain relatively unobtrusive whilst in operation. Municipal records (Maitland City Council, 1991) and more recent reviews (Engdahl, 1997) identify many such sites, a number of which still illustrate the longer term nature of environmental and engineering geological problems which limit their subsequent use. Often in the past environmentally sensitive areas, for example wetlands, now considered as areas to be avoided in landfill site selection (DUAP, 1996), were infilled; Tuxford Park and Astra Street, Shortland, on the edge of the Hexham Swamp, being examples. In many cases poor or uneven compaction and vegetation regeneration impeded by prolonged methane generation, have hampered refurbishment to the extent that former sites have remained unused for long periods following closure. Elsewhere their use has commonly been as parks, eg Stevenson Park, Mayfield, or golf courses, eg Beresfield Golf Course, Beresfield.

Existing waste disposal sites of the Lower Hunter Councils are identified in the Draft Regional Waste Plan (Hunter Waste Planning and Management Board, 1997) and, along with other existing sites in the Upper Hunter, for example at Singleton and Muswellbrook, range from relatively small sites with limited remaining life, eg Raymond Terrace and Lemon Tree Passage (Mitchell McCotter, 1997) and Singleton (Whitehead, 1996) to large, highly engineered sites with a significant life ahead of them, eg Summerhill.

Whilst tighter legislative controls and consequent environmental guidelines (EPA, 1996) and more pressing economic imperatives will limit the number of new sites, and despite the initiatives of the Federal and State Governments to respectively reduce the amount of waste to landfill by the year 2000 by 50% and 60% on the 1990 figure; there remains substantial potential capacity in currently available and planned future holes in the ground in the Hunter, to accommodate much of the waste to be landfilled in NSW in the foreseeable future. The large number of opencut coalmine final voids, conveniently located at the end of the F3 Freeway and well served by rail connections, has helped make the region the recent target of several companies interested in accommodating waste from North Sydney. Of a longer list of candidates, including the unsuccessful Waste Services Cessnock proposal, the proposals of Thiess Environmental Services at Ravensworth No2 and Collex at Muswellbrook No1, along with a further Collex proposal at Woodlawn Mine near Goulbourn, have now been shortlisted to develop more detailed proposals. One or more of these Hunter proposals has every chance of being developed in the not too far distant future to cater for waste not only from northern Sydney, but from other Regional Waste Boards short of suitable local sites and, indeed, from the Hunter Region itself, as further capacity is required on the closure of existing Local Council waste disposal sites.

Not only are there a large number of opencut coalmine final voids with landfill potential but there are many areas left derelict as a consequence of former coalmining operations, both opencut and underground, which invite imaginative restoration and which could exercise the minds of environmental and engineering geologists. Other abandoned quarry sites, often worked down to the water table, have potential if groundwater integrity can be maintained, as do sites which offer potential for supplying the ever expanding Sydney market demand for sand and crushed rock aggregates, cheaply transported as backloads, from an extractive operation doubling as an engineered landfill. Although a proposal in 1992 to develop such an operation at Stockrington failed to materialise, the idea still bears merit. Furthermore, as the rail network extends to service some of the less accessible Upper Hunter coal mines and as rail loading and unloading facilities and materials handling become more sophisticated, so the number of sites with potential as future landfills increases.

GEOMORPHOLOGY

Geomorphological constraints significantly restrict the locations of future waste disposal sites, and whilst wetlands, abandoned and diverted watercourses, subsidence hollows and former pits in superficial deposits in the floodplains and coastal fringe were highly likely to be used for landfill in the past, these are no longer permitted, significantly because of the potential impact on surface waters and groundwater.

Geomorphological aspects of much of Port Stephens Shire have been significant in planning for future waste disposal. Much of the Shire is low lying, flood prone, in close proximity to the coast and sensitive estuarine waters. The Grahamstown Reservoir and underlying Tomago Sandbeds aquifer are within the Shire. Whilst a 1992 study (Sinclair Knight & Partners, 1992) identified a number of possible landfill locations, most were of limited size, some were proximal to existing or planned residential developments and almost all would be uneconomic in the light of the necessity to contend with geomorphological constraints and the need to protect surface water and groundwater. This has lead to Port Stephens Council consider the development of a Bedminster co-composting plant which will combine domestic and industrial waste with sewage sludge to produce a compost product which in turn will be used to assist in the rehabilitation of an abandoned quarry site at New Line Road (Mitchell McCotter, 1997).

The existing Singleton Council waste disposal site is located at Gresford Road, approximately one kilometre to the north east of the Hunter River and in the head of Fern Gully, a tributary of the Hunter. This site is above the 1 in 100 year flood level for the Hunter River, is situated within the Sedgefield Soil Landscape (Kovac & Lawrie, 1991) and lies upon weathered mudstones, siltstones and silty sandstones of the Branxton Formation. The weathered rock and colluvium of the site provide adequate materials for the construction of a liner system comprising natural materials in the base of the cells and recompacted engineered containment walls with permeabilities of less than 1×10^{-9} ms^{-1}. Water quality data gathered over a long period of time indicates that the design of this site adequately protects both groundwater and the waters of Fern Gully and the Hunter River. Whilst such materials satisfy the requirements of the EPA for liners and the Sedgefied Soil Landscape potentially yields other similar sites which might be similarly satisfactorily developed in the future, such proximity to the Hunter River and tributaries would now be considered unacceptable and preclude approval. Changing perceptions of what is acceptable in terms of site location will send the search for a replacement for this site, due to be filled within the next five years, to a different geomorphological setting.

FLOODING

Current legislation seeks to avoid the risk of landfill washout in the event of significant flood and would preclude the location of future sites in areas subject to a 1 in 100 year flood event. A number of former landfill sites in the region would not satisfy this condition and remain at risk in such a flood. The former Newcastle City Council site at Astra Street, located on the edge of the Hexham Swamp, would be so exposed in a major flood event.

IMPACTS ON SURFACE WATERS AND GROUNDWATER

Whilst strenuous efforts are now made to protect surface waters and groundwaters it has been an increasing awareness of the adverse impact of former waste disposal sites in this regard that has led to tightening legislation. Many former waste disposal sites were not lined at all and often the unfortunate location of these sites, low in the landscape and near to water bodies, made for ease of contamination of the water bodies by leachate. The temptation to fill the edges of swamps and the heads of valleys often exposed sensitive water bodies to contamination. The need to preserve water quality for stock and potable use and to protect estuarine waters in important fisheries and oyster leases has led to careful consideration of the suitability of sites. In the case of the current Summerhill site located close to the edge of Hexham Swamp, the site has been designed with a high density polyethylene (HDPE) and geocomposite clay liner, a leachate collection and treatment system and recirculation of leachate or disposal to sewer to avoid any impact of offsite discharge.

The tendency to work quarry sites to the water table left many abandoned extractive industry sites with landfill potential already connected with the groundwater. Where past practice was not to adequately line such sites before landfilling there remained significant potential for offsite migration of leachate. The difficulty of containment of leachate in these situations has been a significant factor in determining the lack of suitability of some sites for waste disposal. One such site was that proposed for North Arm Cove, where the proximity to the oyster leases and fisheries of the Karuah River and Port Stephens was a factor in persuading Great Lakes Council to review their proposal and develop an alternative site (Whitehead, 1994).

CONTAINMENT OF LEACHATE AND LINERS

The requirement for extension of existing sites and for all new sites of clay or modified soil liners of permeability less than $1 \times 10^{-9}\ ms^{-1}$, or in areas of poor hydrological conditions, of flexible membrane liners of permeability less than $1 \times 10^{-14}\ ms^{-1}$, limits by availability of material and cost, the ease with which prospective sites may be developed. Whilst some natural materials in the region can meet this specification, for example the weathered mudstones and siltstones of the Branxton Formation mentioned previously, the significant quantities required for construction of leachate barriers at the larger, more modern sites and the difficulty in maintaining adequate quality control of the material, have lead to reliance on flexible membrane liners. The Summerhill site has a sophisticated multilayered system of a prepared base subgrade, overlain by an on-site clay material compacted in layers of between 0.5 and 2.0 metres to minimise any possible subsidence, which is in turn overlain by a bentonite filled polypropylene sandwich geocomposite clay liner with the capacity to "self-repair" if punctured. A two millimetre thick HDPE layer completes the containment system and on this sits the geofabric wrapped 300 millimetre slotted HDPE leachate collection pipe (NCC, 1995). The drainage layer within which the leachate collection pipe sits places further demands on the available natural materials as this layer must be of at least 300 millimetres thickness and of permeability greater than $1 \times 10^{-3}\ ms^{-1}$. Such designs are likely at the proposed Ravensworth No2 and Muswellbrook No1 sites, where suitable natural materials may not be so readily available yet a high degree of integrity will be required.

LANDFILL GAS

Landfill gas generation is a function of moisture content, temperature, pH, bacteria content, nutrient availability, particle size, the presence of toxins or inhibitory substances, refuse composition, refuse age and management practices such as degree of soil covering, lift height, compaction, shredding and leachate recycling (Engdahl, 1997).

Problems associated with methane generation include the displacement of oxygen from the root zone of vegetation on restored and revegetated sites and migration of methane gas into buildings on site and nearby with the risk of explosion. Such hazards are not unknown in the Hunter Region and in 1992 the methane contribution of the underlying swamp, the accumulated waste and possibly the chitter used for final rehabilitation, confined by the clay cap placed on the landfill and channelled by the conduit carrying the cable to the floodlights on the newly installed golf driving range, was sufficient to cause an explosion in the clubhouse meter cupboard when the floodlights were switched on at the Astra Street site. Fortunately, the outcome was no more than singed eyebrows for the curator. Incidents such as this have prompted both Newcastle City Council and Lake Macquarie City Council to commence investigations into the possibility of safely and, if possible, profitably harnessing the methane generation potential of their Astra Street, Summerhill and Redhead sites.

For former sites it is most often a matter of hazard control as retrofitting a site with a methane collection system is both difficult and costly. Methane may be vented, flared off or recovered and utilised in brick kilns, typically at brickworks claypits doubling as landfill sites, or boilers to heat swimming pools or greenhouses.

There is a need to reclaim the methane at the optimum time in the life of a site and it is really only the large, modern and prospective sites of the region that will be planned to effectively harness this resource. Those sites operating as bioreactors with leachate recycling will optimise methane generation potential whilst those excluding moisture from the waste cells will produce methane at a lower rate and for a much longer time. Should potential waste disposal sites be developed on the former mining leases of the South Maitland (Cessnock) Coalfield, or indeed in any other area with deep mine coal workings, there is potential to combine methane drained from the deep workings with that from the landfill and possibly supply the gas as a fuel supplement for conventional power stations or those designed for fluidised bed combustion of coal waste and fine washery reject (McNally, 1998).

SUBSIDENCE AND UNDERGROUND OPERATIONS BENEATH LANDFILLS

Subsidence as a consequence of shallow coal workings in the region is well documented and doubtless the contribution of subsidence to land dereliction has, in the past, been a contributory factor in determining that former mine sites had potential for waste disposal. For modern waste disposal sites the potential for subsidence is of greater concern for liner integrity. In the design of the Summerhill site significant consideration was given to the potential for further subsidence in the abandoned workings beneath. Equally the Thiess proposal for Ravensworth No2 acknowledges the need to accommodate the potential for subsidence with suitable flexibility built into the liner and promises that a proven design, used at their Swanbank Landfill in Ipswich Shire, Queensland, will be used to accommodate both subsidence and possible earthquake induced movement. It would be important, too, to consider the potential conflicts between development of major landfills and the sterilisation of any remaining coal beneath.

LIFTING THE LID OFF OLD WORKINGS

There is potential to combine the extraction of the coal from the remaining pillars of old shallow workings with preparation for backfilling of the opencut with waste. The sale of previously unmined coal has potential to enhance the economic viability of the landfill operation by providing an upfront "cash crop" to part pay for initial site development and supplement the revenue generated from waste charges. Such extractive operations have been successful when combined with road construction on the Pacific Highway and F3 Freeway (Francis & McNally, 1997) and add to the likelihood of derelict land being restored in the longer term.

Were the Cessnock area to be so developed some 6-10 metres of the Greta Seam, worked from approximately 1905 to 1925, might be extracted with possibly 30-70% of the coal remaining as this coalfield was substantially "first workings only". There are many geotechnical challenges associated with pillar removal and the very variable subsurface conditions, stable and overloaded pillars, unworked blocks, partially- and fully-goafed panels and burnt-out panels would require careful extraction. Nevertheless, this has been done economically for the coal alone at several sites, eg Pelton and Wallsend Borehole Collieries. Marketing of this coal might present problems as, despite its very low ash, the top of the seam is high in sulphur and distinctly pyritic. Blending with other Hunter Valley coals would probably be necessary.

FIRES AND SPONTANEOUS COMBUSTION

Fires and spontaneous combustion bear consideration in some of the areas of proposed landfill development. Development in areas of former workings in the spontaneous combustion prone Greta Seam would be hazardous, especially on first exposing dry, hot and timbered bords. Furthermore, panel working, with surrounding border pillars, did not become general practice until perhaps the 1920s; hence large areas of interconnected tunnels may be present. This raises the possibility of a small fire spreading rapidly along the seam subcrop. Such a fire, similar to that at Burning Mountain, Wingen, burned out the whole cropline of the Greta Seam along 24 kilometres from Millfield to Kurri Kurri in prehistoric time (David, 1907).

Fires and spontaneous combustion are recognised problems in the Ravensworth No2 and Muswellbrook No1 proposals too. In the former instance removal of combustion prone material is proposed, along with construction of a compacted foundation layer to seal off oxygen and insulate the liner. At the latter, where fires have been experienced in the past, the subsidence hollow above another prehistoric fire, has facilitated the accumulation of a clay rich horizon in the overlying sequence which might have some potential as a liner material. Further considerations at Muswellbrook No1 are the necessity to retain access to underground workings, now mothballed and probably unlikely to reopen, and highwall stability in the opencut, a potential problem in any final void site.

GEOMATERIALS USAGE AND SITE REHABILITATION POTENTIAL

Interesting aspects of the use and availability of other geomaterials arise with the possible development of waste disposal sites in the region. Extractive operations provide the potential for backloads which make for attractive economics provided markets for the materials are available at the point of origin of the waste. The Sydney Region has a substantial demand for construction materials, in particular sand and crushed rock aggregate, so proposals involving extraction of such materials have an advantage provided materials handling and road or rail vehicle design considerations can be satisfied. Some sites have potential for the supply of suitable liner material, eg the Branxton Formation above the Greta Seam, along with hard sandstone and conglomerate which might be crushed for sale as sand and roadbase provided quality could be maintained and specifications met.

Power station flyash, itself a material with increasing potential in construction as further uses are identified, is already being landfilled at Ravensworth No2. This flyash will be utilised in the reshaping and compaction of the existing side slopes and base of the voids to provide a protective subbase for the HDPE/Geosynthetic Clay Liner in addition to sealing potentially combustible materials in the existing backfill from oxygen.

Imaginative use of available materials drawn either from the landfill site or the waste streams reaching the site can assist with final rehabilitation. The Astra Street site was capped with coal chitter imported from Gretley Colliery and a final cover of clay prior to closure. Foundry sand, refractory bricks and construction wastes from the ANI Comsteel plant in Mayfield will be selectively landfilled and used for rehabilitation of the Port Stephens New Line Road site along with the mulch product generated by the co-composting of municipal waste with sewage sludge by the Bedminister system. Lake Macquarie City Council is currently exploring the potential to blend demolition and construction waste with quarry product to produce roadbase at a new quarry at Awaba. Above all, the combination of extractive operations, innovative use of geomaterials and waste disposal create the potential for creative and well engineered solutions to derelict land rehabilitation problems whilst effectively managing waste in an environmentally acceptable and economic manner.

REFUSE DERIVED FUEL

Further innovation is illustrated by the proposal of Thiess Environmental Services and Macquarie Generation to develop a Refuse Derived Fuel option at Ravensworth No2. It is proposed that waste from Sydney, already stripped of metals, glass and plastics at a transfer station in Sydney, be transported to the Hunter by rail where pelletised refuse derived fuel would be prepared to be blended with coal as a fuel for Bayswater and Liddell Power Stations. This would substantially reduce the amount of waste going to landfill and would achieve, for the waste reaching Ravensworth No2, the 60% reduction in waste to landfill sought by the State Government.

PROSPECTS FOR THE FUTURE

For those environmental and engineering geologists able to view waste as a resource, and who can think imaginatively of sound scientific and engineering solutions to the complex range of geotechnical challenges in the areas of waste management, geomaterials usage and land rehabilitation, the Hunter Region has sufficient holes in the ground to provide interesting employment opportunities for the foreseeable future, whilst offering some of the most environmentally acceptable solutions to the ever growing waste management problem.

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GEOLOGY AT KIMBRIKI RECYCLING AND WASTE DEPOT

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Introduction

The Kimbriki Recycling and Waste Disposal Depot, near Terrey Hills, offers a number of unexpected geological delights. The depot is situated in a deep valley, incised into the Hornsby Plateau at the headwaters of Deep Creek, which drains into Narrabeen Lake (Fig. 1). It is the site of (a) several interesting dyke occurrences cutting Hawkesbury Sandstone with observable contact metamorphism, (b) a well-exposed low angle fault zone (probably a thrust), (c) several small normal faults, (d) several zones of vertical strike slip faulting, (e) a 500 m continuous 3 m thick shale within the Hawkesbury Sandstone, (f) a number of distinctive units within the sandstone, including several zones of shale breccia (Fig. 2).

The dykes

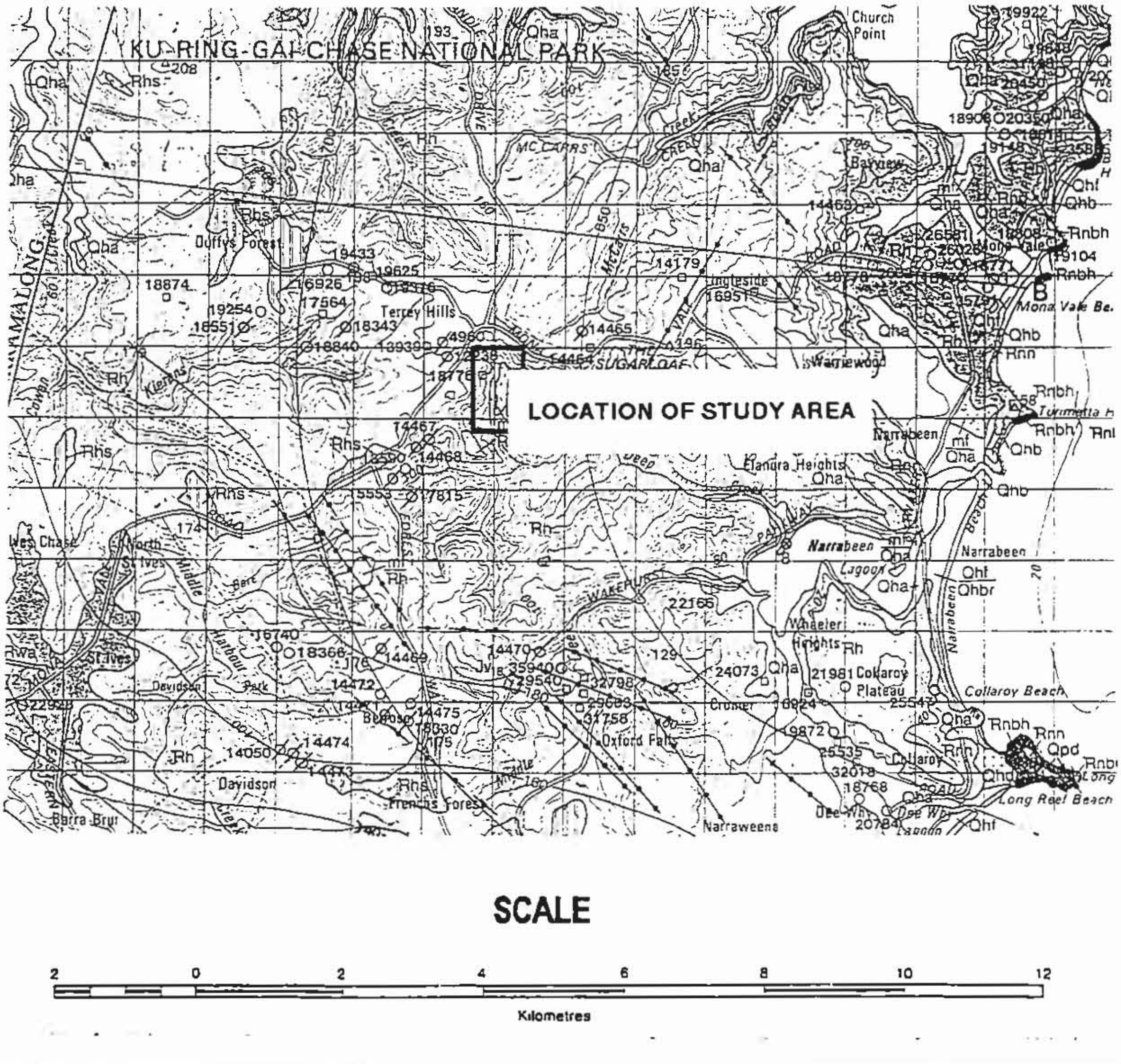
The larger dyke (2.8 m wide), trending 115° magnetic, is exposed over a vertical distance of 25 m, and bifurcates 4 m from the cliff top to enclose a massive sandstone block (Fig. 3). Formerly exposed over a length of 450 m across the floor of the original garbage pit, the dyke is now only available for study on the western and eastern sides of the pit. A smaller dyke (< .5 m), trending parallel to the larger dyke, and 100 m to the north, is exposed over a vertical distance of 4 m on the west face. Dip of the main dyke is variable, from nearly vertical to 70° towards the SW.

The main dyke shows three major zones of alteration: (a) an outer zone of very soft, plastic, off-white, generally massive clay, up to .3 m wide, (b) an inner zone of soft and moderately hard, intensely iron-oxide-stained dyke rock up to 0.5 m thick; and (c) a central zone of moderately hard, granular moderately iron stained, massive, highly-altered dyke rock. The boundary between the dyke rock and the enclosing sandstone and shale is irregular, but sharp, while the boundary between the inner and central zones is gradational. Intense fracturing and marginal discolouration of sandstone occur along the northern margin of the dyke, but there is little or no increase in hardness of the sandstone along the immediate dyke margin.

A layer of hard, massive yellow and red-brown ironstone of indeterminate thickness overlays the vertical exposures of the dyke on both sides of the pit, although that on the eastern side has been broken away in places. Vertically, as seen on the western cliff face, the dyke becomes increasingly highly jointed, fractured and completely altered to clay.

Road widening operations have partially removed the eastern exposure of the dyke. This eastern face now displays an oblique section of the dyke, some 3.5 m wide, and only 3 m high. Originally it displayed up to five highly fractured joints sub-parallel to its length, and the basal part of its southern margin contained brecciated, sub-parallel close-spaced joints. The upper portion incorporated a very small block of prismatically jointed sandstone.

DR. L. Baron, Principal Research Scientist, Geological Survey of New South Wales, petrographically examined specimens from the large Kimbriki dyke (PETROX



LEGEND

Dyke (accurate or approximate)

Base credit: Sydney 9130 1:100 000 geology

N

Fig. 1 : The regional setting of the Kimbriki site.

database slide Nos T 65580-65583). These specimens show intense alteration that was probably active during intrusion. The groundmass is granular, 1-3 mm average grainsize. Iron oxide veins, up to 4 mm wide are common. The dykes are olivine porphyritic and strongly microlitic in plagioclase. The latter feature suggest that this dyke is more likely to be tholeiitic rather than a more primitive alkali basalt or nephelinite. Therefore the main Kimbriki dyke is not necessarily of Tertiary age. All specimens contain undulose, rounded grains of quartz predominantly derived from the host Hawkesbury Sandstone and fragments of wood invisible in thin section.

Neither of these dykes has, to our knowledge, been previously recorded

Hawkesbury Sandstone

The intruded rock consists predominantly of massive bedded, fine and coarse-grained off-white to grey and red-brown quartzose sandstone. Some units are strongly cross-bedded. Individual beds are up to 3-5 m thick. Several of the units are fairly persistent, particularly towards the northern end of the pit. A prominent channel sand is exposed on the western face of the pit (Fig. 4).

Shale Unit

At the SW corner of the pit, a large drain has been has been cut down through the rock exposing a steep face of sandstone and a 500 m continuous, 3 m thick, shale (Fig. 5). This shale is also exposed along the SE of the pit where deepening is being carried out. Consequently this shale within the Hawkesbury Sandstone has a considerable extent, and might be approaching member status. Both the basal and top boundaries of the shale are sharp, but not perfectly regular. At the northern end of the drain the shale appears to be 'draped' over a hump of sandstone.

The shale would certainly repay a careful examination for fossils, including both fishes and vertebrates, as well as plants.

Structures

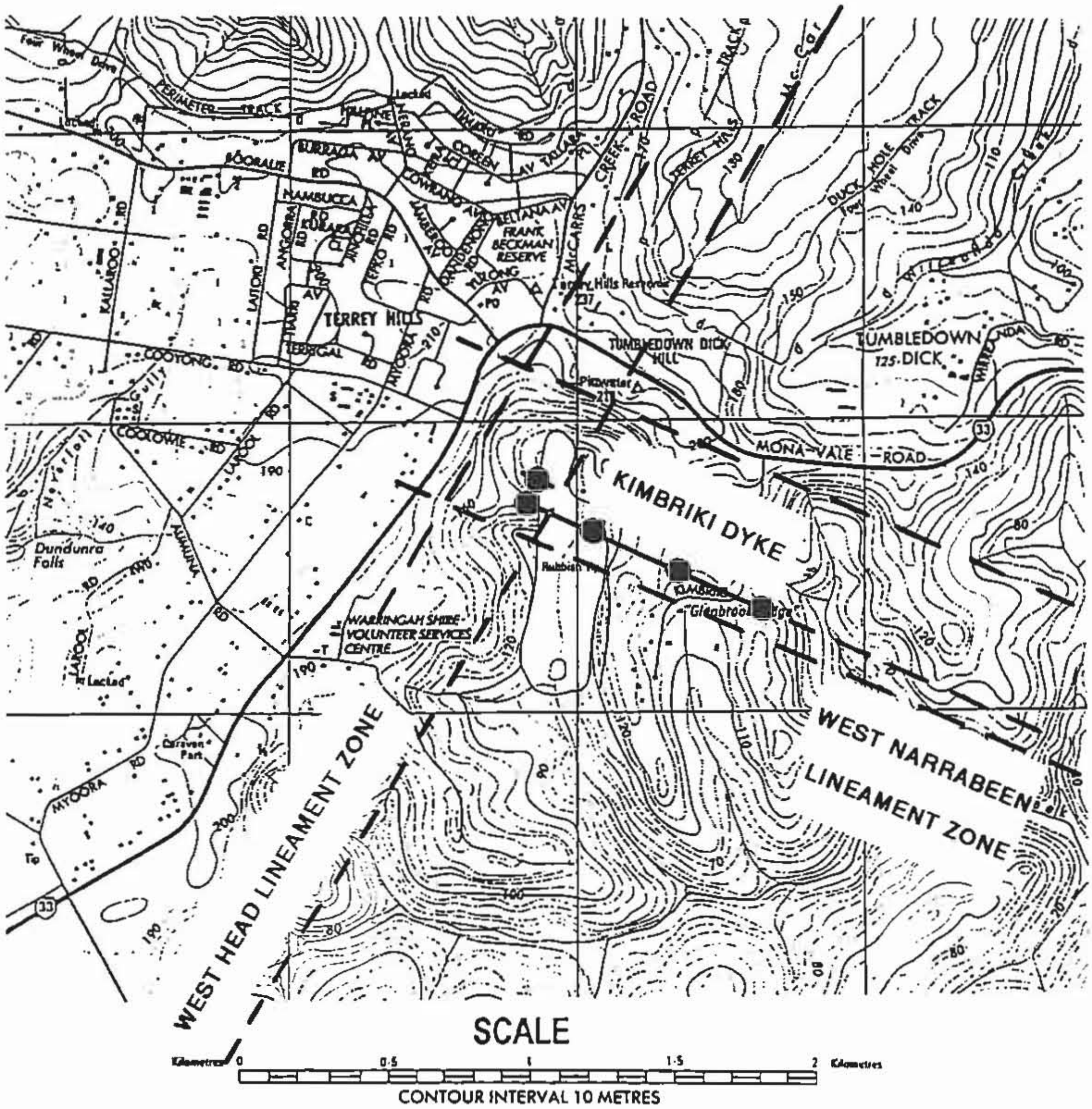
(A) Jointing

Two principal joint sets occur (Norman, 1986). The first consists of three to four NNE trending planar master joints, about 20 m long, developed at a spacing of 25-30 m. These joints dip to the NW and are variably iron oxide stained or infilled along most of their exposed lengths. Minor displacement has occurred along several of these joints where they impinge on the major dyke. As they probably predate the dyke, one of the joints may have provided the means for the dyke to bifurcate (Fig. 4). The second set of joints is generally left stepping and trends SSE. These joints are largely confined to individual sandstone units.

(B) Low angle Fault

The main dyke also cuts across a low angle fault, dipping southerly (Fig. 4). This fault consists of a number of small splays, with its upper surface cutting off a zone of shale breccia and dying out up sequence in a bedding plane. The fault is comparable with other thrusts faults mapped in the Sydney region by Branagan et al (1988). As might be expected such faults take advantage of weak locations within rock masses and adjustments take place through a volume of the rock mass, although, unlike some other such faults in the region there is no tectonic brecciation.

KIMBRIKI GEOLOGY



LEGEND

Dyke (accurate or approximate)

Lineament (accurate or approximate)

F - · - · - · - · - · F Fault (accurate or approximate)

N

Base credit Hornsby 1:25 000 9130-4-S

Geology credit A.R. Norman (1986)

Fig. 2: The Kimbriki Waste Disposal site showing location of key geological features.

Fig. 3: The main dyke as exposed on the west face of Kimbriki Pit.

(C) Lineaments

Although the dyke thins rapidly westerly and concludes abruptly easterly in bush land, it is part of a well-marked lineament 250-750 m wide, in which there are up to five well-developed, sub-parallel, highly developed continuous fractures. The lineament (Fig. 2) can be traced some 4 km SE toward Narrabeen Lake (Mauger et al. 1984).

A more prominent lineament zone (Fig. 2), the West Head Lineament Zone of Norman (1986), which trends NNE-SSW, and can be traced at least 10 km, cuts across the Kimbriki site, and is some 500 m wide. Aspects of this zone can now be studied in detail at the SW corner of the pit, along the large drain previously referred to. The sandstone and shale within the Hawkesbury Sandstone are cut by the near vertical fractures of the lineament zone (Fig. 6). The fractures are mostly very clean and show evidence of near-horizontal strike slip, although there is also oblique slip on some surfaces. However brecciation occurs along a few fractures.

Whether the intersection of the two lineaments has influenced the emergence of dykes at this location is uncertain. However the dykes fill a previously 'barren' region on the southern Hornsby Plateau between the numerous dykes of the Oxford Falls area 3 km to the S, and the Ingleside dykes (Fig. 1) (Branagan, 1995) 4 km to the N, all of which trend northwesterly. The Church Point and Bahai dykes trending NNE (Fig. 1) are not echoed by similar dykes on the West Head Lineament, which, perhaps, gives credence to the suggestion that movement within the lineament fractures was essentially strike slip and that there was limited extension in the E-W direction as compared with the tensional movement(s) which opened up the NNW-SSE fractures and allowed the intrusion of basaltic material, possibly on a number of occasions post mid-Triassic time.

Engineering and environmental aspects of the site

This paper cannot deal with the numerous engineering and environmental aspects of the site. There is some degree of localised slope instability along the western side of the pit

Fig. 4: Western face showing major dyke cutting across the Hawkesbury Sandstone succession, including a prominent sandstone channel unit. Note the low angle fault dipping southerly.

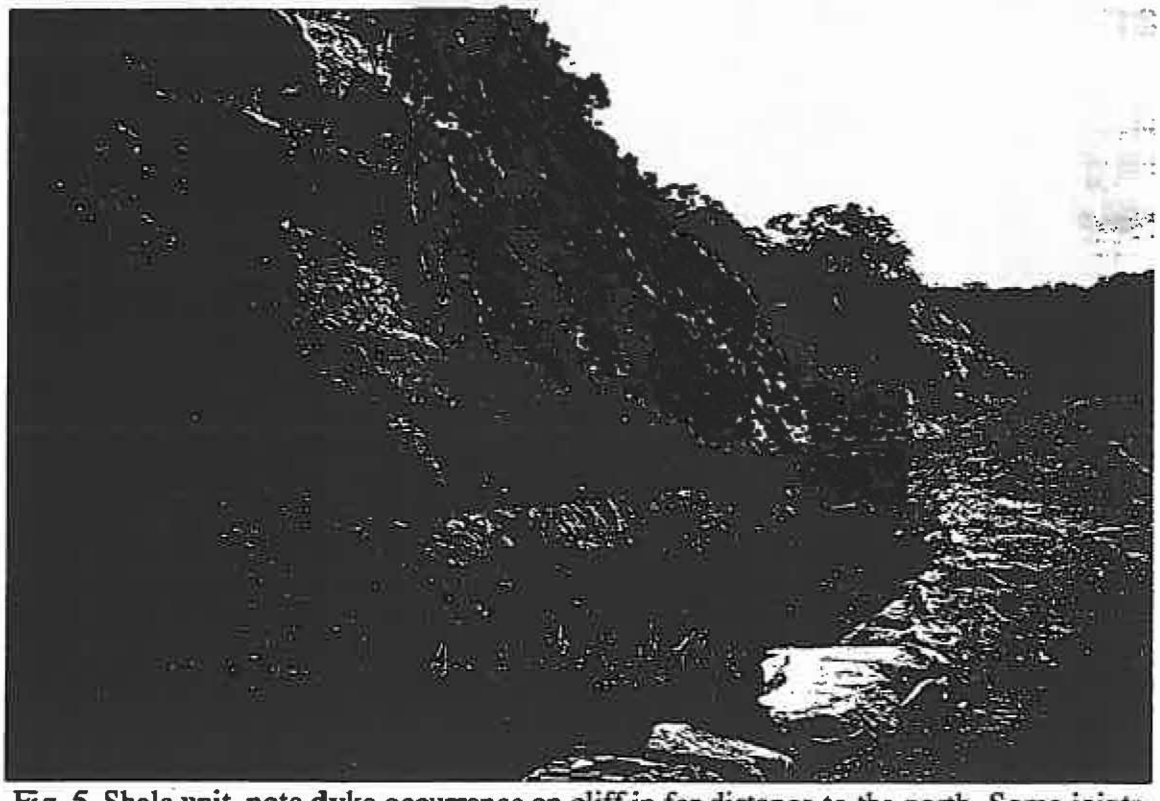


Fig. 5. Shale unit, note dyke occurrence on cliff in far distance to the north. Some joints are clay-filled.

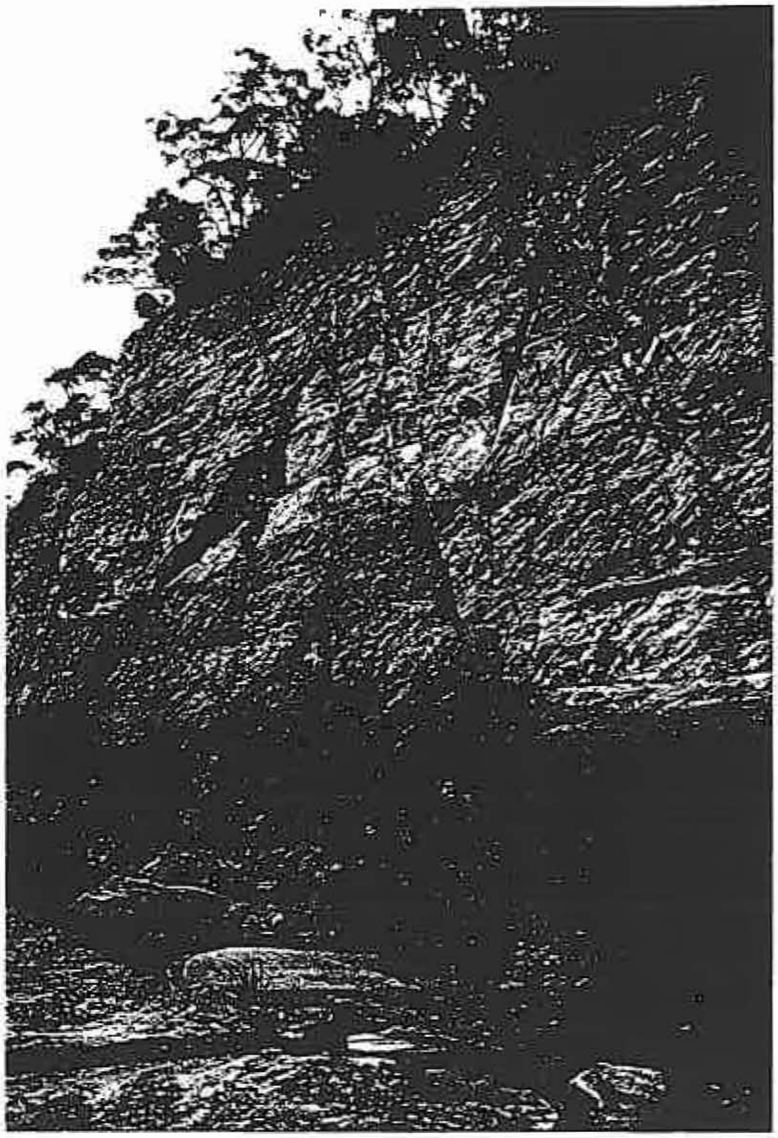


Fig. 6: West Head Lineament exposed at Kimbriki

caused by the highly weathered and fractured nature of the dyke. However as waste is apparently to be stockpiled along the wall no long term problems are likely. Leachate from the waste deposits may be partly diverted into the dyke, or more likely will build up on its northern side in the adjacent fractured sandstones, which will reduce the amount flowing into the artificial drains and into the catchment dams downstream.

Acknowledgments

Mr. Peter Duffy, Manager, Kimbriki Recycling and Waste, granted access to the site. This paper has been published with the permission of the Director General, NSW Department of Mineral Resources.

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HEAVY METAL CONTAMINATION IN SEDIMENTS OF THE NORTH SHORE LAGOONS, SYDNEY NSW

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INTRODUCTION

Waringah Shire is situated to the north of Sydney's CBD. It contains four marine lagoons: Dee Why, Narrabeen, Curl Curl and Manly, as well as Manly Dam, which contains freshwater and is located in the upper part of the catchment. As all of these water bodies are used by the community for recreation and provide a habitat for marine and wetland animals, it is important to establish their environmental status.

Sediments from Manly Dam, Narrabeen Lake, Curl Curl, Manly and Dee Why Lagoons on Sydney's North Shore were collected and analysed for heavy metals by flame AAS. Results were compared to sediment quality guidelines and previous studies in the area. This showed high metal concentrations in all the lagoons, including Manly and Dee Why Lagoons with Curl Curl having the highest average concentrations. Substantially lower heavy metal concentrations occur in Narrabeen Lagoon and Manly Dam. This distribution of contaminants has been attributed to different landuses within the catchments.

All the lagoons contained concentrations of heavy metals higher than those recommended for pristine sediments (Gray, 1996), and Manly, Curl Curl and Dee Why Lagoons possibly have levels of Cu, Pb and Zn in the range to have an adverse effect on biota (Long et al., 1995). A previous study in the same region (Currey et al., 1992) also found high concentrations of heavy metals in the surficial sediments, although they were generally lower than in the present study.

METHOD

Ninety six surface sediment samples were collected from Manly Dam, Curl Curl, Manly, Dee Why and Narrabeen Lagoons as well as creeks and stormwater drains within their catchments. Sampling was done using a stainless steel box corer and surficial sediments were collected with plastic spoons and stored in plastic bags until analysed. Where very fluid surficial mud was encountered, two samples were taken: an upper hydrous layer (A); and the more compacted mud below (B). Large amounts of organic debris (sticks and leaves) were avoided during collection as these were considered unrepresentative. Each sample was subsampled and separated using a 62.5μm nylon sieve to separate the mud from coarser fraction. Faecal pellets were disaggregated and included with the fine fraction. The sediment was dried at 45 ℃ before being weighed to determine the percentage mud, sand and gravel.

A 0.5g subsample of the fine fraction was crushed and digested in a mixture of $HClO_4^-$ and HNO_3 in a ratio of 1:2 at 120℃ for 16 hours. The diluted solution was then analysed using a Perkin Elmer (model 3000) flame atomic absorption spectrometer (AAS) to determine concentrations of Cd, Co, Cu, Fe, Mn,Ni, Pb and Zn. Precision determined by repeated analysis of samplesis 5% relative standard deviation (RSD) for Cd, Co, Cu, Pb and Zn and <10% RSD for Fe, Mn and Ni. Blanks and international reference materials were run with every set of samples. Analyses were size normalised (62.5μm) to reduce the confounding effects of variable grain size (Birch et al., 1998). Heavy metal concentrations and textural data were georeferenced and compiled into a GIS database using Mapinfo to display spatial distribution.

RESULTS AND DISCUSSION

The present study showed that the fine fraction of the sediments within the Manly, Dee Why and Curl Curl lagoons contained high concentrations of heavy metals, with the highest mean concentrations (except Fe) occurring in Curl Curl Lagoon (Table 1). High Fe concentrations in Narrabeen Lagoon could be due to larger amounts of Fe associated with weathering of the Gerringong Volcanics, or dykes in the area, or more likely from iron coatings on regressive beach sands deposited in the estuary from offshore.

Table 1: Mean, Maximum and Minimum Heavy Metal Concentrations in the Northern Lagoons and Manly Dam (62.5μm)

		Cd	Co	Cu	Fe	Mn	Ni	Pb	Zn
Narrabeen	Mean	0	8	46	4	95	17	145	302
	Max	1	11	206	6	325	34	426	1107
	Min	0	5	25	2	43	13	44	80
Dee Why	Mean	1	10	209	3	110	31	645	996
	Max	3	17	731	4	235	79	1196	611
	Min	0	3	72	1	47	15	379	304
Curl Curl	Mean	3	10	247	4	115	36	766	1805
	Max	4	13	484	7	215	44	1240	3068
	Min	0	7	138	1	10	27	384	1204
Manly	Mean	1	10	216	2	88	26	549	1304
	Max	5	44	762	10	187	39	729	3564
	Min	0	4	60	1	37	10	349	384
Manly Dam	Mean	0	4	32	2	44	13	90	197
	Max	0	6	39	3	56	16	447	247
	Min	0	3	23	0	33	10	54	123

All concentrations in $\mu g\ g^{-1}$ except Fe in %

The concentration of heavy metals decreases downstream in creeks and stormwater drains, indicating that the source of the heavy metals are in the upper and middle catchment and that they are transported into the lagoons. The distribution of contaminants within the study area is related to landuse within the catchment. This relationship is supported by the low concentrations in Narrabeen Lagoon and Manly Dam which are predominantly surrounded by bushland. The catchments of the other lagoons are heavily urbanised and contain light industry which is thought to be the main contributor of metals to these fluvial and estuarine systems.

Where an upper and lower sample was taken at the same locality, higher concentrations generally occurred lower in the sample. However, because this is not consistent for all metals within the same lagoons this may not be used to indicate a decrease in heavy metal concentrations within recent sediments.

Currey et al.(1995) collected near surface sediments from the lagoons and analysed them for Co, Cu, Hg, Ni, Pb and Zn. Their sampling density is less dense than in the present study, nevertheless the latter concentrations are generally higher. This may be an artifact of the different methods of analysis used in the two investigations.

A comparison of background and enrichment values (Birch et al.,1998) for the lagoons and Manly Dam with other New South Wales estuaries (Table 2/3) indicates that background levels of metal contaminants in Narrabeen Lagoon and Manly Dam are lower than those for the other lagoons, but no estuary/lagoon contains consistently lower concentrations for all metals.

Sydney Harbour has the highest enrichment values for Cu, Pb and Zn compared to all the other water bodies (Table 3). This is to be expected due to the high urban, industrial and recreational usage of the Harbour and its foreshores. Although the North Shore

Table 2: Background Heavy Metal concentrations for New South Wales estuaries and Sediment quality guidelines

	Cd	Co	Cu	Fe	Mn	Ni	Pb	Zn
Sydney Harbour[1]	2	16	10	3.9	131	26	33	47
Port Hacking[1]	<1	2	9	2	58	29	31	40
Georges River[1]	<1	7	10	3	55	26	33	47
Hawkesbury River[1]	<1	6	16	-	130	15	22	62
Narrabeen Lagoon[2]	0	5.1	25	1.6	33	13	44	80
Manly Lagoon[2]	0	3.8	60	0.9	37	10	349	384
Curl Curl Lagoon[2]	0	6.8	138	0.9	10	27	384	1204
Dee Why Lagoon[2]	0	3.4	72	1.4	47	15	379	303.5
Manly Dam[2]	0	3.1	23	0.3	33	10	54	123
Pristine Sediments[3]	<1	-	<10	-	-	-	<5	-
Biological Effects[4]	<5	-	<300	-	-	ERL<30	<300	<260

All concentrations in $\mu g\ g^{-1}$, except Fe%

[1]Birch et al.,1998 [2]This work [3]Gray, 1992 [4]Long et al.,1995

Table 3: Maximum enrichment of heavy metals in New South Wales estuaries, North Shore Lagoons and Manly Dam

	Cd	Co	Cu	Fe	Mn	Ni	Pb	Zn
Sydney Harbour[1]	-	-	108	-	-	-	24	48
Hawkesbury River[1]	-	-	13	-	-	-	79	4.4
Narrabeen Lagoon[2]	-	223	8	3	8	3	10	14
Manly Lagoon[2]	-	11	13	10	5	4	2	9
Curl Curl Lagoon[2]	-	2	4	7	22	2	3	3
Dee Why Lagoon[2]	-	5	10	3	5	5	3	2
Manly Dam[2]	-	2	2	9	2	2	8	2

All concentrations in µg g-1, except Fe%

[1]Birch et al., 1998 [2]This work

lagoons have much lower enrichment values than the Harbour or the Hawkesbury River, they are nevertheless still substantially enriched relative to pre-anthropogenic concentrations. Elevated Pb and Zn values in Narrabeen lagoon are due to input from South Creek which runs through a developed part of the catchment.

CONCLUSION

The concentration of heavy metals decreased downstream in creeks and stormwater drains which suggests that they are being transported away from their source in the upper and middle catchment. Industry, road use and urbanisation contribute heavy metals to the creeks which then collect in the lagoons. Point sources of the metals could be traced with more intensive sampling of creeks and drains, using both water and sediment.

An assessment of bioavailability would also be useful as an indication of how biota in the lagoons and Manly Dam are affected by the high sediment heavy metal concentrations.

Waringah Shire Council is aware of the pollution within the lagoons and has begun to address this issue by increasing community awareness (Waringah Council, 1994, Patterson Britton and Partners,1994a,b/1995) and by assessing different methods of rehabilitation, which although expensive, are necessary.

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SEDIMENTARY CONTAMINANTS IN THE UPPER PARRAMATTA RIVER, NEW SOUTH WALES

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INTRODUCTION

The growing interest in the contaminant status of river bed sediments is largely due to their ability to faithfully record 'environmental impact' on fluvial systems (Bubb and Lester, 1994). The marked tendency for hydrophobic pollutants, e. g. heavy metals and organochlorines, towards solid phase partitioning and their ability to provide long-term integrated information makes sediments attractive for identifying and assessing the impact of mining, industry and urban development on fluvial environments (Mann and Lintern, 1983; Rule, 1986; Castaing et al., 1986; Murray, 1996).

Regional monitoring of river sediments is taking place in Britain (Bubb and Lister, 1994) and in Europe where geochemical atlases have already been compiled (Muller and others. 1994). However, little contaminant work has been undertaken of fluvial sediments in the Sydney region (Thoms and Theil, 1995; Arakel, 1995; Birch et al., 1997). In the present study, fluvial sediments of the Parramatta River, New South Wales, are examined to determine the extent of industrial and urban impact and to identify possible contaminant sources to the estuary.

STUDY AREA AND METHODS

Urbanisation has reduced natural bushland to about 30% of the total Parramatta River catchment. Large industrial estates are located in Seven Hills and Girraween, whereas forests, recreational areas and bushland are confined mainly to the Darling Mills Creek subcatchment.

Heavy metal samples were wet-sieved with ambient water using a nylon 62.5 μm sieve to minimise the confounding effects of variable grain size (Forstner and Wittmann, 1979; Barbanti and Bothner, 1993). Samples were analysed for Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn after nitric-hydrochloric acid digestion (USA EPA method 200.8) on a Perkin Elmer 3100 flame atomic adsorption spectrophotometer. Precision, as determined by replicate analysis on internal laboratory standards, was less than 5% relative standard deviation (RSD) for Cd, Cu, Co and Pb and less than 10% RSD for Fe, Mn and Ni. Analyses of International Reference materials were within, or close to recommended values.

Selective extractions were made on bulk, wet sediment using 0.5M HCl and EDTA as prescribed by Weimin et al., 1992. Sequential extraction procedures were carried out on size-normalised material according to the scheme of Kersten and Forstner (1995). Organochlorine analyses were on total sediment as described by Birch, et al., 1997.

RESULTS

The 188 samples analysed for heavy metals provide a strong and well-defined spatial distribution of contaminants in stream sediments from the Parramatta River catchment.

Co, Cu, Pb and Zn display similar distribution patterns. The highest concentrations of these elements are adjacent to the Seven Hills (maximum values Co 31, Cu 784, Pb 1324, Zn 9350 mg g^{-1}) and Girraween (Co 28, Cu 294, Pb 940, Zn 3741 mg g^{-1}) industrial centers on the Toongabbie and Greystanes Creeks, respectively. Creeks receiving runoff from two large freeways in the catchment, Pendle Hill (Co 31, Cu 148, Pb 626, Zn 951 mg g^{-1}) and Finlaysons Creeks (Co 28, Cu 158, Pb 634, Zn 653 mg g^{-1}) also contain high concentrations of these heavy metals, whereas sediment concentrations from the least urbanised subcatchment - Darling Mills Creek - are substantially lower (Co 16, Cu 98, Pb 146, Zn 298 mg g^{-1}).

The spatial distribution of Ni, Fe and Mn is not so well defined as the previous elements and their relationship to landuse is not so distinct. Concentrations of Fe and Ni in sediment adjacent to the Seven Hills (maximum Fe 9% and Ni 94 mg g^{-1}) and Girraween (Fe 5% and Ni 67 mg g^{-1}) industrial centers are difficult to distinguish from concentrations in the Darling Mills Creek (Fe 7.2% and Ni 64 mg g^{-1}). Concentrations of Mn are variable, with highest concentrations located adjacent the Girraween industrial complex (2803 mg g^{-1}), with moderate concentrations in the Toongabbie (1628 mg g^{-1}) and Darling Mills Creeks (890 mg g^{-1}).

Bioavailable heavy metals

Dilute (0.5M) HCl extractions liberated consistently higher concentrations of Cu, Ni and Zn than did EDTA, but more Pb and Mn is extracted on average by the EDTA treatment (Table 3). These procedures liberated only a small proportion of that extracted by the nitric-hydrochloric acid treatment, i.e. for Cu and Pb about 10%; for Ni approximately 2.5%; and for Mn and Zn about 10-15%.

Sequential Extraction

The majority of Cd is associated with the carbonate phase and most of the Cu resides with the oxides and sulphide/organometallic phases. Almost all of the Fe is present as oxides, whereas Pb is associated with sulphides/organomatallics and to a smaller proportion with the adsorbed/exchangeable and carbonate phases. Cu is mostly associated with the oxide phases and to a lesser extent with the carbonate and sulphidic phases, whereas Zn is related mainly to the exchangeable/adsorbed and to the oxide phase in a smaller proportion.

Organochlorine/Pesticides

Only minor quantities of HCB and Lindane were detected in total sediments in the catchment. Toongabbie and Graystanes Creeks sediment contained high concentrations of Heptachlore and Heptachlor-epoxide, Chlordane, Dieldren and DDT. Pendle Hill Creek sediments contain similar organic contaminant concentrations, but included DDD and DDE. Parramatta Creek sediments contained moderate concentrations of Chlordane, whereas Darling Mills and Blacktown Creeks had only minor quantities of organic contaminants.

DISCUSSION

Background concentrations and Enrichment

To assess the significance of sediments heavy metal concentrations in the Parramatta River catchment, it is necessary to establish the anthropogenic contribution to the system. This can be done by normalising heavy metal data to a conservative element, e.g. Al or Fe, or analysing a particular grain size and relating these results to pre-anthropogenic background levels. Because of the markedly variable grain size and mineralogy encountered in fluvial sediments, the latter approach has been favoured by many researchers (Forstner and Wittmann, 1979; Bubb and Lester, 1994; Muller et al., 1996).

The mean concentrations of the least impacted sediments of the Darling Mills Creek and core data from Lake Parramatta and from adjacent Port Jackson are used to determine background heavy metal concentrations for Parramatta River fluvial sediments. High Cu, Pb and Zn concentrations suggest that the Lake Parramatta cores are not sufficiently deep to establish pre anthropogenic heavy metal levels, except for Co and Ni. The metal concentrations in Lake Parramatta cores and sediments from the least influenced sediments in Daring Mills Creek are similar and lower than background values in Port Jackson, suggesting an additional source of Co and Ni for the estuary. Similar Cu and Zn concentrations in Darling Mills Creek and deep Port Jackson cores suggest that parts of this catchment are close to pristine for these heavy metals. Adopting this approach, the following heavy metal concentrations have been accepted as background for Parramattta River catchment: for Co and Ni (16 and 15 mg g^{-1}), the mean of Lake Parramatta cores and Darling Mills Creek sediments; for Mn, Pb and Zn (135,32 and 45 mg g^{-1}), the mean of Darling Mills Creek sediments and Port Jackson background values.

Using background concentrations estimated above, enrichment for mean heavy metal concentrations for the catchment range from near parity for Fe and Ni, to between 3 and 5 times for Co, Mn and Cu, and up to 7 and 22 times for Pb and Zn, respectively. Maximum concentrations are less than 10 times enriched for Co, Fe and Ni, but for Mn (21x), Pb (41x) and for Zn (221x) maximum values are substantially elevated.

Regional distribution of heavy metals

The Parramatta River catchment was chosen for study primarily because of its very well defined land use distribution and uniform geology and soils. Three major land uses can be identified in the catchment, i.e. forest, urban and industrial. The catchment is highly urbanised with only 30% remaining undeveloped bush, parkland and recreational (Water Board, 1992). Industry is largely confined to a small number of specifically designated centres, the two largest of which are the Seven Hills and Girraween complexes.

The Darling Mills Creek subcatchment comprises predominantly forest and bushland and is devoid of industry. Mean Co, Cu, Pb and Zn concentrations for this area are substantially greater than local background levels, especially for Zn. Mean Cu concentration is approximately twice background and a single high value may indicate unauthorised dumping. Pb and Zn concentrations increase gradually downstream, suggesting a diffuse source, possibly increased input from sewer overflows, road and stormwater runoff as well as by atmospheric input. The influence of urban development on creek sediments is assessed by combining data from the totally urbanised upper Toongabbie Creek catchment. Mean Co, Cu, Pb and Zn concentrations for these areas are higher than the predominantly wooded Darling Mills Creek subcatchment and substantially greater than background. The main diffuse sources to these creeks are

probably road and stormwater runoff, as well as, unauthorised dumping which was often observed in the catchment. Mean sediment concentrations of Co, Cu, Pb and Zn in streams adjacent to the major industrial centers of Seven Hills and Girraween are substantially higher than creek sediment in other parts of the catchment. Higher Pb and Zn concentrations in sediments adjacent to the Seven Hills complex may reflect the presence of a number of large metal-based industries in that industrial centre.

Heavy metal concentrations of fluvial sediment downstream of the industrial areas decline noticeably until the confluence with the main river channel, downstream of which levels are irregular and in general comparatively low. Metal concentrations increase again markedly in the estuarine section below the weir. Declining concentrations away from source can be explained by dilution by less contaminated sediment, or desorption into the water column. Mineralogical data does not support that the declining trend is due to an increase in the essentially metal-poor silt fraction of the material analysed. A substantial proportion of Cu, Pb and Zn is associated with the easily exchangeable/adsorbed phase in these sediments (see following section) and remobilisation of these metals into the water column is possible. However, the irregular nature of the distribution pattern in the main Parramatta River channel suggests dilution may also be an important process. The estuarine sediments of the Parramatta River are considerably finer and more organic rich than the fluvial sediments, suggesting that river-transported metals, especially if in colloidal form, coagulate into larger aggregates and settle rapidly on entering the saline environment.

Bioavailability

Not all heavy metals in aquatic sediments are available to water- or sediment-dwelling organisms. The factors controlling the potential availability of metals, and therefore their toxicity is complex, but speciation and chemical reactivity are known to be important factors (Morse, 1994). Estimates of the biologically available fraction can be made by selective extractions (Weimin et al., 1992), sequential extraction (Tessier et al., 1979).

The proportion of metal (Cu, Mn, Ni, Pb and Zn) released by EDTA and HCl was variable and low compared to the aqua regia extractions in the current study, mainly because the former analyses were carried out on wet, total sediment, whereas the results of the strong acid extraction were for size-normalised material. These results are similar to those of Chaung (1996) for other catchments of the Port Jackson estuary, but considerably lower than that of a nearby estuary (Chenhall and others, 1994) where results were compared to total sediment. Lower metal extractions in the current study may also be due to the coarser, less organic-rich, and more variable nature of these fluvial sediments compared to the estuarine sediments studied in the previous work. Sediments adjacent to the Parramatta industrial estates released the highest (10-20%) proportion of EDTA- and HCL- extracted material, but high concentrations released from sediments in the main channel and in the urban areas, as well as, the variable nature of the results, makes direct comparisons with land use difficult.

Geochemical phases

The mobility and bioavailability of trace metals in natural aquatic environments is a function of its chemical form which is dependent on the physico-chemical and biological characteristic of the environment. The tendency for elements to accumulate in biota depends in part on the ability for the element to be removed from the solid phase into solution and thus information on the chemical form of the trace element is very much more informative than total element chemistry.

The variable physico-chemical nature of fluvial systems results in contaminants being associated with a wide variety of chemical forms. The affinity of Cd to the carbonate phase in the current study is commonly reported (Tessier and others, 1980), but the minor association with the exchangeable fraction is unusual, rather this element is associated with oxides (Gadh and others, 1993), or the organic phase (Pardo and others, 1990). Cu shows a diverse chemical affinity in fluvial sediments and an association with the oxide (Jha and others, 1990) and organic fractions (Pardo and others, 1990) in the present study is often reported. Although Pb is often associated with the oxide fraction, high concentrations in the sulphide/organometallic fraction in the present work is not unusual (Pardo and others,1990). A large proportion of the Zn in the current work is associated with the exchangeable/adsorbed phase. This is especially the case for the metal-rich samples from adjacent the industrial complexes including the Seven Hills centre where zinc-plating is carried out. Although the dominant Zn association in estuarine and fluvial sediments is with the residual fraction (Hong and Forstner,1983) an affinity with the oxide phase in the Parramatta River samples is common for bed sediments (Veil and others, 1983) and for suspended particulate matter.

The exchangeable/adsorbed phase being the most reactive, is generally regarded as being potentially the most mobile and bioavailable fraction (Kersten and Forstner, 1995). Large proportions of Zn and to a smaller extent, Cd and Pb would thus potentially be available from this fraction to aquatic fauna and flora of the catchment. In the case of substantial changes in pH (such as through industrial discharges) and Eh (such as by erosion during storm events), additional Cd, Cu and Pb may become available through remobilisation of oxide and sulphidic phases in bed sediment. If environmental impact can be related to the potential for remobilisation, then Zn would pose the highest risk, followed by Pb and Cd.

Organochlorine/pesticides

Generally, organic contaminants are substantially more toxic than heavy metals and they have been identified as being potentially one of the highest environmental threats (Windom, 1992). The concentrations of HCB, Lindane, Aldrin, Heptachlor and its derivative Heptachlor-epoxide are low in sediments of Parramatta River catchment. Chlordane and DDT are the most prevalent and Dieldrin and DDD and DDE are common. Over 50% of the samples have DDT concentrations in excess of the ER-M values of Long and Morgan (1990) and maximum concentrations are 10 times this guideline level. In general, regional distributions of organochlorine compounds are similar to those of the major heavy metals, i.e. they are highest in creeks adjacent to the industrial complexes. A common source for these two classes of contaminant is not surprising considering the multifaceted nature (petrochemical, tyre, rubber, steel works, concrete and furniture manufacturers) of these industrial centres (Dept. of Environ. and Planning, 1986).

CONCLUSIONS

Landuse in the Parramatta River catchment is clearly differentiated between industrial. urban and largely undeveloped bushland/forest. This discrete subdivision has been used to test sediments of the fluvial system for adverse environmental impact related to land use practice. The detection of landuse impacts has been greatly facilitated by restricting analyses to the fine fraction (<62.5 mm) of the sediment to moderate the confounding effects of variable grain size and to improve sample comparability, whereas low small-scale spatial and temporal variance has allowed meaningful regional differences to be established.

Industrial discharges have substantially effected the quality of adjacent stream bed sediment both in heavy metals and organic contaminants. High concentrations of, especially, Zn and to a lesser extent Cu and Pb in the exchangeable/adsorbed, as well as, moderate concentrations of reduceable and oxidisable chemical phases increases the remobilisation and bioavailability potential.

Fluvial sediments in urbanised catchments are considerably enriched in heavy metals relative to pre anthropogenic background and even stream sediments in a partially undeveloped subcatchment have elevated contaminant levels.

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VEGETATIONAL RESPONSE TO NATIVE SEED TREATMENT AND BIOSOLIDS APPLICATION IN THE REHABILITATION OF A SPOILPILE AT COORANBONG COLLIERY

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INTRODUCTION

This study addresses two challenges which the minerals industry faces in the rehabilitation of minespoils. The first is to re-establish a soil ecosystem that will sustainably support native vegetation. The second is to overcome seed dormancy mechanisms that often lead to the failure of native plant establishment on sites affected by mining.

The ongoing study involves the rehabilitation of a coal stockpile at Cooranbong Colliery, Dora Creek, New South Wales. The study methodology was described previously (Newton & Whitehead, 1997). This paper outlines the results to date.

The trial was established to determine the benefits of utilising dewatered biosolids as a soil conditioner for the growth of native trees by direct seeding techniques, and also to investigate the effectiveness of seed treatments on seed germination rates. Two seed treatment techniques, new to attempts to re-establish native species on minespoils, were trialed using, in turn, hot water and smoke.

REHABILITATION CONCEPTS

The success of any rehabilitation project depends upon to what extent limitations to plant growth exist. Limitations vary significantly among different mine sites and relate to climate, plant adaptability and chemical and physical limitations of substrates. Other constraints are found as a result of dormancy mechanisms that exist within native seeds. The mechanisms involved in overcoming the constraints that exist within substrates and native seed was the focus of the research project and are discussed here.

Substrate Amelioration

To overcome the deficiencies within the substrate in relation to plant growth, poor ground conditions must be ameliorated. The success of this is dependent on the method used in applying soil amendments such as phosphorus and nitrogen as well as organic matter and how effective they are in re-establishing a self sustaining soil ecosystem.

Burns (1988) discusses earlier work by Irving (1986) who demonstrated that high levels of both nitrogen and phosphorus produced a synergistic increase in growth. A nutrient balance is, therefore, important in the development of plants on minespoils.

Chemical Fertilisers

Through natural succession or by conventional reclamation practices using inorganic fertilisers, the recovery of native organic matter levels and soil structure on minespoils can be expected to take from 30 to 300 years. On such sites, vegetation may initially be established, but poor physical conditions result in deterioration of the vegetative cover before it can begin to improve the mine spoil. Organic matter decomposition and cycling are difficult processes to re-establish in disturbed soils. Organic amendments are, therefore, extremely important to successful reclamation (Seaker & Sopper, 1988).

Biosolids

Biosolids, commonly known as sewage sludge, is the nutrient rich organic material produced as a result of the biological and physical treatment of wastewater. With increasing quantities of biosolids being produced, much research has been undertaken to determine the effectiveness of utilising biosolids in the reclamation of disturbed lands. The success of such projects can be attributed to the ability of biosolids to improve soil structure by increasing organic matter and water retention capabilities; to provide a source of plant nutrients such as nitrogen in a slowly available organic form and phosphorus; and, to promote the re-establishment of microfauna and microflora which are essential for nutrient cycling (Phillips, 1994).

The majority of biosolids trials, set up in the Hunter Valley, have focused upon the effects of biosolids on pasture species. The effect on the germination and growth of native tree species from direct seeding methods has not been well documented and is, therefore, the major focus of the research project.

Seed Dormancy

Australia's diverse vegetation types are a consequence of the wide range of climatic regions, habitats and soil types. Survival of species within the ecosystem often depends on germination responses that ensure maximum survival and establishment of seedlings. Timing of germination in response to favourable seedling development conditions is controlled by an interplay between the physiological state of the seed, such as dormancy; and, the seed responses to environmental factors (Langkamp, 1987).

When growing plants from seed, difficulties are often encountered in germinating certain seed lines. Although favourable environmental conditions may exist, germination may still be inhibited by a block existing in the seed itself. This is referred to as seed dormancy. This dormancy can be overcome by exposing the seed to a certain set of conditions, acting to prime the seed for germination (Langkamp, 1987).

The actions of light and temperature are usually the most important conditions in nature responsible for breaking seed-dormancy. In most Australian ecosystems, the major factor involved in breaking the mechanisms of seed dormancy is fire. Langkamp (1987) discusses earlier work by Mott and Groves which describes other factors responsible for breaking seed coats, thereby facilitating germination. These include the actions of weathering, microbial decay, ingestion by animals or abrasion from soil disturbance.

NATIVE SEED TREATMENT AND BIOSOLIDS IN SPOILPILE REHABILITATION

Seed treatments trialed in the Cooranbong Colliery project involved the methods of immersion in hot water and smoking seeds, both designed to promote germination.

Boiling and Hot Water Treatment

Species with thick seed coats require to be either cracked, broken or pierced so as to allow water and oxygen entry into the seed. In nature, this is commonly by means of fire, however, artificial heat treatments are also effective. Heat treatments, either wet or dry, are used to crack the seed. Ralph (1994) suggests that wet heat treatments such as boiling or hot water are more effective, particularly for species such as *Acacias*.

Smoke Treatment

An innovative technique that is relatively new to Australia uses smoke to promote the germination of native seeds. The technique was first developed by South African botanists in 1991 when it was realised that the application of smoke was important in germinating native plant species. Research has since been undertaken by a team of scientists at the Kings Park and Botanic Gardens plant science facility in Western Australia. It has been found that over two hundred species of Australian native plants respond positively to smoke application, particularly those that shed their seed into the soil seed bank. However, those species that retain their seed in capsules on the plant, such as Eucalypts and Banksias, appear to have a lesser requirement for smoke (Dixon, 1996).

The effect of smoke relies on an as yet unknown chemical that breaks down the dormancy of seeds. The scientific team at Kings Park believe that once the identity of this chemical is established and isolated, only the smallest concentrations will be required to treat hectares of bushland (Dixon, 1996).

Trial Design

The characteristics of the area to be rehabilitated at Cooranbong Colliery provided an excellent opportunity to establish a biosolids trial. The deficiency of organic matter and plant nutrients within the substrate meant that any change in these parameters could be directly attributed to the application of biosolids. Further, due to the size of the area, biosolids could be applied using machinery that would normally be used as part of a mine rehabilitation project.

Three 30m × 60m trial areas were designed to determine the effectiveness of two application rates of biosolids and their effect on the establishment of a range of native tree species from direct seeding. The application rates included 50 and 100 dry tonnes per hectare (dt/ha) as well as a nil application rate, designed as a control.

To investigate the effectiveness of seed treatment techniques on germination rates, each application area was further divided into three separate plots, each representing a different treatment. The plots were designed to show the effects of hot water emersion, a commonly used treatment in mine rehabilitation; smoking, a method relatively new in the treatment of Australian native seed; and nil seed treatment (Table 1).

Table 1: Cooranbong Colliery biosolids application and seed treatment plots.

Plot	Seed Treatment	Biosolids application rate
1	Nil	Nil
2	Hot water	50 dry tonnes/ha
3	Smoke	100 dry tonnes/ha
4	Nil	Nil
5	Hot water	50 dry tonnes/ha
6	Smoke	100 dry tonnes/ha
7	Nil	Nil
8	Hot water	50 dry tonnes/ha
9	Smoke	100 dry tonnes/ha

RESULTS

The Cooranbong Colliery trial was limited in that the majority of data was collected over the winter months. Results are, therefore, only representative of the initial phase in rehabilitation. The trial does not take into consideration the effects of seasonal variation as it is limited to a winter germination and growth period.

Soil analysis completed on the site prior to the application of biosolids indicated that the site was alkaline in nature with pH values ranging from 7.7 to 9.4. According to Burns (1988), pH values above 8 can limit the availability of plant nutrients such as phosphorus. Further analysis showed a coarse spoil pile with very low organic matter content.

Transport of Biosolids

Biosolids were found to be economically feasible for the Cooranbong Colliery rehabilitation trial, as an alternative to both topsoil and fertiliser application. This is in contrast to a study undertaken by Phillips (1993) on Rix's Creek Mine located within the Upper Hunter Valley. Phillips concluded that, as a result of high transport costs, biosolids is only feasible as a topsoil replacement when topsoil is not available on site. The advantage of the Cooranbong trial is that it is located within the coastal region close to the major population centres of the Hunter Valley and, hence, the sources of biosolids. As a consequence, the relatively low cost of transport was met by the Hunter Water Corporation.

Biosolids Spreading and Incorporation

Although the Cooranbong project utilised what was known as a dewatered biosolids product, the water content was found to be still relatively high. Due to the high water content, the biosolids product resembled a jelly-like substance and consequently was difficult to spread over the application area. Using a tractor and spreader, biosolids was spread in large clumps rather than distributed evenly across the soil surface. As a consequence, loss of traction was a common problem experienced by the operator, particularly across moderate slopes.

During the spreading operation, odour generation significantly increased. Again, this is due to the high water content and high ammonia concentrations, evident in the surface water runoff, within the biosolids product.

Incorporating biosolids into the rehabilitation substrate met with limited success. Due to the coarse nature of the substrate, a D6 bulldozer with ripping tynes was used, but this failed to adequately incorporate the biosolids product. This was particularly evident in the 100 dt/ha application area.

Post-biosolids Soil Analysis

The soil analysis shows a sharp decline in pH levels associated with the application of biosolids. Within the 100 dt/ha application area, pH values range from 4.8 to 6.9, while a similar range of 4.9 to 6.7 exists within the 50 dt/ha application area. In contrast to pH values of 7.7 to 9.4 established from spoil analysis prior to the commencement of the study, decreases in the order of two to four pH units have occurred. Phillips (1994) believes that the process of applying biosolids will lower soil pH values by approximately one unit, due to the breakdown of organic matter in the sludge to form humic acids. In the case of this project, the low values of pH may be related to poor application and incorporation methods.

Germination

The mix of upper tree species was designed to introduce to the rehabilitation site, a diverse species mix, representative of the surrounding bushland (Table 2).

Figure 1 shows that, germination response is greatest in the nil biosolids application plot areas. Germination response is reduced in areas to which biosolids was applied, particularly in the 100 dt/ha application area where plot 4 recorded no germinants. Germination response differs significantly over all three application rate areas. The number of germinants decrease with the higher application rate of biosolids. This trend may relate to the lower pH levels and the competition associated with the growth of tomato plants that were found to occur with the application of biosolids.

Table 2: The proportion by weight, of the seed mix applied to the site.

Species	Proportion
Angophora costata (Smooth - Barked Apple)	5%
Eucalyptus eugenioides (White Stringybark)	5%
Corymbia gummifera (Red Bloodwood)	5%
Eucalyptus umbra (Bastard Mahogany)	10%
Eucalyptus maculata (Spotted Gum)	10%
Eucalyptus haemastoma (Scribbly Gum)	15%
Acacia longifolia (Sydney Golden Wattle)	25%
Acacia falcata (Sickle Wattle)	25%

A germination response is also evident from the seed treatments. The results show that in each of plots 1 to 8, with the exception of plot 4 which recorded no germination, there is a significant difference in germination response between the two groups of species in response to seed treatments. There was no significant difference in germination response between species in plot 9. Germination responses vary according to the type of seed treatment. The boiling method promotes the germination of the *Acacia spp* while it appears to be detrimental to the germination of the Tree species mix. The germination response of the Tree species mix is best in either the nil or smoke treatments.

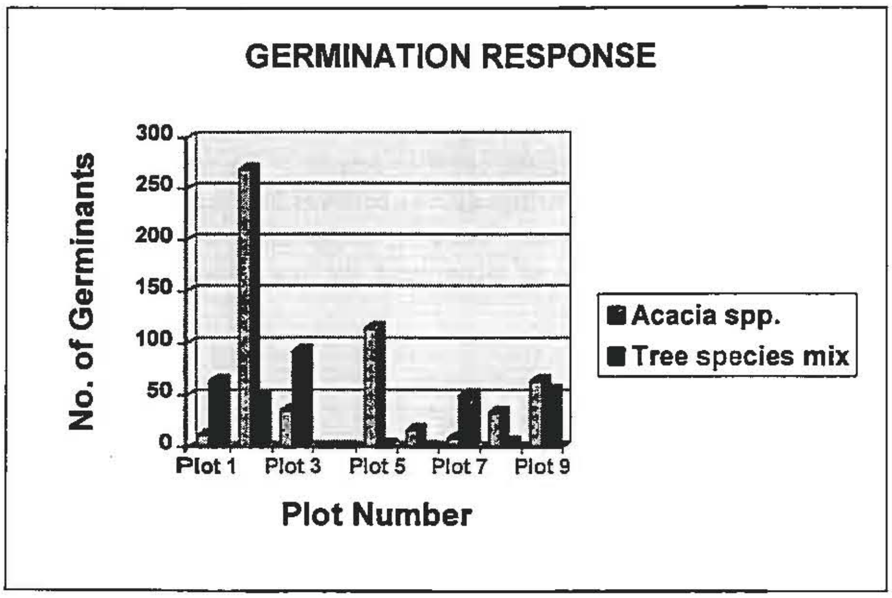

Figure 1: Germination response on rehabilitation site

Growth

As growth measurements were undertaken during the late winter and early spring, development of germinants was low. However, plant height is greatest where application rates of biosolids were highest. Growth rates of plants in the nil application area appear to be very limited, which is possibly related to the low phosphorus and nitrogen conditions experienced in the substrate.

Tomato Biomass

An interesting effect of the application of biosolids was the vigorous growth of tomato plants. Seeds from these species are not separated during the sewage treatment process and consequently settle with the sludge and are collected. The biosolids provide ideal conditions for their germination and growth.

The vigorous nature of tomato growth was directly related to the fact that there was no competition from other species. In the long term, the growth of tomatoes is seen to be beneficial for the rehabilitation project, providing a source of valuable organic matter to the soil, contributing to the soil ecosystem recovery.

Surface Water Runoff

The application of biosolids was completed during April 1997. Water samples were taken at the entry to the final catchment dam on site. An increase in nutrient levels in surface water runoff in May, directly after the application of biosolids, is possibly due to poor incorporation techniques. The increase in nutrient levels was only evident during the rainfall period experienced in May 1997. Surface water runoff generated by rainfall in June 1997 contained lower nutrient concentrations within acceptable limits.

Weed Infestation

With the onset of the spring and summer months, the extent of tomato growth throughout the plot areas had declined. The decline was followed by a rapid emergence of a wide variety of weed species, possibly introduced with the biosolids product. In fact, in some areas, the weed species have out competed the developing native tree species.

During January 1998, a herbicide applied to the area met with limited success. In order to eradicate weed growth on site, burning of designated areas is scheduled for late March and re-seeding is to commence during early April.

Importance of Clay

Adjacent to the biosolids trials, an area was rehabilitated using clay extracted from a dam, seeded with the same seed mix as the trials and chemically fertilised. The high density, high species diversity and strong growth rates of seedlings that have emerged suggest that the clay plays an important role in binding nutrients. Incorporation of clay with the biosolids product may enhance the benefits for use in rehabilitation.

CONCLUSIONS AND RECOMMENDATIONS

The results of the Cooranbong Colliery trial show that there is a potential benefit in utilising biosolids with direct seeding techniques in the re-establishment of native tree species on a coal mine spoilpile. With an increase in the application rate of dewatered biosolids, there is a subsequent increase in the growth of native tree species. However, with an increase in the application rate of dewatered biosolids above 50 dt/ha, there are no beneficial advantages for the native tree species. In fact, germination rates decline.

This later conclusion is attributable to the difficulties of applying and incorporating the biosolids product to the site. Poor incorporation also contributed to the fact that with the application of biosolids, there is an initial increase in the concentration of pollutants in surface water runoff as well as pungent smell that is present during the first month after application.

The success of hot water and smoke seed treatments on the tree species used in the rehabilitation trial show was mixed. It can be concluded that the Tree species mix has greater germination response to the nil seed treatment. The germination of the *Acacia spp.* is greatest with the hot water treatment. However, the hot water treatment appears to be detrimental to a range of the Tree species mix.

It can also be concluded that the smoke seed treatment is relatively ineffective in enhancing the germination of any species and is in fact, detrimental to some species.

It is evident from the results of the Cooranbong Colliery trial that a number of improvements are required to successfully utilise biosolids as a part of a mine rehabilitation project. It is recommended that:

- lighter applications of biosolids, below 50 dt/ha be applied when using native tree species by direct seeding;
- improved incorporation methods be used so that biosolids can be evenly mixed within the top 15 to 50 centimetres of the substrate; and
- a drier biosolids product be developed to alleviate the problems of spreading and incorporation and subsequent odour generation.

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TOOL LOSS IN DIRECTIONAL DRILLING - RECOVERY OR BUST!

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ABSTRACT:

Directional drilling for in-seam coal mine exploration and gas drainage has been increasingly applied in recent years. The valuable information obtained from this type of drilling comes at a potentially high cost. A lost drill string includes expensive downhole motors and electronic survey equipment, valued conservatively at AU$400,000. Tool loss is invariably associated with adverse geological factors. This paper addresses what can be done to prepare an exploration hole in advance, and what should be done when all appears lost.

1. INTRODUCTION

In 1989 directional drilling was introduced to Australian underground coal mining and provided limited early success. At the time, all in-seam drilling activities were carried out by rotary drilling and were mainly short holes (<300m). This type of drilling was, and still is, cheap and fast but difficult to control, particularly with regard to azimuth and to a lesser degree, in elevation.

Gas drainage requirements have driven the development processes and today, in excess of 500 kilometres of directional drilling is carried out in Australia every year. Extreme accuracy is required to ensure even drainage of gas from virgin coal in order to minimise the risk of dangerous outburst events when mining development proceeds.

In exploration drilling, directional control is important because of its capacity for multiple branching off a primary drill hole. This enables geological structure to be investigated and seam profiles to be ascertained from multiple roof touches (Figure 1). The level of information obtained from this type of drilling is driven by the hole planner, usually a geologist , and is mainly limited by the budget the mine is willing to allocate towards investigating the structure.

A major advance in directional drilling was the advent of (almost) real time electronic survey equipment which enabled fast sampling and true "guided" drilling. Extreme accuracy was also achieved (approximately 0.5°). Prompt feedback on the whereabouts of the drill string has given the driller the power to direct a hole to a prescribed target and correct adverse deviation before it becomes irreversible. Mine planners can now direct a hole towards a chosen target, and have real confidence in the outcome.

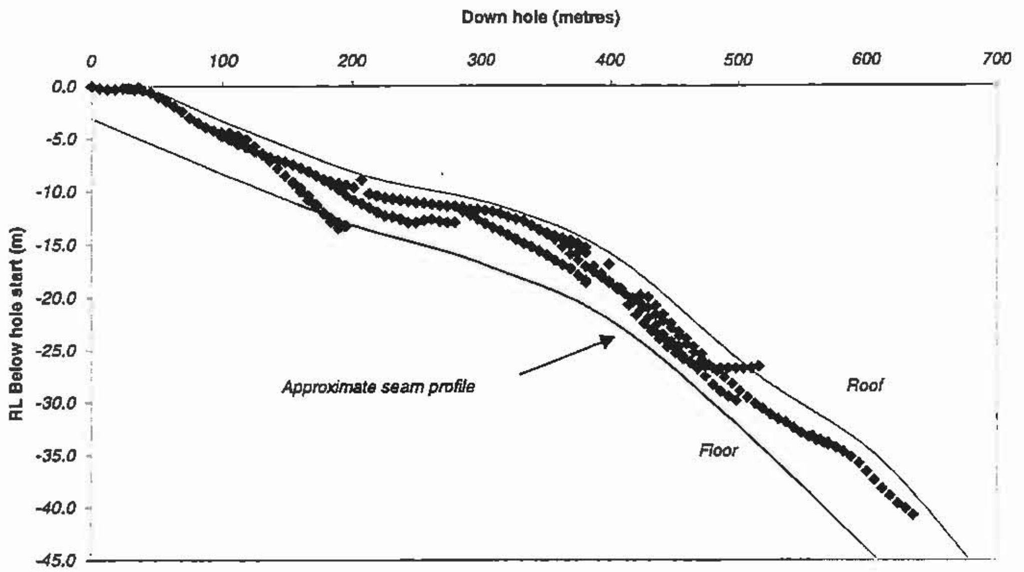

Figure 2
Exploration Borehole

2. THE EQUIPMENT

The environment in which drilling is undertaken in coal mines imposes severe restrictions on the type of drilling equipment being used. The main concern is the presence of coal dust and methane in confined spaces and the potential for an explosion. As a consequence all components have to be Mines Department approved for safe operations including a flameproof electric motor and starter (control box), no exposed aluminium components, methane monitor and automatic shut-off, fire resistant anti-static components, fire resistant hydraulic oil, and a Mines Department approved survey instrument.

The necessary modifications result in a safe drill rig which is heavier and more expensive than an equivalent rig utilised in surface or hard rock operations. A suitable underground gas drainage and exploration rig would have the following specifications:-

(i) 75 kW, 1000V hydraulic power unit to power the rig and the water pump,
(ii) 250 l/min @ 10 MPa high pressure pump,
(iii) 135 kN thrust and pull,
(iv) 1500 to 2000 Nm torque, NQ capacity rotation unit,
(v) track mounted,
(vi) compact enough to operate in a roadway and allow vehicles to pass.

TOOL LOSS – RECOVERY OR BUST

Although rotary open-hole drilling has traditionally been predominant, down-hole-motor drilling has become the major form of in-seam drilling in recent years. In-seam exploration drilling has also become more common with a need to better identify and define structures which would adversely affect the high levels of longwall production. This has created a need for longer directionally controlled boreholes with the increased use of down-hole-motors. Longer boreholes have meant higher strength rods, improved surveying techniques and higher capacity rigs.

Borehole depths with down-hole motor drilling has also been restricted by increased surging as the depth increased. For long-hole exploration, the bit diameter has been increased from 89 to 96mm with an increase in the size of the bend of the downhole motor from 1 to 1.25 degree to maintain the ability to climb. With the increased clearance, reduced surging and the use of more powerful downhole motors, borehole depths in excess of 1500m are possible.

The DDM MECCA (Downhole Drill Monitor utilising Modular Electrically Connected Cable Assembly) long-range communications systems gives an accurate reading of the survey point in less than five (5) seconds, enabling critical drilling progress decisions to be made with minimal interruption to the drilling cycle (Figure 2).

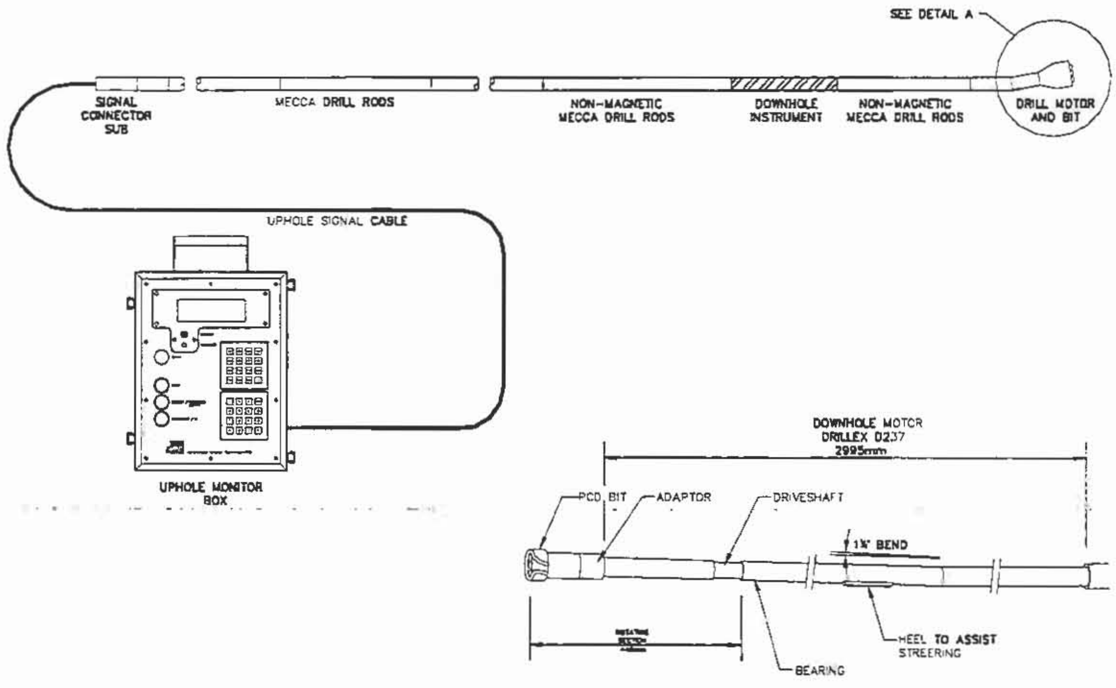

Figure 2 – Schematic survey tool configuration and downhole assembly.

This technology can also provide borehole placement accuracy to within 0.5 degrees while at the same time drilling more than 150m per shift.

3. THE RISK

Current retail cost of a 1000m drill string in Australia is approximately $40,000. Assuming that the electronic communication system known as MECCA is included, drill operators can budget for another $40,000. Downhole motors cost approximately $45,000, depending upon type and source. The electronic survey tool, usually a DDM MECCA, can cost up to $320,000. At risk down the hole is up to $445,000 of equipment.

The purpose of longhole directional drilling is to investigate for structure. When it is found, expensive equipment may potentially be lost. Drilling is acknowledged as a risky business, and the stakes are high for the drilling company, and the mine. Therefore the cost of information is expensive. Despite this, there is currently no more cost effective way to explore for geological information in-seam. The risk is borne because the information obtained is of such importance to the future of the mine.

Drilling contractors essentially absorb the risk, pay heavy insurance premiums and expect mining companies to accept a cost per metre that reflects the true cost of drilling. In-house drillers may cite apparently lower costs per metre to drill but invariably the risk and insurance factors are not considered. Generally, major mining companies do not insure for tool loss, but major capital cost dilemmas occur if equipment is irretrievably lost.

So how risky is the process? There are currently around 25-30 DDM MECCA electronic survey instruments in service world-wide, drilling approximately 500km/year. Since 1989 there have been three tools lost, never to be recovered (one at Moura, a pre-MECCA DDM – not drilling related, one at Tower and one at West Cliff).

This year there has, however, been three tools lost by leading contract drilling companies and, at time of writing, only one retrieved.

4. AVOIDING TOOL LOSS

The first step to avoid a potential financial disaster is to offer as much geological information to the drilling company as possible. The whereabouts of possible faults, dykes, seam rolls, shears, etc are important. Of course, if this was entirely known beforehand, why would you drill?

Successful directional drilling requires the driller to understand the geological environment. The key drilling operator must be aware if mylonite zones are likely to be encountered, whether swelling clays are present in the sequence, local stress parameters, and expected gas and water conditions.

From a geological perspective, the driller should be armed with this knowledge prior to job initiation. With this information on board, the geologists work is largely done and the operator now enters the realm of drill management.

The first and most obvious diagnostic of a potential problem area is lost water circulation. Water pressure gauges will rise and the driller has little time to react (probably 1-2 minutes at most). If drill bit rotation is lost, water flow must be cut immediately and the drill string should be retracted away from the potential problem area. Water flow must be reduced because fracturing the formation through drilling induced water pressure (if the coal is already sheared) will only exacerbate the situation.

Avoidance of a linear, near vertical structure in the path of the drill is difficult, if not impossible to avoid An alert driller will sense such a problem area, through the reaction of the drill to the formation. If trouble occurs, the driller will endeavour to maintain rotation by pulling back with the drill string and attempt to keep the cuttings moving. If the problem area is a claystone which has swelling properties there is no alternative but hasty retreat of the drill string.

If the bit and motor is jammed, excessive pull on the drill string will invariably result in rod failure under tensile strain. If this happens, the expensive components of the string (motor, survey tool) are lost, perhaps forever.

5. RECOVERY

The most effective retrieval method for a lost, expensive drill string is through the use of overcoring. This requires the purchase of a rod string, a rod size bigger than the rods that are lost. For example, if an NQ string is lost, HQ rods will be required. If BQ rods are lost, NQ rods will be required.

A specially designed reamer can be fitted onto the advance overcoring rod and a new hole created over the lost drill string. For a normal NQ string, hole diameter will be 89-96mm. Using a HQ overcoring system, a larger hole can then be created. If successful, the original string can be overcored and retrieved through the protective annulus created by the HQ rods.

The reaming device used by Valley Longwall Drilling was developed by Darrel Von Stanke. The tool varies from normal industry standard shoe bits and has proved highly effective in recovery exercises in NSW and Queensland.

Overcoring will only be successful if there are no major deviations in the drill hole. NQ rods have the ability to turn approximately 1.5°-2° in 6m whereas HQ rods can only turn 1° every 6m. A sharply deviating borehole offers little hope of successful recovery through overcoring. The natural "flip-flop" directional control mechanism used in directional drilling creates subtle bends which will impact on the ability of HQ rods to overcore. Frictional forces will build up, and, at depth, the exercise will be terminated due to the inability of the driller to rotate the HQ rods.

A lost survey tool down a branch from a survey hole offers particular challenges for retrieval. The sharper bends required for branching probably preclude successful overcoring, and the instrument may be irretrievable.

Recently, Valley Longwall Drilling Pty Limited carried out a successful overcoring exercise for a lost string at 642m in an underground mine in the Hunter Valley. The retrieval process took approximately one week to carry out. A similar exercise was carried out in excess of 400m to retrieve a downhole motor at Southern Colliery in Central Queensland by Darrel Von Stanke in the mid 1990's.

The Hunter Valley overcoring success was particularly noteworthy given the seam was dipping up to 5.6° away from the drill rig (see Figure 1). The stuck motor and survey tool were located at an RL over 40m below the rig, thereby increasing the tensile strain on the drill string and increasing the risk of the string parting on a joint outbye of the stuck instruments. The tool was retrieved and an additional five successful branches initiated off the main hole at the request of the mine.

6. CONCLUSIONS

Lost survey instrumentation, downhole motors and a drill string can spell economic disaster to drilling contractors and to a lesser extent, mining companies. Geologists have a role to play in foreshadowing the kinds of problems that drillers can expect to experience and ensuring that they are well acquainted with the risk prior to hole start-up.

After time, the fate of the equipment is in the hands of the driller who will require all the guile and experience that can be mustered to pre-empt a major loss. Prevention by fast reaction is much better than the cure of retrieval.

The most effective cure, overcoring, has its limitations but works well on relatively shallow non-deviated holes. The most successful overcoring exercise carried out to date in Australian underground coal mining was achieved by Valley Longwall Drilling (642m).

7. ACKNOWLEDGEMENTS

Darrel Von Stanke ("Roundy") of Valley Longwall Drilling pioneered the overcoring technique of tool recovery in underground coal mining at Central Queensland in the early-mid 1990's. His advice helped ensure the record overcoring retrieval exercise to 642m was a success. Chris Freer assisted by proof reading the paper and offering useful comments.

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HIGH RESOLUTION GROUND MAGNETICS AND DYKE DELINEATION IN THE HUNTER VALLEY

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Abstract

What percentage of coal mines in the Hunter Valley have basic dykes ? How many dykes are accurately delineated prior to mining ? What have these unexpected lithology's cost the community ? Is there a better way of defining such hazards to mining a priori ?

High resolution ground magnetics is a well proven, extremely cost effective, high-tech, low environmental impact way of mapping basic dykes, and, in limited cases faults and sills prior to exploration drilling and mining. The technique has the potential to save the coal industry millions of dollars especially in respect of longwall and pit design, geological hazard reduction and coal delivery scheduling.

Several recent ground magnetic surveys from the Hunter Valley coal industry will be presented as colour images and interpretations discussed.

Introduction

Mapping basic dykes and sills with magnetometers is not new - a survey was successfully conducted over 50 years ago in Boolaroo (Russell Rigby pers. com.). A few regional airborne magnetic surveys have been flown in recent times. These have tended to define more regional structures. The potential of high resolution ground magnetics has been, until recently, been sadly under utilised.

No longer. The last 3 years have seen a renaissance in magnetic survey work in the coal mining industry for several reasons, including :- presentation of data as colour images, geologists education in geophysics, advances in position control (GPS), and advances in magnetometers and PC for data processing. Ground surveys are also "clean & green" - a criterion of growing importance.

Data sets for the following areas are presented and discussed :-

- Bayswater Colliery, Saddlers Pit
- Marine Magnetic Survey, Southern Lake Macquarie
- An underground coal mine in the upper Hunter
- Southern Hunter Valley

Digital terrain models (DGPS) are collected at the same as time as magnetics with the aid of real time DGPS. Such DTM's can be useful for visualisation and interpretation of data including magnetics and air photography. It is not uncommon in the Upper Hunter for recent drainage to follow weathered dykes.

The colour images presented are available from the author or from Ultramag Geophysics web site :-

http://www.ultramag.com

Conclusions

High resolution ground magnetics is very effective in mapping basic dykes as thin as 1 meter, faulting cutting across magnetic lithology's and shallow silling in the Hunter Valley.

Such surveys provide the following advantages over aeromagetic surveys :-

- Detection of thin dykes (ie. sub 5m).
- Deeper detection of dykes.
- Better delineation of weathered dykes.
- More flexible - can undertake small survey areas as required.
- Quick data turn around time.

As society seeks to exploit coal reserves in more difficult geological conditions, high resolution ground magnetics will be utilised on a routine basis for coal project evaluation as well as during mining operations.

THE ROLE OF ACCOMMODATION SPACE IN NON-MARINE STRATIGRAPHY: CONTRASTING EXAMPLES FROM WESTERN CANADA AND EASTERN AUSTRALIA

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INTRODUCTION

Non-marine deposits are inherently difficult to analyze in terms of sequence stratigraphy because the dynamics of fluvial systems in response to relative sea level changes are much less clearly understood than the dynamics of corresponding marine systems (Posamentier & Vail, 1988; Westcott, 1993; Shanley & McCabe, 1994). Moreover, alluvial sections have a paucity of widespread internal features which can be used as chronostratigraphic markers, and therefore are difficult to subdivide into time stratigraphic units. As a result, a reliable sequence stratigraphic framework capable of predicting the organization and geometry of non-marine facies has remained elusive.

CONCEPTS OF ACCOMMODATION SPACE

Our approach to non-marine sequence stratigraphy is based on the fundamental concepts of variation in accommodation space caused by eustasy and tectonics and the sediment flux available to fill it. Accommodation (i.e. the space available for sediment to accumulate) varies in the non-marine environment just as it does in the marine realm, and the sediments deposited will reflect that variation by responses in such parameters as thickness, composition and geometry. A preliminary model for non-marine sequence stratigraphy (Fig. 1) indicates that a predictable organization and geometry of

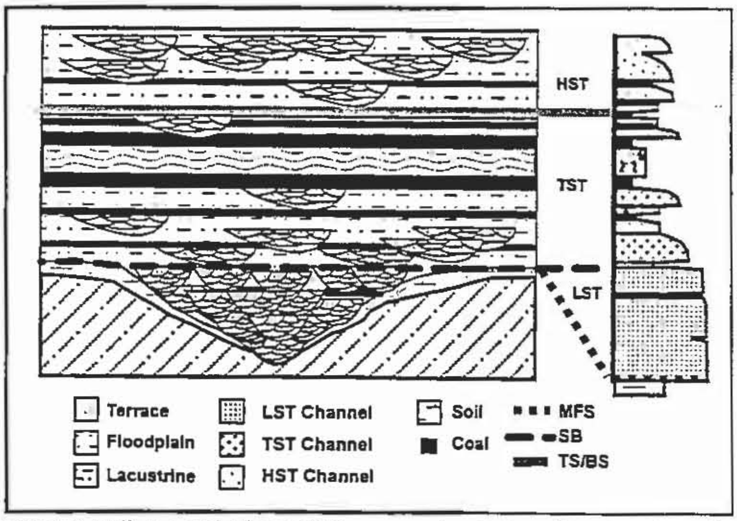

Figure 1. Prelimary model for predicting non-marine stratigraphic geometries and facies. Variations in accommodation result in characteristic fluvial geometries and coal thickness and composition. In our collaborative study we will develop this concept into an exploration model (from Boyd & Diessel, 1994).

lithofacies will result from a relative sea-level/accommodation cycle. Lowstand conditions, characterized by low accommodation, generate river terraces, incised valleys and soil profiles at the erosional sequence boundary (unconformity). Fluvial style here favours coarse-grained, amalgamated deposits formed in braided fluvial environments, and peat deposits are scarce. Increasing accommodation occurs during transgressive conditions, with a resulting change in depositional style. Incised valleys fill with estuarine, fluvial and marine deposits, and outside the valleys meandering to anastamosing fluvial sediments are deposited. Thick, widespread peats may develop, and if sediment supply cannot keep pace with accommodation then lacustrine conditions may result near the maximum flooding surface. During subsequent highstand conditions, accommodation decreases and the fluvial style changes to meandering fluvial deposits and thinner, more localised peat deposits.

APPROACH

The model outlined above suggests that coal-forming peat deposits may be good indicators of accommodation space in the non-marine environment. The key to applying sequence stratigraphy to peat and coal deposits is to examine the relationship between peat accumulation rates and rates of accommodation generation (Fig. 2). In order for peat to accumulate, the original organic production capacity must balance the space available below depositional base level (i.e. the water table). Data from Holocene peat-forming environments suggests that peats accumulate at rates ranging from 0.1 to more than 5 mm per year (Boyd & Diessel, 1994), primarily as a function of the climate under which the peat accumulated and is thus latitude dependent. This upper range of peat production exceeds the calculated accommodation rates generated by tectonic subsidence or eustatic rise (Gardner et al., 1978), suggesting that given optimum environmental conditions, peat production can fill virtually all accommodation space generated by changes in relative base level. Coal can form at any stage of the accommodation cycle, and is not necessarily confined to a particular position within a sequence stratigraphic framework, as has been previously suggested (e.g., Cross, 1988, Shanley & McCabe, 1994). However, we suggest that coal geometry, continuity, and geochemical properties are likely to vary as a function of their position within the accommodation cycle. By developing this predictive scheme for accommodation variations in coal, we believe we can move on to develop the first sequence stratigraphic model for coal. We can then use this approach to characterise a hierarchy of different coals in a sequence stratigraphic setting, from lowstand, transgressive and highstand system tract coals, to composite seams

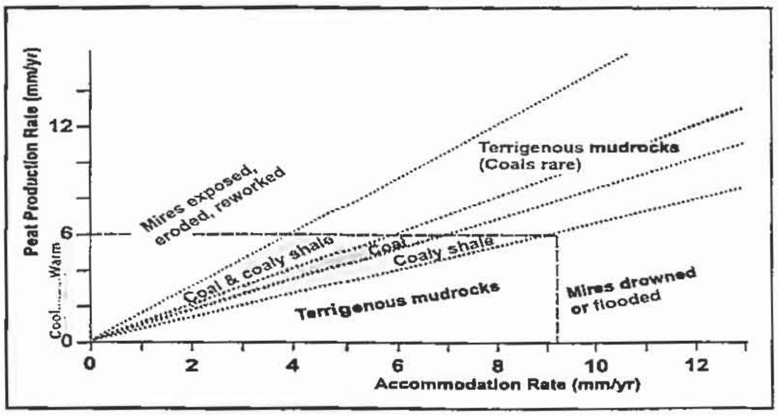

Figure 2. Relationship of peat production rate to accommodation rate. Ranges for major climate zones are indicated. If too little accommodation space is available, peat formation will be inhibited due to falling groundwater table, sediment bypassing, and fluvial erosion. With rising water table and increasing accommodation, mires develop and thrive. If accommodation space increases beyond the capacity of peat production rate to fill it, mires are stressed and eventually flooded or inundated by clastics (modified from Boyd & Diessel, 1994; Bohacs & Suter, 1997).

spanning a full sequence, and even composite seams spanning several sequences. We believe this approach to coal is a vital component of interpretation in non-marine sediments and forms the key to a sequence stratigraphic model in these settings.

FIELD EXAMPLES

We are currently developing a set of six field examples over a range of accommodation settings in the Western Canada Sedimentary Basin and the Sydney Basin (Fig. 3). These data are derived from a combination of outcrop study where possible, high-resolution subsurface correlations, core-logging, and existing studies. From this range we plan to synthesise a set of common principles that can be developed into a stratigraphic model. Our approach has concentrated on both clastic sedimentology and coal analysis, including compositional, petrographic and geochemical coal data. Examples 1 - 4 are from the Cretaceous Mannville Group in the Western Canadian Sedimentary Basin. Examples 5 - 6 are from the Permian Coal Measures in the northern Sydney Basin.

1) The Lloydminster Formation in the Lloydminster area is located in a trough between two Paleozoic highs near the cratonic margin of the foreland basin, and represents a low accommodation regime. The style of sedimentation here is confined mostly to large, mainly composite, incised valley complexes with thin regional units (5-10 m thick) between sequence boundaries outside the valleys (P. Elliott, pers. comm). Coals often overlie sequence boundaries which are characterised by extensive soil horizons on valley

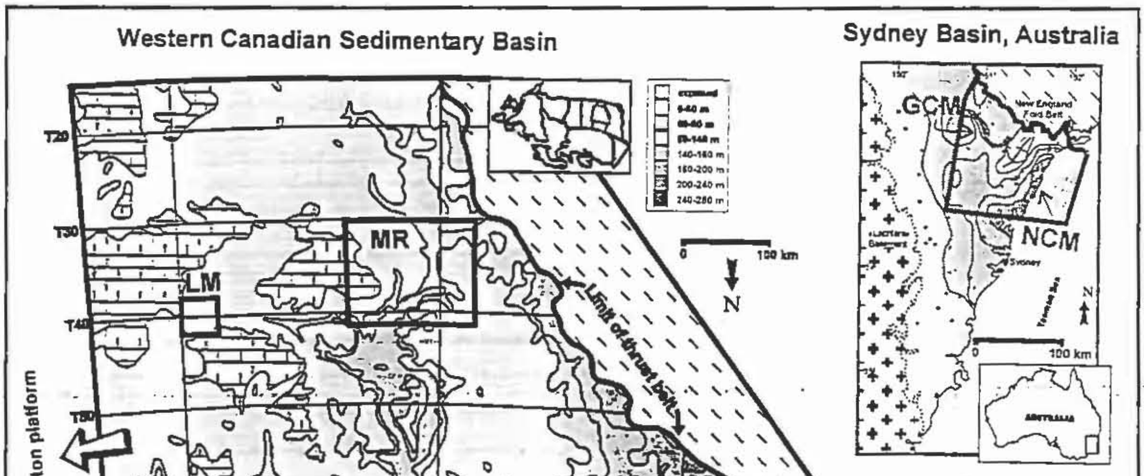

Figure 3. Location of six study areas in the Sydney Basin, Australia and the Western Canada Sedimentary Basin. For ease of comparison, both basins have been depicted at the same scale, and the WCSB is turned "upside down" so that the thrust belts and cratonic platforms of both foreland basins are in the same relative positions. Isopachs in the WCSB are of the Mannville Group transgressive package, from the Paleozoic carbonate basal unconformity to a regional MFS (modified from Cant and Abrahamson, 1994). Isopachs in the Sydney Basin are of the Upper Coal Measures. Although not directly comparable, these two isopach maps provide a good sense of the regional subsidence (and accommodation) patterns (from Brakel, 1989).

interfluves. Regional correlation shows a broad pattern of progradation at low angles with downlap surfaces and basinward splits in the coal seams. Coal analysis reveals that coals have a complex accommodation signature, indicating a composite nature. These coal seams are diachronous as they develop during the overall regression and include transgressive components, but also contain multiple transgressive/regressive cycles.

2) The Glauconite and Upper Mannville Formations in the Medicine River area (Fig.3) occurs in the central foreland basin adjacent to a Paleozoic carbonate high, and represents a relatively low to intermediate accommodation setting. The sedimentary package comprises a 100-200 m thick unit of multiple sequences characterised by an overall regressive trend from shoreface to brackish to non-marine deposits (Rosenthal, 1988). Incised valleys occur throughout and are 25-50 m thick, with both fine-grained and coarse fill. Multiple coal horizons are present, and occur mainly as thin (<1 m) single seams (both continuous and discontinuous) in the lower transitional/ brackish part of the succession, and mainly as moderately thick to thick (1 - 8 m) single or composite seams in the upper non-marine part (Fig. 4). The development of incised valleys in the units between coal splits suggests that the composite coals represent amalgamated transgressive/regressive cycles, similar to the Lloydminster example.

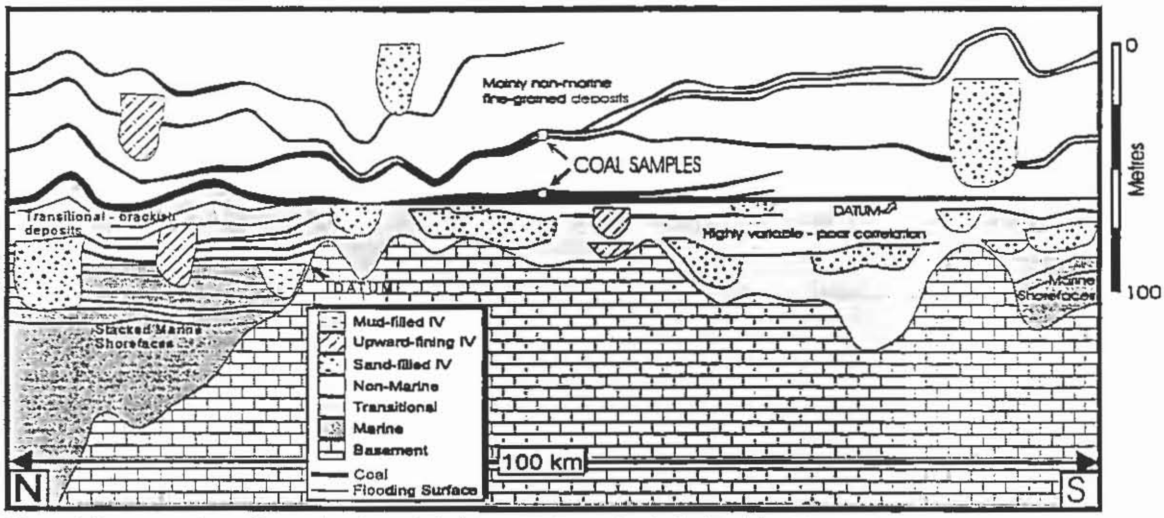

Figure 4. Representative strike section through the Mannville Formation in the Medicine River area, with an overall regressive trend from marine to non-marine deposits. The carbonate paleotopography strongly influences deposition: marine cycles onlap onto it, transitional/brackish deposits converge on top of it, and non-marine split coal seams appear to merge above it. Note location of coal samples. The upper sample spans a composite coal which splits into five coals to the south, with two of the lower coals apparently spanning a thick incised valley deposit. See coal analysis presented in Figure 6.

3) The Falher Member of the Spirit River Formation in the Elmworth area (Fig. 3) occurs in an intermediate accommodation space setting near the Cordilleran thrust belt. The sedimentation style is aggradational and consists of five stacked shoreface parasequences, each approximately 30 - 80 m thick and associated with an updip fluvial and coal package (Cant, 1983; Rouble & Walker, 1997). Individual coal seams are continuous over 40 - 60 km, thin basinward (from 2 - 4 m thickness, to < 1 m thickness), and show only minor splitting (Fig. 5). No incised valleys are recognized.

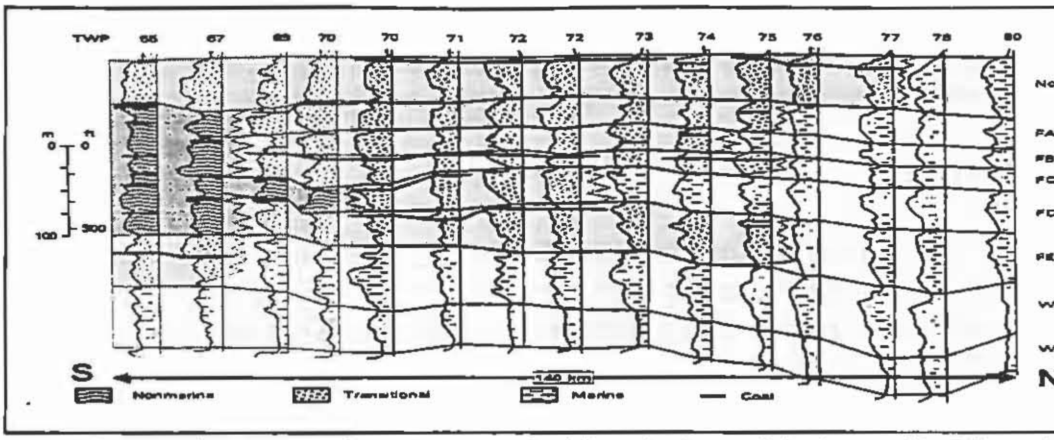

Figure 5. Representative dip cross-section (with gamma ray logs) illustrating the aggradational nature of the Falher cycles (labeled FA through FE). North is basinward. Each cycle typically comprises a shallowing-upwards succession of marine, transitional (interbedded marine and non-marine), and non-marine, coal-bearing sediments. Landward the cycles converge and the coals thicken; basinward the cycles tend to break up and coals thin and disappear (from Cant, 1983).

4) The Gates Formation in the Bullmoose/Tumbler Ridge area (Fig. 3) is developed in an intermediate to high accommodation regime adjacent to the thrust belt. The Gates Formation is interpreted to be the lateral equivalent of the subsurface Falher Formation (Carmichael, 1974; Leckie and Walker, 1982), and consists of at least five coarsening-upwards marine to non-marine, coal-bearing parasequences forming a 350 - 450 m thick aggradational package. Coals seams are thick (max 10 m) and laterally extensive in the lower units, and are thinner (<1 m) in the upper units. No incised valleys are recognized.

5) The Greta Coal Measures (GCM) consist of two non-marine wedges deposited in a high accommodation setting at the base of an Early Permian thrust zone on the northern margin of the Sydney Basin (Fig. 3). Only the lower of the wedges is found in the lower Hunter valley (63-70 m thick), while both wedges are found in the Muswellbrook area of the upper Hunter Valley (average 200 m thick). In the Muswellbrook area the wedges are separated by a marine incursion which flooded as far inland as the Savoy region. In the lower Hunter area the lower wedge of the GCM is primarily a polymictic conglomerate and a mire, whereas in the upper Hunter it is a fine-grained clastic unit (Van Heeswijck, 1997). The upper wedge contains mainly coals and fine-grained clastics. The coals are commonly split in a complex pattern and may have a transition at the top to cannel coal, indicating a drowning of the mire. Overall, both wedges initially prograded then aggraded and were eventually transgressed, by estuarine deposits of the Ayrdale Sandstone in the case of the lower wedge, and by marine deposits of the Maitland Group in the upper wedge.

6) The Newcastle Coal Measures (NCM) of the northeastern Sydney Basin are set in a high accommodation, tectonically active regime adjacent to the New England thrust belt (Fig. 3). The NCM comprise a 410 m thick unit of interbedded fluvial and floodplain sediments, tuffs, and coal (approx 18% of total succession). The coals show a broad change from brighter at the base of the succession to duller at the top, but otherwise show no systematic change in thickness or continuity. Coal thickness is variable throughout (<1 m to 10 m). No sequence boundaries or incised valleys are recognized by us, but the tuffs can be used as time markers. The succession is characterised by an overall coarsening upwards of fluvial systems, probably reflecting tectonically-driven sediment supply. Almost all coal

seams are split, frequently by sheet-like tuffs (<0.1 m to 25 m) or fluvial clastic material. Due to the high accommodation available, the peat mires are interpreted to have aggraded contemporaneously with adjacent clastic deposits such as thick fluvial conglomerates.

COAL ANALYSIS

A critical part of our research group's collaborative effort has been to determine the sequence stratigraphic signature of coal. Coal samples have been obtained from various seams in each of the six study areas outlined in the previous section, and are currently being analysed in terms of their compositional, petrographic and geochemical nature. One aspect of this coal analysis is to identify evidence of increasing or decreasing accommodation space at the time of peat deposition, and to compare this signature with the stratigraphic framework established by independent correlations. Table 1 summarises the characteristics associated with coals formed in different accommodation settings.

An example of the level of detail provided by coal analysis is shown in Fig. 6. A suite of samples were obtained from a thick coal in the Medicine River area (upper sample, Fig. 4), interpreted to be a composite coal with multiple cycles of accommodation, as indicated by the occurrence of incised valleys contained between the coal splits. Coal analysis reveals a similar complexity in the petrographical signature. Eleven distinctive intervals can be recognized in the coal, and are grouped into 4 cycles (1-5; 6-8; 9; 10-11). Each cycle is capped by an influx of inorganic material (% Total Mineral column) which represents drowning of the peat. The thickest of the beds of inorganic material (interval 8) corresponds to a split in the coal which expands dramatically to the south. Contained within the split is a 50 metre thick incised valley, indicating the presence of a sequence boundary. The expression of this sequence boundary in the coal is not obvious; its detection may require further analysis, or it may be so thin that it was not sampled, or else it may have been removed by flooding. A lower flooding of the peat (interval 5) probably correlates to a smaller coal split which occurs south of the incised valley. The flooding event identified at the top of interval 9 correlates to one of the coal splits above the incised valley.

Table 1. Coal Characteristics for Different Accommodation/Peat Production Ratios

Increasing accommodation up to balanced conditions (accomm. > production accomm. = production)	• Underlain by soil profile and/or root horizon. • Upward increase in fluorescence, vitrinite and sulphur content, H/C ratios, hypautochthonous and allochthonous components, volatile matter • Upward decrease in reflectance, ash content • Overall brightening up trend as peat growth matches accommodation
Flooding of peat (accomm. >> production)	• Suppressed vitrinite reflectance, increase in fluorescence and sulphur content • Dulling up trend as peat is flooded • Increasing ash due to influx of adventitious inorganics • Peat overlain by lacustrine or marine roof rocks, transported macerals, limestone deposition, sapropelic coal, bioturbation
Decreasing accommodation (accomm. < production)	• Dulling up trend as peat growth exceeds accommodation and stops • Upward decrease in fluorescence, sulphur content • Upward increase in reflectance • Slightly increasing ash due to concentration of inherent inorganics
Peat exposure (accomm. << production)	• Low groundwater conditions and/or exposure, indicated by peat oxidation and deterioration or erosion • Very high ash level due to concentration of organics • Coals may correlate with sequence boundary, and/or incised valleys

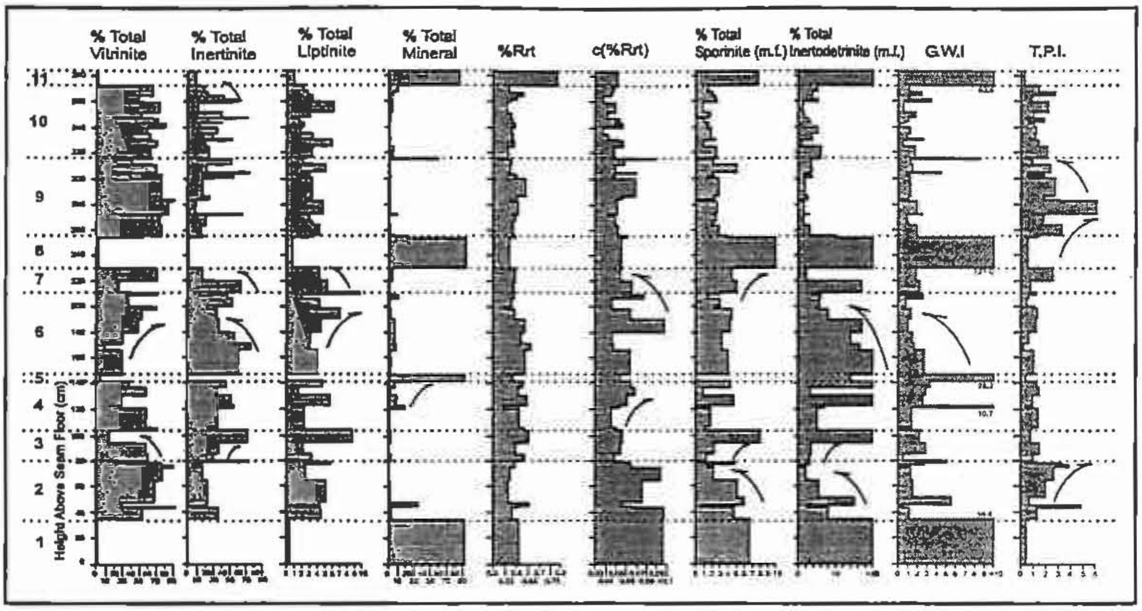

Figure 6. Coal quality downhole trends for the upper seam in borehole 16-4-36-20W4 (Medicine River area, Canada). **Interval 1:** Seat earth. **Interval 2:** Increase in structured vitrinite (autochthonous) - raised mire. **Interval 3:** Decrease in vitrinite reflectance, coefficient of variation [c(%Rrt)] of vitrinite reflectance remains low, lack of minerals - all suggest oxidation phase. Slightly dry raised mire. **Interval 4:** High vitrinite, very low mineral content, moderate inertinite, low [c(%Rrt)], low dispersal sporinite and inertodetrinite suggests normal raised-mire. In upper portion signs of increasing accomodation-tendency to increase minerals and dispersed sporinite and inertodetrinite, vitrinite passes through a low then increases, so does [c(%Rrt)]. **Interval 5:** Flooding of mire (high mineral content). **Interval 6:** Increasing vitrinite content suggests thriving raised-mire conditions. **Interval 7:** Brief initial phase of increase in accommodation (high dispersed sporinite and inertodetrinite but low mineral content indicate localised event without influx of external minerals=hypautochthonous), then balanced accommodation/accumulation returns. **Interval 8:** Dispersal indicators are high = extensive flooding. **Interval 9:** Well balanced raised-mire conditions (high vitrinite, low minerals). Pulses of high inertinite might indicate forest fires (= fusain bands). Slight decline in vitrinite content and TPI indicate unstable conditions upwards. Capped by brief inundation. **Interval 10:** Raised mire conditions still balanced but increasing mineral content heralds change to limnotelmatic mire. **Interval 1:** Influx of minerals, other dispersal indicators suggests drowning of peat.

SUMMARY

Our research has focused on the stratigraphy and coal analysis of a number of contrasting coal-bearing successions developed under a range of accommodation settings. Our studies are still in progress and so we can provide no conclusive results as yet. However, sufficient analyses have been completed to offer some preliminary insights concerning sedimentation style and coal development in different accommodation regimes. In the following year we aim to finalise and integrate the stratigraphic and coal analysis for each of the study areas, with the final aim of developing a comprehensive model for non-marine sequence stratigraphy.

Low Accommodation (Lloydminster and Medicine River areas). The accommodation does not provide much space between successive cycles, and sediment supply exceeds the rate of accommodation generation. The resulting stratigraphic style is characterised by multiple unconformities, relatively thin regional packages, abundant deep (and often composite) incised valleys, and a wide range of coal geometries. Coals are thin to relatively thick, patchy to widespread, simple to composite. The composite coals are the most significant component, and may represent several cycles of accommodation.

Intermediate Accommodation (Falher Member and Gates Formations). In both these examples, accommodation is balanced by sediment supply resulting in an aggradational style of stacked shoreline sequences, each associated with an updip fluvial and coal package. Coals are laterally extensive, relatively thin and splitting is minor. No incised valleys or composite coals are recognized.

High Accommodation (Greta and Newcastle Coal Measures). Rate of accommodation generation and rate of sediment supply are both very high, due to proximity of the active thrust margin. There is a contrast between these examples in which sediment supply exceeds accommodation (NCM and lower GCM) and accommodation exceeds sediment supply (upper GCM). In the case of the NCM, the sedimentation style is characterized by a uniform succession of rapidly aggraded fluvial deposits and peat mires. No sequence boundaries or incised valleys are recognized. Coals are abundant, locally thick, and often show a complex pattern of splitting. The coal splits are interpreted to represent the effects of contemporaneous fluvial deposition, rather than composite accommodation cycles. The GCM are regionally more variable than the NCM, comprising two full sequences and a number of relatively thick, uniform coals in each sequence.

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RECENT COAL EXPLORATION IN THE NORTHERN NEWCASTLE COALFIELDS

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OVERVIEW

Over the past two years Wootmac Consulting has undertaken the exploration of two prospective coal deposits within the Lower Hunter Valley of N.S.W., both of which have been previously rejected as viable mining developments. The first is the Donaldson Coal Project (EL5071), which is located in the Thornton area and covers part of the former proposed Ironbark Colliery. Exploration and development of a geological model and proposed mine plan is in the final stages. The preliminary geological and coal resource data was gained from exploration by R.W. Miller & Company Pty. Ltd. The stratigraphic interval with the most potential for mining at Donaldson is the sequence from the Ashtonfield to Beresfield seams of the Tomago Coal Measures. It is currently proposed to be mined by open cut methods utilizing truck/shovel techniques. The second deposit is the O'Donnell project (EL5337) which is held by Newcastle Coal Company. It is located in the Mt Sugarloaf /O'Donnelltown vicinity. This project is at preliminary drilling and exploration stage. The exploration is targeted to define the coal seam continuity, quality and mining potential of the Fassifern seam. The coal is proposed to be extracted using underground techniques.

LOCATION

The Donaldson Project area is located near the intersection of John Renshaw Drive and Weakleys Drive which is the northern extremity of the Sydney/Newcastle expressway. The O'Donnell project is located at Mt Sugarloaf, west of the Sydney/Newcastle Expressway (Figure 1) and forms part of the former Strockrington No.2 Colliery Holding.

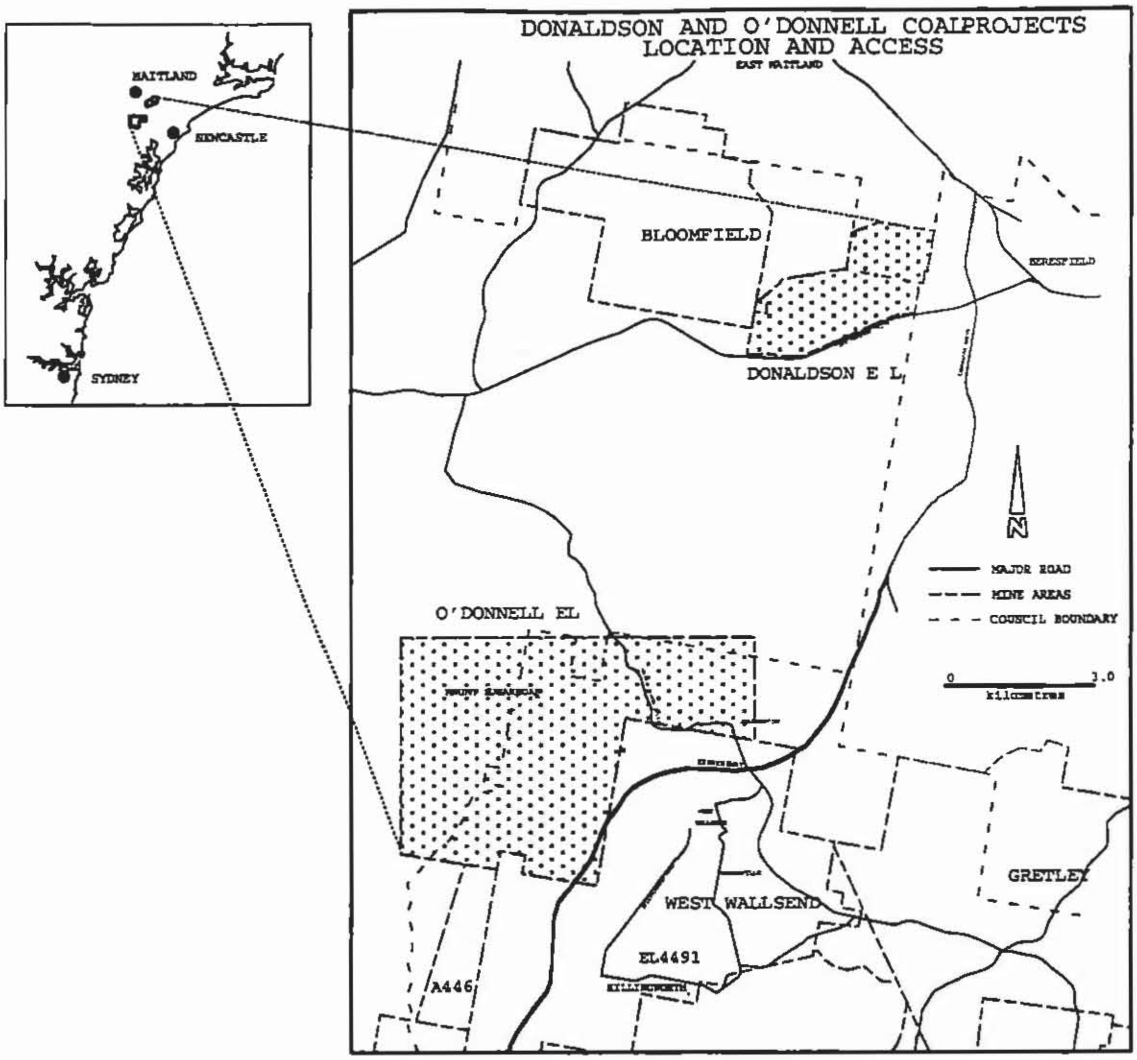

Figure 1 : Location of Donaldson and O'Donnell coal projects

MINING HISTORY

Donaldson

The Donaldson area has a long history of coal extraction utilizing underground and open cut methods. The first recorded mining dates back to 1830 at Stockrington No.2 Colliery which mined the West Borehole seam of the Newcastle Coal Measures. Four Mile Creek and Shamrock Hill were also operational into the early 1900's. Underground mines which were developed in the 1900's include Hartley, Woodfall and Kent Collieries which mined the Donaldson and Big Ben seams of the Tomago Coal Measures. All collieries had ceased operations by 1959. Most of the development of the Tomago Coal Measures was in the western part of the region with a series of open cut operations of which only Bloomfield Colliery remains. There were also a number of mines operating around Black Hill, working the West Borehole seam which is the basal seam of the Newcastle Coal Measures. These include Hilltop, Mountain, Black Hill, Rosewood, and Taylors.

O'Donnell

In the Mount Sugarloaf area there were several small underground mines working the Borehole seam. Of these Stockrington No. 2 Colliery ceased operations in the early nineteen seventies. Mt Sugarloaf mine was an underground mine which extracted coal from the Great Northern Seam. It was operational from 1949 to the early 1980's.

EXPLORATION HISTORY

Donaldson

Exploration in the Donaldson area commenced with a steam driven fully cored borehole in 1885. By 1915 only seven holes had been completed with 20 boreholes recorded by 1933. These early exploration activities cannot be located with enough accuracy to be considered a reliable data source.

R.W.Miller gained exploration title of the area in 1933 and conducted a number of exploration programmes. The exploration lead to a feasibility study of the Ironbark project which consisted of both open cut and underground mining proposals.

O'Donnell

Joint Coal Board records indicate that there are several previously drilled boreholes around the O'Donnell area. These were drilled by Stockrington No.2 colliery but only two holes intersected the Fassifern seam.

GEOLOGY

Donaldson

The Donaldson coal resource lies within the Tomago Coal Measures. The seams which subcrop in the area include the Beresfield, Donaldson, Big Ben, Buchanan and Ashtonfield. The seams were divided into 20 plys labeled from A through T, which split and coalesce throughout the area (Figure 2). The sequence dips to the northeast and then south over the Four Mile Creek anticline. The coals are of high volatile bituminous rank capable of yielding moderate ash steam and coking coals of high quality. The sediments are from the Four Mile Creek formation and consist of sandstones , shales, coals, siltstones, mudstones and claystones. A typical stratigraphic column in figure 3 below shows the coal seams of interest.

O'Donnell

The O'Donnell exploration area lies within the Newcastle Coal Measures. The Great Northern, Fassifern and the West Borehole seams subcrop within the area. The Fassifern seam is of interest as a potential mining section. It lies within the Boolaroo Formation which is overlain by the Awaba Tuff Formation. The seam is approximately 5.0 m thick and has a working section of approximately 2.3 m which is a potential underground resource. It strikes north east and dips into the Macquarie syncline.

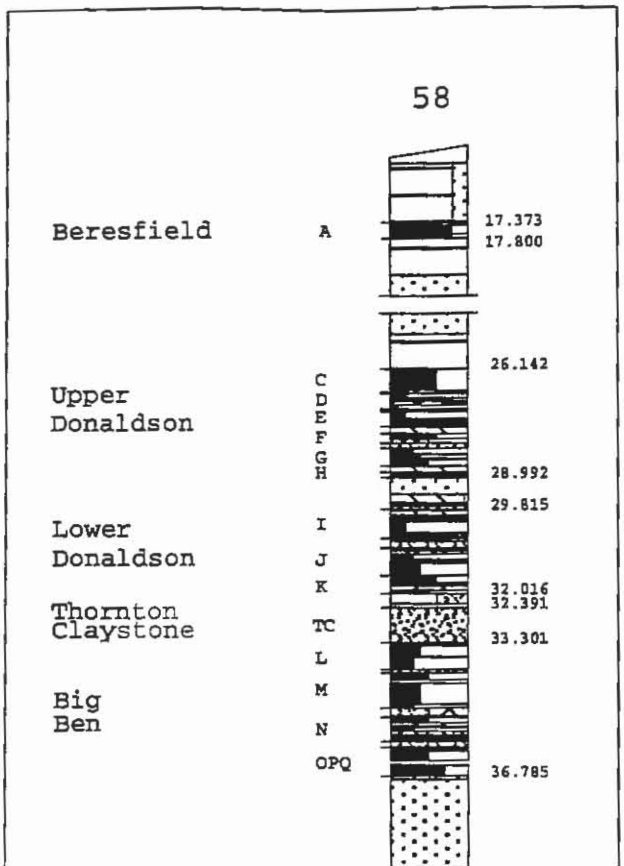

Figure 3

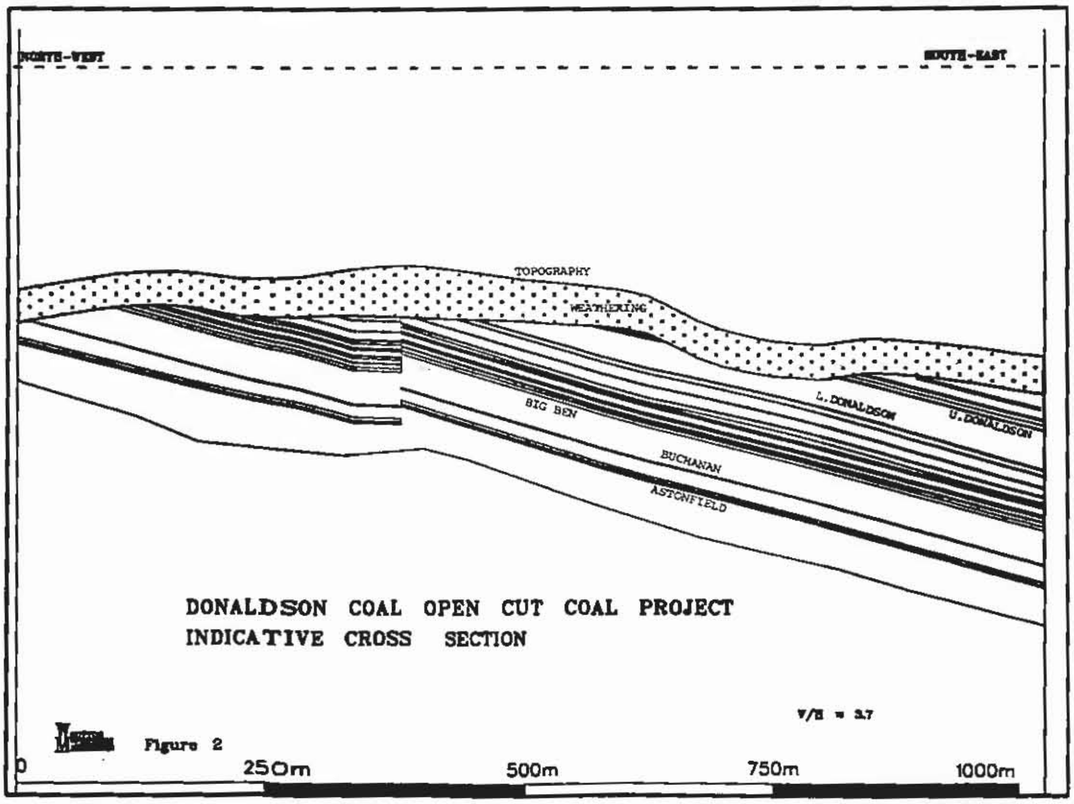

Figure 2

CURRENT EXPLORATION

Titles

To maintain an exploration license Donaldson and O'Donnell projects must honour the conditions of authority 1992. This includes strict conditions governing Exploration Activities, Drilling, Bulk Sampling, Reporting, Environment, Rehabilitation, Public reserves, Private property, roads, Archaeological sites, Inspectors, Royalties Project management and Community Liaison.

Drilling & Sampling

Donaldson

R.W.Miller undertook extensive drilling within the exploration area during their feasibility study of the Ironbark project in the early ninteen eighties. Further drilling was conducted by Wootmac Consulting for the purposes of hydrogeological assessment and to acquire additional stratigraphic and coal quality information. A total of 13 holes was drilled by Wootmac Consulting of which four were fully cored and nine were open hole. The four cored holes were drilled through the sequence from the Beresfield seam to below the Big Ben seam. Samples were taken from the coal and interseam sediments for coal quality assessment and geotechnical testing. Piezometers were installed in each of the 13 bore holes to monitor groundwater levels.

O'Donnell

The terrain around Mt Sugarloaf is very steep and rugged which limited access to potential drill sites. Initially drilling began in the southwestern area where there was little available geological information. Three open boreholes were drilled with one successfully intersecting the Fassifern seam. More drilling is planned for the area to further delineate coal seam continuity, quality and quantity.

Geophysics

Donaldson

All of the 13 recent holes were geophysically logged using a full suite of slimline downhole tools including full waveform sonic and acoustic scanner sondes. The geophysical logs were downloaded and interpreted in an inhouse program C-LOG. The program provides a plot of the various logging parameters with a graphical lithological interpretation including coal brightness. Interpretation of acoustic scanner data provides information on the orientation and characteristics of bedding, joints and faults. Interpretation of full waveform sonic provides information on the mechanical properties of the rock mass. The geophysical logs of four fully cored boreholes were compared to those drilled nearby by R.W. Miller. In all cases the interpreted logs indicated an increase in coal thickness of each seam.

O'Donnell

The hole within the O'Donnell area which intersected the Fassifern Seam was also geophysically logged using a full suite of tools including full wave sonic and acoustic scanner. This enabled accurate identification of the seam, seam splitting and seam thickness.

Model

Donaldson

All available geological logs and coal quality analysis from R.W.Miller was entered into the computer database. This included all survey, lithological, geotechnical and analytical data from 73 fully cored bore holes in the area covered by, and within 500m of EL5071. From this a preliminary layer cake model was produced using Vulcan software. The lithological logs and coal quality data from the recent drilling were added to the data base and the model was updated. Cross sections of bore holes were created to verify seam splitting, ply and coal working section correlation. Coal seam thickness and structure were modeled as was relative density, insitu ash and cumulative floats 160 yield and ash. These analytical parameters are all on an air-dried basis.

Proposed mining will be undertaken in two pits (figure 4). The northern pit will mine the plys from A through to O which include the Beresfield to the Big Ben seams. The western pit is only planned to extract plys A through to K, which includes the seams from the Beresfield to the Lower Donaldson. The quality of the bottom four plys of the Big Ben seam place them outside the economic envelope for development.

The total insitu coal resource is estimated at 19,000,000 tonnes ROM. With a product yield estimated at approximately 11,000,000 tonnes .

O'Donnell

A preliminary model for the area was produced using recent drilling and previous borehole data. The resource was modelled using four boreholes, which intersected the Fassifern Seam and the structure of the Great Northern and West Borehole seams. The modelling process is ongoing and will be updated when more data is available.

Mine Planning

Donaldson mine design is limited significantly by environmental, geological and geographical constraints. For extraction the resource has been divided into two pits separated by a Hunter Water Corporation main water supply surface pipeline. The northern pit is limited to the north by Scotch Dairy Creek and to the east and south by Weakleys Drive and John Renshaw Drive respectively. A buffer zone of at least one kilometre was designed to minimize any impact on residents living along Weakleys Drive. The western pit is limited by the line of oxidation to the west, the water pipe to the east and John Renshaw Drive to the south.

It is proposed that mining commence in the north end of the northern pit. The overburden will be dumped externally for the first two years by which time full extraction will have taken place sufficiently to allow in pit dumping to follow. Rehabilitation and revegetation of the external dump will also begin after the first two years. Donaldson mine is planned to operate over a period of nine years including its construction. The primary consideration is to produce coal of 14% ash quality at a rate of 1.5 million tonnes per year.

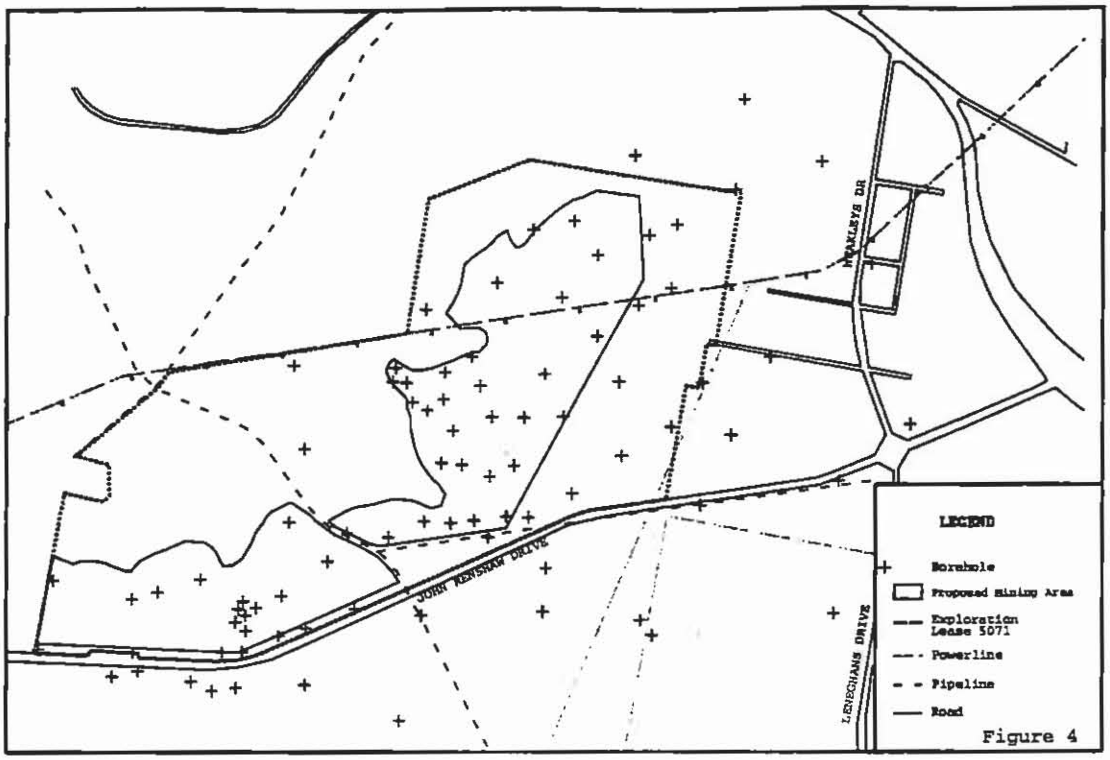

Figure 4

COMMUNITY LIAISON

Donaldson

A Donaldson Projects office was established in Beresfield to inform the community of the exploration and any future project development. A community liaison committee, which is chaired by a government appointed person meets once a month to address the points of view , any concerns and opinions of local residents, mine proponents, various government departments, state bodies and workers unions.

O'Donnell

The project is at the preliminary stages at present but it is planned that a community liaison committee with a government appointed chairperson will be set up in due time.

ENVIRONMENTAL

The Donaldson exploration programme has been significantly influenced by environmental and geographical factors. This led to the development of an Environmental Impact Statement (EIS) produced by independent consultants. The EIS covered air quality, noise, vibration, water, soil erosion, soil stability, flora, fauna, heritage, agricultural, social and economic issues. As the relative proximity of the Donaldson Project to the surrounding community was a primary concern, a number of monitoring tasks were identified and carried out in the early stages. These included baseline studies of noise, air quality, visual, flora, fauna and water. A thorough literature review of all available published works, unpublished works and completed environmental impact statements was carried out. These studies and surveys, combined where possible with computer modeling were used to accurately determine the environmental impacts of the proposed mine.

CONCLUSIONS

There are still areas of reassessment and exploration of potential coal resources in the Lower Hunter Valley.

Old and small areas can be assessed and modelled for potential coal resource development before sterilization by urban development.

Proper geological planning involves , desk studies of old data, new drilling and the use of modern technology including accurate geological interpretation, geophysical data and computer modelling.

There is a need to adopt an interactive approach with the community and statutory agencies to identify environmental issues and performance expectations at early stages of mine project development.

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DISTRIBUTION OF THE SYDNEY SUBGROUP, SOUTHWESTERN MARGIN OF THE SYDNEY BASIN

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INTRODUCTION

The southern Sydney Basin has long been a major producer of prime coking coal and many studies have been directed at the stratigraphy and general geology of the region, especially the economic units of the Sydney Subgroup in the Southern Coalfield. However, the distribution and nature of the units are not well understood along the southwestern margin of the Southern Coalfield where the absence of the economically important Bulli Coal has not been adequately explained by previous studies.

Hanlon (1956) was one of the first to briefly described the distribution and characteristics of the coal units of the Illawarra Coal Measures and the relationship between structure and sedimentary patterns was discussed by Wilson *et al.* (1958), Wilson (1969 & 1975), Cook (1969), Bunny (1972) and most recently Mullard *et al.* (1996). All studies noted the relationship between various structures and the Bulli Coal. The significance of these works was that regional structures were to thought to have influenced the sedimentation patterns in the Sydney Basin.

Amongst the first workers to propose a fluvio-deltaic origin for the Illawarra Coal Measures were Bunny (1972) and Bowman (1980). Unfortunately their work was restricted to the eastern portion of the Southern Coalfield. Later, Bamberry (1992) used facies analysis to interpret the depositional environments of the Illawarra Coal Measures within the Southern Coalfield. Using drill core and outcrop data, Bamberry identified six depositional systems; four of these systems covered the Sydney Subgroup. The environments of deposition ranged from braided fluvial to floodplain and shore-zone systems. Bamberry's study was very extensive. However, like most earlier studies, the marginal areas of the coalfield did not receive a lot of attention.

Sims (1996) attempted to redress the lack of study in the marginal areas and examined drill cores from the Robertson area of the coalfield. Depositional environments and lateral variations were discussed. However the study was restricted to the southeastern part of the coalfield and was centred approximately 40 km from the margin to the south and southwest. Variations toward the west and southwest were not considered and these areas remained largely undefined in terms of depositional environments and distribution of the units. Clark (1992) and Sims (1996) both proposed that the Bulli Coal was absent because it had not been deposited rather than it had been eroded.

STRATIGRAPHY

In this study, it was necessary to establish the stratigraphy of the Sydney Subgroup before the geological history of the area could be discussed. Along the margins of many basins, coal seams thin and change character, compared to the centre of the basins, thus making it difficult to correctly identify respective seams. Accurately tracing units across the basin, allows lateral variations in any unit to be observed. However, in the case of the southwestern margin of the Sydney Basin this was often difficult due to the thin, commonly discontinuous nature of some units and wide spacing between drill holes.

Bamberry (1992) and Armstrong *et al.* (1996; Table 1; Fig. 1) argued the need for revision of the stratigraphic nomenclature of the Southern Coalfield and proposed numerous revisions. The Southern Coalfield Subcomittee of the Standing Committee on Coalfield Geology (SCCG) accepted many of Bamberry's proposed changes and added others. These are now being prepared for publication. The stratigraphic nomenclature used in this study takes advantage of these proposed revisions, but also proposes others, as the stratigraphy of the southwestern part of the Southern Coalfield is markedly different to the central area.

This study recommends the following modifications to the stratigraphy, especially as to the distribution of units, of the Illawarra Coal Measures in the southern Sydney Basin:

- the definition of the Kembla Sandstone should be modified to include the disconformable upper contact with the Hawkesbury Sandstone in the Sutton Forest area.
- the definition of the Wongawilli seam should be broadened to include a clastic interseam unit found in the Sutton Forest area.
- the definition of the Eckersley Formation should be modified to account for the upper boundary with the Balgownie Coal, and the fining-upward character of the unit, over much of the study area.
- the definition of the Balgownie Coal needs to be modified to account for the distribution of the unit which is much farther south than previously defined; it must also account for the erosional contact with the Hawkesbury Sandstone along the southwestern margin of the unit.
- the definition of the Loddon Sandstone needs to be modified to account for the occurrence of the unit farther to the south than previously defined.
- the definition of the Bulli Coal should be modified to account for its distribution which is further to the north than previously defined.

STRUCTURAL AND SEDIMENTARY RELATIONSHIPS

In order to better understand the structural elements in the southwestern marginal areas of the Sydney Basin, a contour map of the top of the Wongawilli Coal was constructed; this was used as a datum surface for all cross-sections. The Wongawilli Coal (Fig. 2) was chosen because of its widespread distribution, ease of recognition and subhorizontal nature at the time of deposition. Subsequent erosion, while having some affect, was not seen to be very significant. The structure contour map of the top of the Wongawilli Coal (Fig. 3) mirrors two major and distinctive features - the Mount Murray Monocline and an northeast trending syncline. These two features had a major influence on the deposition distribution of the post Wongawilli Sydney Subgroup units.

In the northern part of Berrima Colliery, the Eckersley Formation and Balgownie Coal are above the Wongawilli Coal whereas in the southern part of the Colliery, and in the centre of the study area, the Hawkesbury Sandstone disconformably overlies the Wongawilli Coal. The southern limits of the Eckersley Formation, Balgownie Coal and Loddon Sandstone coincide with an arcuate disconformity at the base of the Hawkesbury Sandstone. It is proposed that the northeast trending synclinal structure in the centre of the study area formed a palaeovalley that controlled the river system that deposited the Hawkesbury Sandstone. In the southern part of the area where the Sydney Subgroup was thinnest, the Hawkesbury Sandstone overlies the Wongawilli Coal and towards the north, as the units of the Sydney Subgroup thicken toward the depocentre of the basin, the Hawkesbury Sandstone overlies stratigraphically higher units, such as the Balgownie Coal as in the Berrima area.

The most important observation made in the course of the study was the correlation between the southern limit of the Bulli Coal and the location of the Mount Murray Monocline - the southern limit of the Bulli Coal coincides with the Mount Murray Monocline. This suggests the Mount Murray Monocline had an enormous influence on the distribution and nature of the Bulli Coal in the Southern Coalfield at the time of deposition.

The Bulli Coal, unlike other units above the Kembla Sandstone, was not eroded by the system that deposited the Hawkesbury Sandstone and the Mount Murray Monocline did not have any observable affect on the stratigraphically lower units of the Sydney Subgroup. This implies this structure developed after deposition of the Balgownie Coal and possibly after the Loddon Sandstone. The structure contours of the top of the Wongawilli Coal decrease from 400m to 250m (above mean sea level) over a distance of 10 km in the northeastern part of the study area. The magnitude of deformation that occurred prior to the deposition of the Bulli Coal cannot be accurately assessed as the deformation may have continued long after the coal was deposited to the north of it. It is suggested that a relatively small base-level change would have beeb sufficient to alter the water-table level and prevent development of the peat.

The interpretations of Clark (1992) and Wilson (1958) infer the Mount Murray Monocline extended as far as Mittagong in the west of the study area. Further to the northwest, the structure contours of the top of Wongawilli Coal do not show the monoclinal structure. However an igneous intrusions in the area affected the structure after deposition of the Illawarra Coal Measures. Post-Permian domes in the Mittagong and Robertson areas are the most notable features of this igneous activity.

In the eastern part of the area, the Mount Murray Monocline is far better defined than in the northwestern part. The concentration of the drill holes in this area, immediately north of Robertson, allowed accurate delineation of the Mount Murray Monocline and the southern limit of the Bulli Coal. The lack of drill holes in the northwestern part of the study area made accurate definition of the limit of the Bulli Coal, in this area, difficult. However, it is suggested that the limit of the Bulli Coal was also controlled by the Mount Murray Monocline in this area as in the east. A detailed study in the area would be needed to resolve the problem of the distribution of the Bulli Coal in this area and the nature of the Mount Murray Monocline.

Clark (1992) stated that the limit of deposition of the Bulli Coal was controlled by the position of the water-table and that basement activity controlling subsidence was the major control on the growth and development of plant communities, and the subsequent preservation of peat. Clark's interpretation was based mainly on the preservation of a gradational claystone roof and coal types attributed to the final stages of peat development. This study agrees with the findings of Clark and has found no evidence to suggest that the Bulli Coal was ever deposited, and later eroded, farther south than the present limit as defined in this study. The mechanism that controlled deposition of the Bulli Coal was the developing Mount Murray Monocline. South of the Mount Murray Monocline, the topographic surface was too high for a water table to sustain peat development whereas north of the same structure, the water table did sustain peat development. Evidence which opposes erosion of a Bulli Coal is found in drill cores in the northeast of the study area; these show no coaly fragments in the base of the overlying Narrabeen Group as might be expected if erosion had taken place. Furthermore, McCabe (1984) stated that peat is not easily eroded and Clark (1992) noted that little coal has been eroded by the Narrabeen Group in colliery sections in the eastern part of the coalfield. This suggests that if the Bulli Coal had been deposited, some or all of it would have remained after erosion.

DEPOSITIONAL SETTINGS AND LATERAL VARIATION

In the centre of the Southern Coalfield, most units are generally thicker and show little lateral variation compared to the respective units along the southwestern margin.

1. The Bargo Claystone was deposited in an interdistributary bay or prodeltaic setting, with the Darkes Forest Sandstone and Allans Creek Formation deposited up-dip of the Bargo Claystone, towards the source of the incoming clastic detritus which was from the New England Fold Belt to the northeast. The Darkes Forest Sandstone was deposited in a river mouth setting whereas the Allans Creek Formation was probably deposited in a poorly-drained floodplain setting with the coaly intervals forming during periods of reduced clastic input. However in the centre of the coalfield the deposition of the Allans Creek Formation was influenced by much higher energy regimes with more sandstone units deposited close to the distributary channels.

2. The Kembla Sandstone was deposited by a very extensive meandering fluvial system and it shows very little variation throughout the study area or the coalfield in general. It

is proposed that the northeast-trending syncline affected the direction of sediment entering the study area.

3. The Wongawilli Coal is a laterally extensive unit which was deposited during a period of tectonic stability although igneous activity was common. At the road cutting at Sam's Mountain, near Joadja, the Wongawilli Coal is only 0.5 m thick and the Burragorang Claystone, an excellent marker interval, almost immediately overlies the coal. However, about 3 km to the east of this locality, the Wongawilli Coal is almost 10 m. The thinness of the coal in the Joadja area suggests that the marginal areas subsided very little compared to the eastern parts of the study area and the more central parts of the basin with consequently less accumulation of peat.

In the Sutton Forest drill hole, New Belanglo 30 (Fig. 4), the Wongawilli Coal is approximately 4 m thick and the coal is interbedded with several medium-grained sandstone layers. However in drill hole New Belanglo 16, only about 5 km away, the coal lacks sandstone beds. The lateral lensing out of the sandstone interbeds indicates that the interseam material is not reworked tuffaceous material and was deposited as penecontemporaneous sediments during peat accumulation. This suggestion is supported by the work of Bos (no date), who examined numerous drill cores from the Sutton Forest area as part of an exploration program; he observed that the Wongawilli Coal was commonly interbedded with claystone, siltstone and sandstone. Some holes were reported to contain 0.6 m sandstone beds, whereas adjacent paired holes, only 15 m away, contained normal coal sections with no clastic sediment. The sediment present as interseam material in coal was derived from the Lachlan Fold Belt along the southwestern margin of the area.

4. Bamberry (1992) attributed the coarsening-upward character of the Eckersley Formation, in the centre of the coalfield, to deposition from shoe-string distributaries. However the fining-upward character of the unit within the majority of the study area, and the lithofacies assemblages, are strong evidence that the unit was deposited by a meandering fluvial system. Braided systems commonly occur close to the sediment source where gradient of the thalweg is usually quite high. Downdip from the source, where energy decreases and sediment supply is reduced, finer grained, meandering systems are more common. The study area was down-dip and a significant distance from the source of sediment, the New England Fold Belt. It is possible that the Eckersley Formation records a change from a braided system in the centre of the coalfield (Bamberry, 1992) to a meandering setting in the study area. Changes in river morphology as is postulated here are not unusual. The fining-upward character of the unit was observed as far west as Berrima; the Eckersley Formation is considerably thinner along the western margin than in the east.

5. The Lawrence Sandstone and Loddon Sandstone were deposited in meandering fluvial systems almost over the entire Southern Coalfield. In the extreme southeast, the Lawrence Sandstone lenses out and the Loddon Sandstone merges with the Eckersley Formation and the fining upward natures of the latter units are lost.

6. The Balgownie Coal and Bulli Coal were deposited during periods when regional tectonics controlled subsidence. The lack of tuffaceous units indicates that no contemporaneous igneous activity took place during this period.

The occurrence of only a thin Balgownie Coal in the study area, compared to the centre of the coalfield reflects, the marginal conditions induced by the proximity of the cratonic Lachlan Fold Belt. The marginal areas underwent much slower rates of subsidence than the depocentre to the north and consequently peat accumulation was slower, resulting in thinner coal seams. The Balgownie Coal is a laterally extensive unit and it can be traced from the thicker, more complete stratigraphic sequence in the northeast to a thinner unit in the southwest. Importantly, the holes in the northeast of the study area also contained the Cape Horn Coal Member and Bulli Coal as well as the Balgownie Coal.

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FORMATION	MEMBER
Bulli Coal	
Loddon Sandstone	
Balgownie Coal	
Lawrence Sandstone	
Burragorang Claystone	
Eckersley Formation	Novice Sandstone Member
	Woronora Coal Member
	Hargrave Coal Member
	Cape Horn Coal Member
Wongawilli Coal	
	Farmborough Claystone Member
Kembla Sandstone	
Allans Creek Formation	American Creek Coal Member
Darkes Forest Sandstone	
Bargo Claystone	
	Huntley Claystone Member
	Austinmer Sandstone Member
Tongarra Coal	
Wilton Formation	
	Woonona Coal Member
Marrangaroo Conglomerate	

Table 1. Stratigraphy of the Southern Coalfield (after Bamberry, 1992)

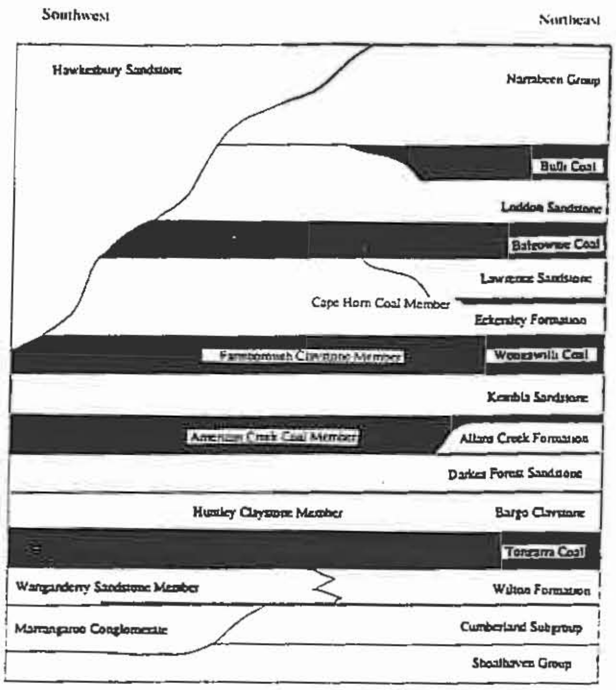

Figure 1. Stratigraphy of the Study Area.

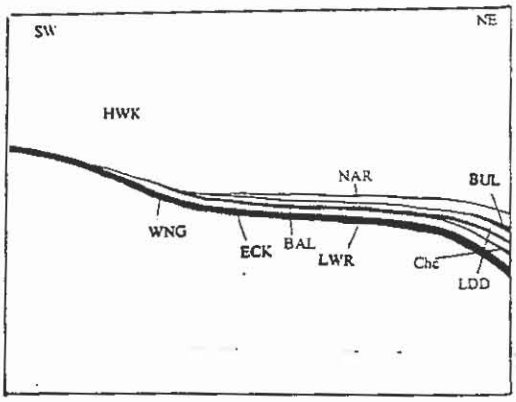

Figure 2. Schematic Cross-section of the Study Area.

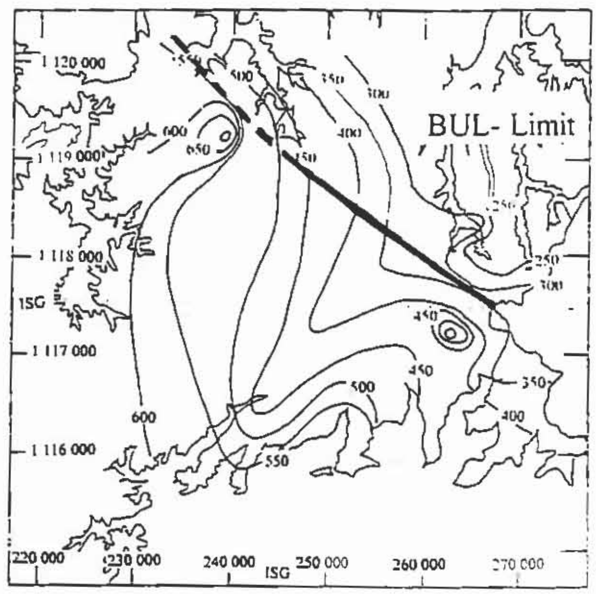

Figure 3. Contour Map of the Top of the Wongawilli Coal and the Limit of the Bulli Coal.

Abbreviations

HWK - Hawkesbury Sandstone
NAR - Narrabeen Group
BUL - Bulli Coal
LDD - Loddon Sandstone
BAL - Balgownie Cal
LWR - Lawrence Sandstone
Chc - Cape Horn Coal Member
ECK - Eckersley Formation
ACK - Allans Creek Formation
DKF - Darkes Forest Sandstone
BAR - Bargo Claystone
TON - Tongarra Coal

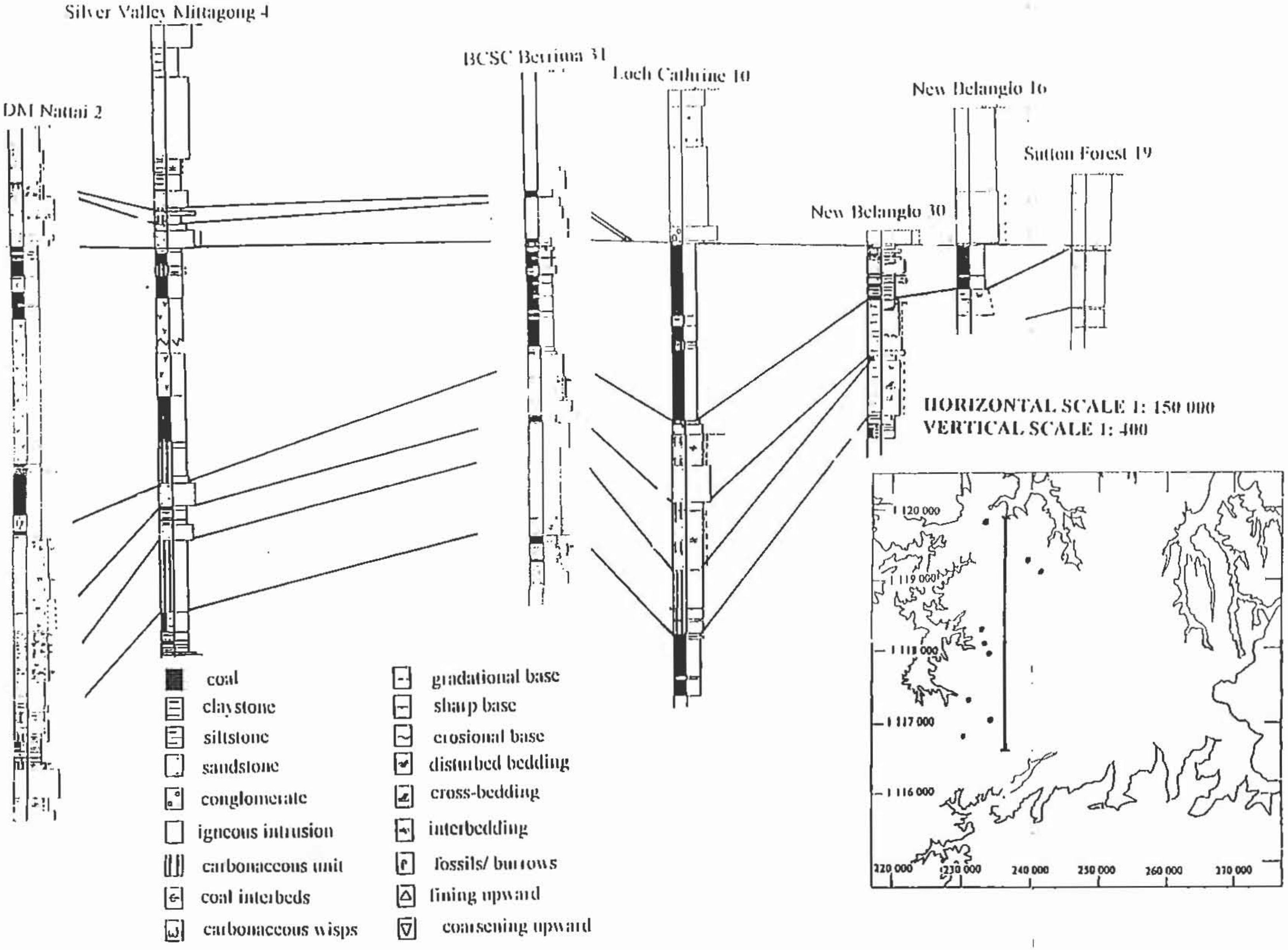

Figure 4 Section through drill holes in the southwestern Sydney Basin.

THE SEDIMENTOLOGY, PALAEONTOLOGY & GEOMECHANICAL BEHAVIOUR OF SEDIMENTS FROM A PERMIAN LAKE

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INTRODUCTION

Lake bed sediments occur above, and replace parts of, the Borehole Seam in the NE corner of the West Wallsend Colliery holding.

The Borehole Seam, in the Lambton Subgroup of the Permian Newcastle Coal Measures, is the lowest seam of these measures and is thought to be of Kazanian age.

In the area of study, the Borehole Seam shows a complex pattern of thinning, deterioration and splitting. Investigations have shown that the upper sections of the seam were lost due to the incursion of a lake and deposition of black shales and claystones whilst the lower sections were split by a palaeochannel.

The black shales and claystones in the roof are extremely weak and have caused roof stability problems in development roadways and on longwall faces.

Tetrapod and fish fossils were discovered by the author in the black shale above the Borehole Seam. This was the first well documented evidence of a Tetrapod fauna from the Permian of Australia.

AREAS OF THE BOREHOLE SEAM DETERIORATION (Fig 1)

(a) Lower Section of the Seam

The lower section of the Borehole Seam is affected by an elongated split striking NE-SW and composed of a central core of sandstone surrounded by shale with a lenticular cross section. This is interpreted as a small palaeochannel. (Fig. 3)

(b) Upper Section of the Seam

This is affected by the progressive overlap of a lacustrine black shale (termed the Black Shale) with a NW - SE striking edge. Its thickness gradually but erratically increases up to 2 m towards a "want" located in the vicinity of 15-1/4 C/T, MG9, where a rapid increase in seam deterioration occurs until the entire Upper Borehole Seam is replaced by carbonaceous and torbanitic shales and claystones. In this area the thickness of Black Shale above the seam increases rapidly to over 5 m as observed in a roof fall at 15-1/4 C/t, MG9.

The area of the want corresponds with the overlap of the lower palaeochannel by the upper lacustrine sediments and there appears little doubt that it is a consequence of these events.

SEDIMENTOLOGICAL CHANGES PASSING INTO THE WANT (Fig 2.)

As the coal seam extends under the overlying lake sediments, its upper layers are gradually replaced by black shale or claystone, down to the Middle Band (a claystone "marker" band) in some areas.

Nearer to the main "want" area, deterioration or thinning becomes pronounced in the lower parts of the seam up to the Middle Band.

The Middle Band itself begins to thicken appreciably and the 0.8 m of coal immediately below thins to 0.15 m and becomes torbanitic. Below is a claystone band which may or may not represent the Bottom Band but at a higher level. Below again is a 0.4 m thick varve-like shale consisting of alternating dark and light bands approximately 5 mm thick. In some areas the varving is disrupted and the layers mixed so that varving is not identifiable and the stratum has the appearance of a grey shale. The lateral extent of the varved shale was not determined.

As the coal under the Middle Band deteriorates the coal above increases in thickness, temporarily up to 1.5 m before rapidly and completely deteriorating to bands of carbonaceous shale split by frequent bands of claystone up to 300 mm thick. Several of these claystone bands do not correlate with any in the seam. Some develop rapidly in thickness into the want.

Further into the want, the carbonaceous shale becomes visibly more depleted in carbonaceous material to develop into a black shale whereas the claystones maintain their identity. In places the shale is torbanitic.

Above the projected horizon of the coal, the claystone bands are not present although some vague wispy traces are still seen but not as bands. In this main want area the Black Shale rapidly increases in thickness to 5 m + and contains moderately frequent carbonate nodules in which remains of tetrapods and fish were found. Glossopteris leaves were also seen in the shales.

Within 50 mm of the top of the Black Shale is a well defined and extensive band of bioturbated shale consisting of black shale with abundant light grey burrows.

Above the Black Shale is an abrupt change to a grey silty shale, considered typical for the Borehole Seam roof in this colliery.

In the area immediately adjacent to the want there are frequent and complex changes from coal to torbanitic coal and shale to carbonaceous shale, with intermediates between these including claystone components. Some shales with a torbanitic groundmass contain abundant small vitrain particles suggesting partial derivation from material sinking from overlying floating coal masses, the latter remaining as isolated coal floaters, or "overhangs" stretching out and up from the remains of the coal seam. In places persistent clay bands are seen following these fingers of coal as if their level has floated higher with a rising water level. This raises the possibility of sections of the seam being of the same age as or slightly older than the algal - clastic - humic strata underlying it.

Narrow deep (up to 2 m) gully-like features extend up to 800 m out from the want in a generally N - S direction, becoming smaller and shallower with distance. They are occupied by thick claystone and Black Shale in varied relationships.

SOME CHARACTERISTICS OF THE CLAYSTONES

The claystones in the area of study show the following characteristics:-

- Occur as thin bands in the coal seam except when approaching the want.
- Thicken considerably into the want as the coal deteriorates into carbonaceous shale.
- Show significant thickness in lacustrine sediments immediately above the seam where the total thickness of these sediments is less than 2 - 3 m. In these areas their relationship with the Black Shale shows complete variations from discrete bands or beds to an intimate mixture.
- In the main "want" area are present as small wisps in the lower sections of Black Shale (but above the projected seam roof level).
- A thin continuous band is laterally consistent at approximately 10 cm below the top of the Black Shale despite the rolling nature of the top of the latter.

- Of particular note is the disappearance of the Bottom Band as the lower part of the seam thins out into the want. Total seam thickness is maintained as the upper part of the seam increases in thickness. As a consequence the Middle Band appears to transgress the seam (or vice versa) over a distance of 10 m.

THE GEOMECHANICAL BEHAVIOUR OF THE LAKE SEDIMENTS IN THE ROOF

The Black Shales and claystones in the roof exhibit very little mechanical strength, caving readily if left unsupported for any distance.

Roof behaviour in the development and gate roads was to a certain degree predictable and related to the thickness of the lake sediments ("soft roof"):-

THICKNESS	ROOF BEHAVIOUR	ROOF SUPPORT
< 300 mm	Minor scaling	Normal
300 mm - 1.50 m	Small falls to top of soft roof	Close up W-straps, 1.80 m bolts
1.50 m - 2.1 m	Falls to top of soft roof	close up W-straps, 2.4 m bolts
2.1 m +	Large falls to top of soft roof occurring with very little warning	Massive secondary passive support (considered uneconomic) Too soft for effective use of cable bolts

The soft roof was also difficult to support along the longwall face, and frequently fell immediately after the shearer passed. Slumping would also occur ahead of the face. The problems were restricted by closing the roof supports to the face as soon as the shearer had passed and working through breaks to restrict time dependent failure. Mine induced shears developed on the face ahead of mining identical to those seen in normal strata during heavy weighting cycles. The problems became worse when moderate periodic loading cycles occurred due to the influence of an overlying massive sandstone channel, in which cases the roof falls extended up into the normally stable grey shales and siltstones overlying the lake sediments.

Recovery from larger falls on the Longwall face took place by bolting and injecting polyurethane.

The deterioration of the seam and instability of the roof strata caused the shortening of Longwalls 9 and 10, and significant losses of production occurred as a result of roof instability in Longwalls 8, 9 and 10.

PALAEONTOLOGY

During an inspection of a fall in Maingate 9, 15-1/4 c/t some carbonate nodules were observed in the fallen material and at several levels in the exposed roof strata. Some of the nodules had split on falling and others split with varying degrees of difficulty. Most of the nodules contained traces of either bone or fish scale, although often the remains were not clear underground and were taken speculatively to the surface.

Inspection in daylight revealed 5 nodules containing skeletal remains and eight containing traces of fish remains (scales and occasionally fins.)

In the case of the skeletal remains, one was clearly a vertebral column 0.5 m long of an amphibian or reptile, one a skull including jaws and teeth which is thought to be a fish (not yet identified) and in the others elements of bone were penetrating into the nodule in 3D and obviously required expert attention for identification.

At the time of writing the 0.5 m long vertebral column is considered to be of a temnospondyl amphibian. The remaining concretions have shown some amphibian-like features, but at least one has part of the vertebral column which shows reptilian features. Teeth have been identified in some of the concretions as well as possible skin impressions. The material is quite difficult to work with as it is hard and both fossil remains and surrounding concretions are of similar hardness.

The fish material in the concretions has not been particularly well preserved with disruption of the remains causing scales to be scattered through the concretion. The best preserved material is in the shale on the edge of the concretions, with scales and fins in some cases in excellent states of preservation. Most of the fish are though to be Palaeoniscids, with at least one deep bodied variety being present.

The main significance of this fossil find is the presence of the tetrapods as only one other tetrapod, an amphibian, has been found in the period between the Early Carboniferous and Early Triassic. This period is important for the emergence of Therapsid reptiles. (A. Warren).

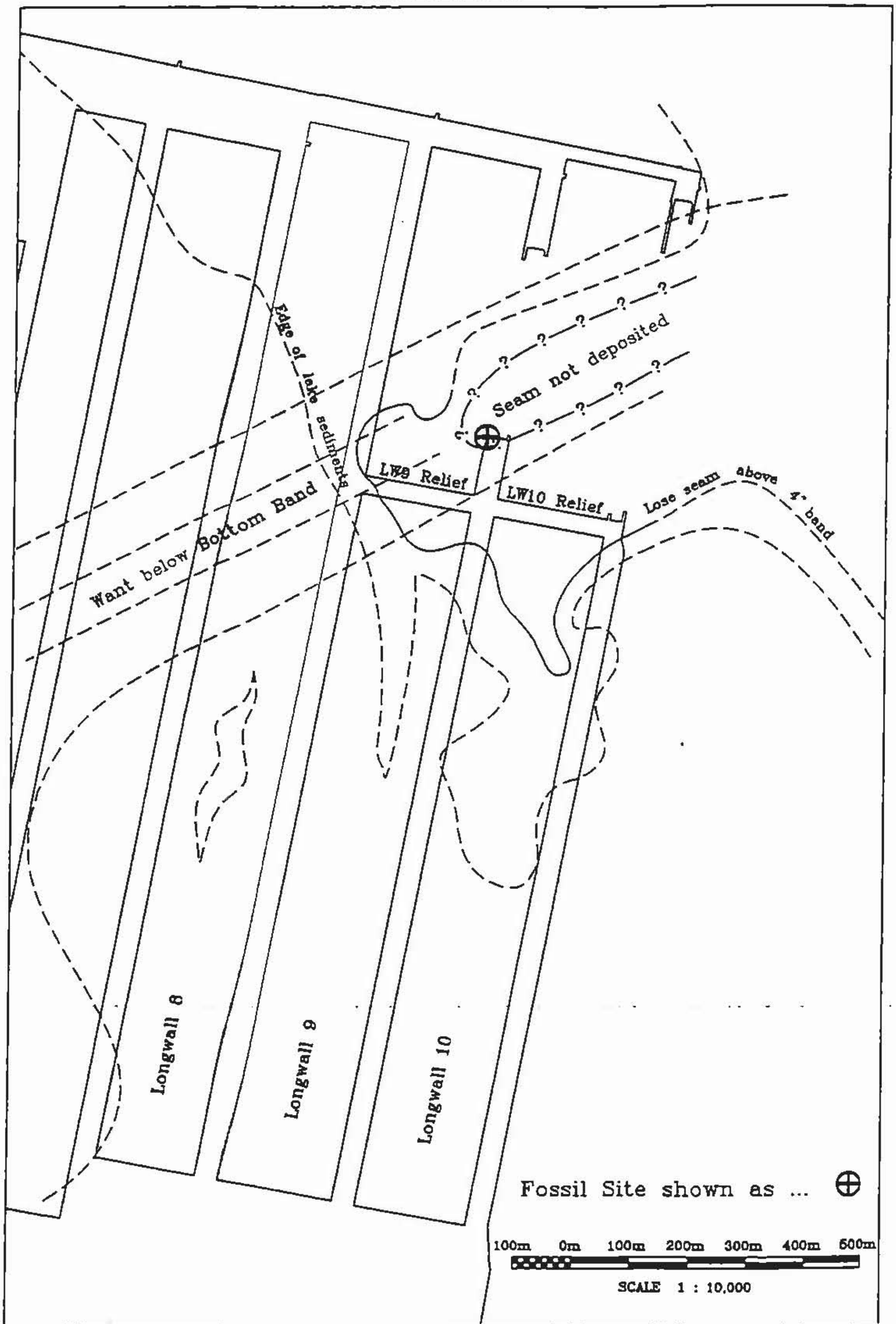

Fig.1 Plan Showing Lake Sediments and 'Want' affected areas

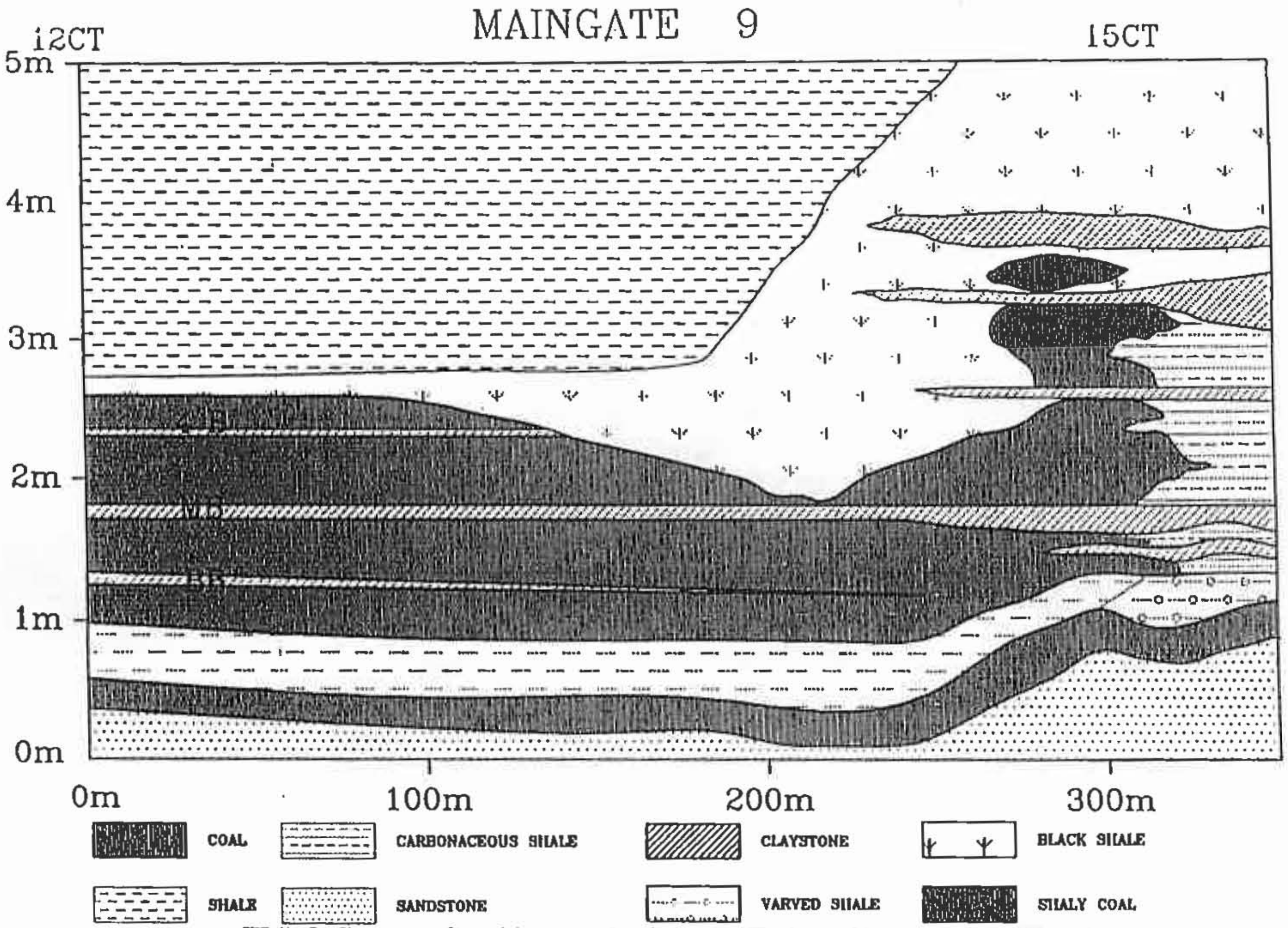

FIG.2.Cross Section of Seam Extending into Want.

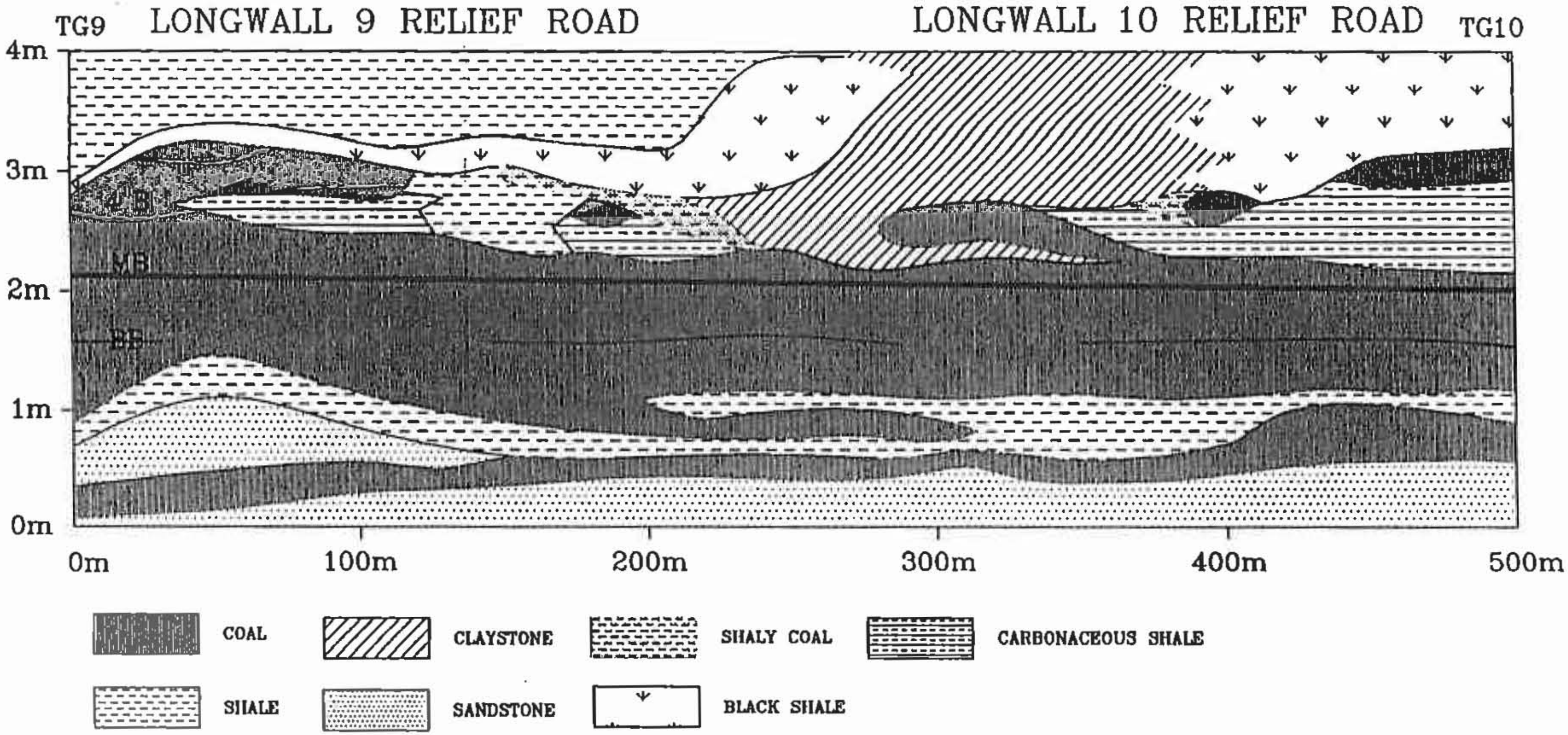

FIG 3. Cross Section along Longwalls 9 & 10 Relief Roads at edge of Want

UNREACTED CARBON IN COMBUSTION AND GASIFICATION

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Coal utilisation technologies are undergoing a rapid rate of change. Pressure to reduce CO2 and particulate emissions, and efficiency drives make pressurised gasification an attractive option. Process conditions in pressurised gasification differ from conventional entrained flow combustion in some critical aspects, such as pressure, atmosphere, feed rate, peak temperature and heating rate. Little attention has so far been paid to observation of the behaviour of coal grains under appropriate conditions. Char morphology studies of particles produced under the desired conditions clarify the behaviour of different components within the parent coal during heat treatment.

Chars produced by combustion, gasification at 1 atm and up to 15 atm pressure, along with their parent coals, were studied using semi-automated image analysis, scanning electron microscopy, petrographic, particle size and chemical analyses. Full coal reflectograms show that parent coal inertinite populations with low standard deviation and skewness are characteristic of higher combustion burnout. Gasification volatile yield cannot be predicted from conventional standard analyses. Daughter chars show distinct variations in morphology with changing pressure and with petrographic composition of the parent coals. While artefacts of feed rate due to grainsize or high pressure cannot be discounted, char morphology studies give insight into performance differences under different process conditions.

THE STRATIGRAPHIC ORGANIZATION OF INCISED-VALLEY SYSTEMS

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An incised-valley system consists of an incised valley eroded during a relative sea level fall, and a valley fill which accumulated during one or more relative sea level cycles. Incised-valley systems provide the most complete, and at times only, evidence of lowstand to early-transgressive deposition in shelf and/or shallow ramp depositional settings.

The fill of incised valley systems is divisible into three segments: i) the seaward reaches of the incised-valley (SEGMENT 1) is characterized by backstepping (transgressive) fluvial and estuarine deposits, overlain by transgressive marine sands and shelf muds; ii) the middle reaches of the incised valley (SEGMENT 2) consist of the drowned-valley estuarine complex that is developed at the time of maximum transgression, overlying a lowstand to transgressive succession of fluvial and estuarine deposits like those in Segment 1; and iii) the innermost reaches of the incised-valley (SEGMENT 3) is developed headward of the transgressive marine limit. Segment 3 is characterized by fluvial deposits throughout its depositional history; however, the fluvial style may change systematically due to changes in accommodation. A sequence stratigraphic approach to the study of incised valley systems results in a model for the predictable organisation of facies and surfaces based on the interaction of sediment supply and relative sea level.

Recognition of incised valleys and their segments is critical for successful hydrocarbon exploration in many areas. For example, recognition of the Segment 1 valley fill of the Senlac heavy oil pool in the Cretaceous Lloydminster Formation of Saskatchewan enables an understanding of production history in a wave dominated incised valley sand plug, with increased production resulting from tidal inlet facies and low production in distal flood tidal delta units. The Glauconite Formation of Southern Alberta is an example of a compound Segment 2 incised valley fill where basal fluvial channel sands are overlain by transgressive tidal channel sands and mudstones. The fluvial channel sands are the best reservoirs, the tidal channel sands have low vertical permeability and the mud filled channels of a younger age act as seals to the underlying reservoirs. The Hunter Valley of eastern Australia exhibits multiple cycles of fill from Tertiary to Quaternary in age, and preservation of all incised valley segments. Studies of high resolution sequence stratigraphy in Quaternary examples such as the Hunter Valley enable the prediction of reservoir and seal architecture in ancient incised valleys, and an establishment of the criteria for their successful recognition.

PHOTOGRAPHIC IMAGES OF COAL AT DIFFERENT RANK LEVELS; EMPHASIS ON LLOYDMINSTER COAL OF EASTERN ALBERTA, CANADA

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INTRODUCTION

In the course of a research project on the depositional conditions of a coal in the Lloydminster region of eastern Alberta, Canada, a large number of optical measurements and observations were made in both white and fluorescent light. The following poster illustrates some of the images of the Lloydminster lignite/sub-bituminous coal and comparisons are made with other coals of lower and higher rank.

COALIFICATION

There are two stages identified for the coalification pathway for accumulated organic matter, biochemical and physico-chemical processes. The biochemical process includes the decomposition of vegetable matter and ends with the polymerisation of humic colloids at the rank of brown coal. The characteristics of brown coal depends on the phytogenic component.

With the continuation of subsidence of the accumulated peat, the physico-chemical processes are initiated when temperature and pressure both increase, resulting in physical and chemical changes in the coal. Condensation of the carbon micelles (aromatics) occurs at this stage, due the loss of aliphatic side chains by devolatilisation. This reorganisation of aromatics into sheets may extend to graphitisation, resulting in anthracitic coal.

CHANGES IN CHEMICAL AND OPTICAL PROPERTIES OF COAL

Rank is assessed by both physical and chemical properties of coal, with the general trends being a decrease in moisture content and volatile matter yield, and increases in specific energy and fixed carbon. As we travel further along the coalification path, the carbon percentage of the coal increases relative to the loss of hydrogen and oxygen. The optical measure of reflectance of telovitrinite is another indicator to the degree of coalification, as the amount reflected light is directly related to aromacity (density of carbon atoms).

Telovitrinite can absorb some of the lipids produced by bacteria which flourishes under near-neutral peat-forming conditions thus suppressing reflectance values In this case, fluorescence analysis can assist in determining the correct rank of the coal.

Microfluorescence is the measure of the emitted long-wave radiation after the maceral has been subjected to a specific (e.g. 436nm) short-wave, high energy beam. *Figure 1* shows the behaviour of microfluorescence of telovitrinite with regard to mean random telovitrinite reflectance. The trough at 0.5%Rrt is the boundary between brown and black (sub-bituminous) coal and is also the cut-off point for primary fluorescence. Primary differs from secondary fluorescence inasmuch as the original plant matter determines the value, based on the biopolymers cellulose, lignin and various lipids. Therefore the primary fluorescence has a large affect on low-rank coals. The secondary fluorescence is a function of the repolymerisation that occurs at the initial stages of physico-chemical coalification. The increase in fluorescence intensity is in response to the recombination of the degraded nuclei that broke down in the biochemical stage. The intensity peaks at high-volatile bituminous coal and then gradually lowers as further coalification breaks carbon-carbon bonds and some of the nuclei are released as fluid and gas (Diessel, 1992).

LLOYDMINSTER STUDY EXAMPLE

Figure 2 illustrates the study area of one of the research projects in Central Alberta, Canada, along with the distribution of the coal deposits. The Lloydminster area is roughly 250km east of Edmonton, on the border of Alberta and Saskatchewan provinces.

A significant factor in the selection of the coal core from the Lloydminster study area was due to it bordering on the brown/black coal boundary. Under the microscope, the coal looks like a black coal and black coal terminology is used in maceral analysis. However, the reflectance and fluorescence analysis gives all indication that this is a brown coal. One possible reason for this is that the telovitrinite reflectance has been suppressed due to the absorption of lipids. The photomicrographs presented in the poster show the high fluorescent nature of the telovitrinite as well as the large volumes of resinite and fluorinite filling fissures, cracks and cell lumens.

The Lloydminster coal is compared, visually, with 3 examples of increasing rank and one example of lower rank from around the world. This allows a good contrast between ranks and illustrates the "red shift" of fluorescence intensity, whereby the actual fluorescence colours emitted change from a greenish yellow to a reddish yellow.

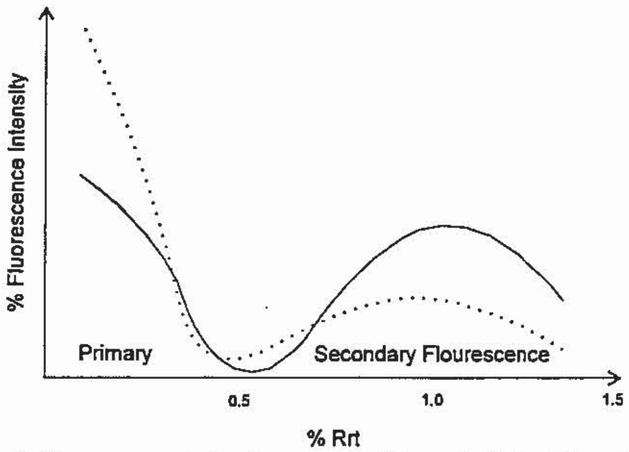

Figure 1: Fluorescence intensity compared to rank. (after Diessel, 1992)

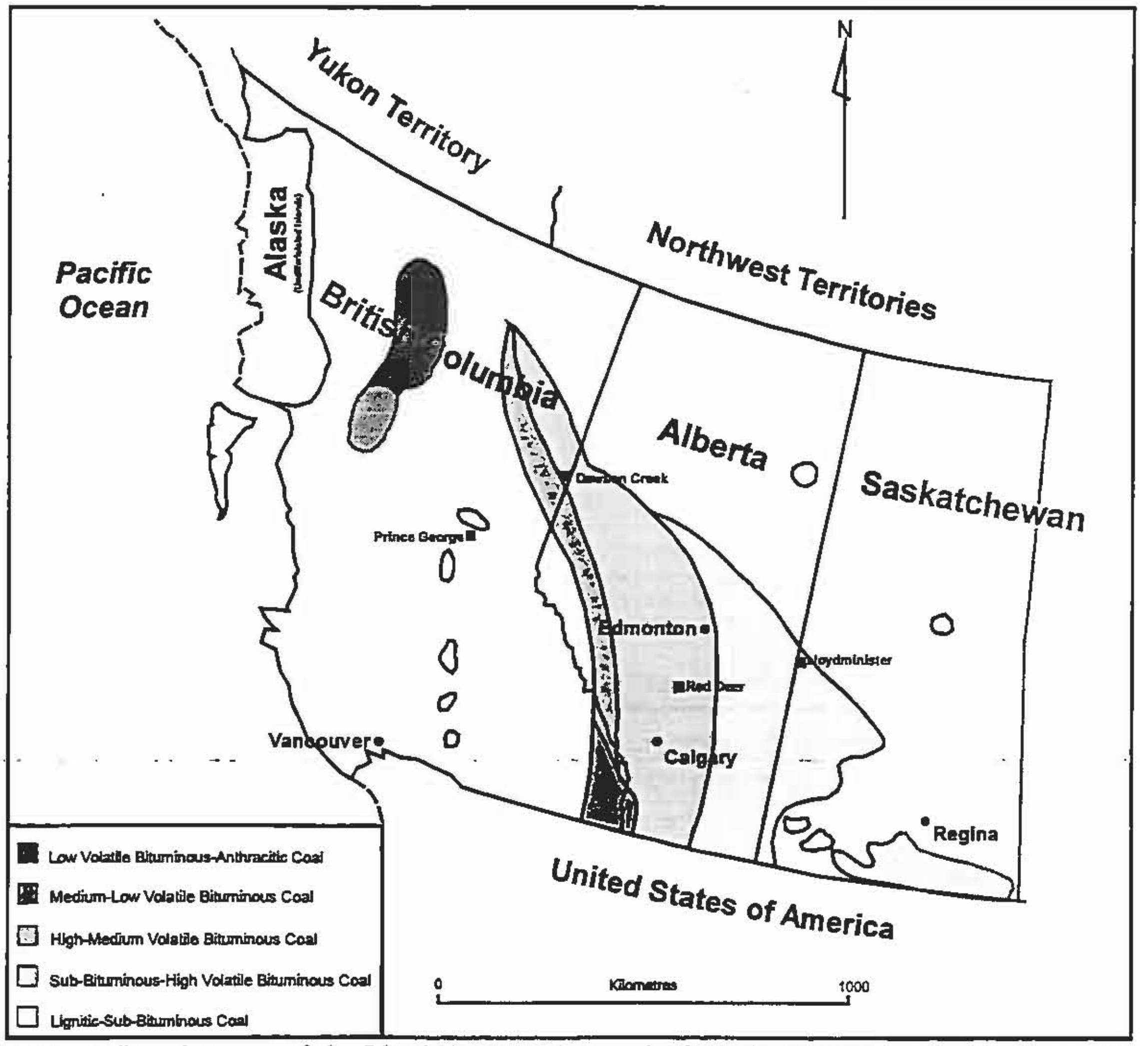

Figure 2: Location map of the Lloydminster study area in Central Alberta, Canada. Map shows the decreasing rank trend towards the east, due to the basins relationship with the Cordillera thrust belt. (after Smith, 1989).

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THE GRETA COAL MEASURES: CLASTIC SEDIMENTATION IN A HIGH ACCOMMODATION SETTING

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The Early Permian Greta Coal Measures are a regressive wedge of coarse clastic sediments with generally discontinuous coal seams of variable thickness. They formed in a high accommodation setting developed by isostatic adjustment of a thrust belt in a retro-arc foreland basin. The Coal Measures are bounded by the lower marine Dalwood Group and the upper marine Maitland Group.

This study concentrates on the Greta Coal Measures in the Lower Hunter Valley of NSW (Fig.1). A framework of outcrop, borehole and electric log data was analysed for the Maitland-Cessnock-Greta Coalfield (Jones, 1939) and the Cranky Corner Basin. The petroleum exploration wells, AOG Belford PDH 1 and Planet East Maitland RDH 1 were interpreted in the interval of interest as they were located on the edge of the framework. Proximate and maceral analysis of the Greta and Tangorin Coal Seams was studied to determine the provinciality of the two seams.

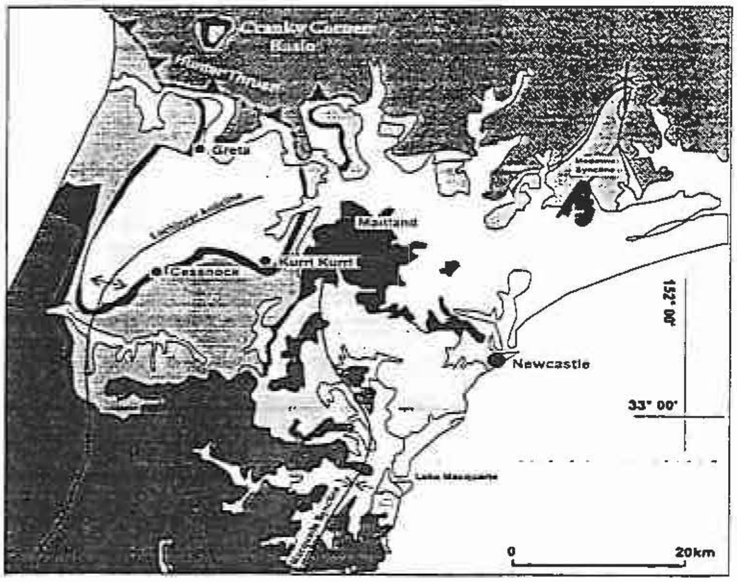
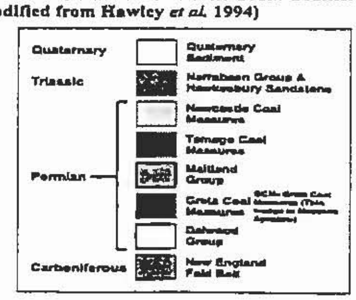


Fig.1. Location of the Greta Coal Measures in the Maitland-Cessnock-Greta Coalfield and Cranky Corner Basin (Modified from Hawley *et al.* 1994)



In outcrop an erosional unconformity was located at the base of the Greta Coal Measures in the Cranky Corner Basin and the Maitland-Cessnock-Greta Coalfield. Close study of borehole and electric log data showed that these unconformities were unrelated. Two

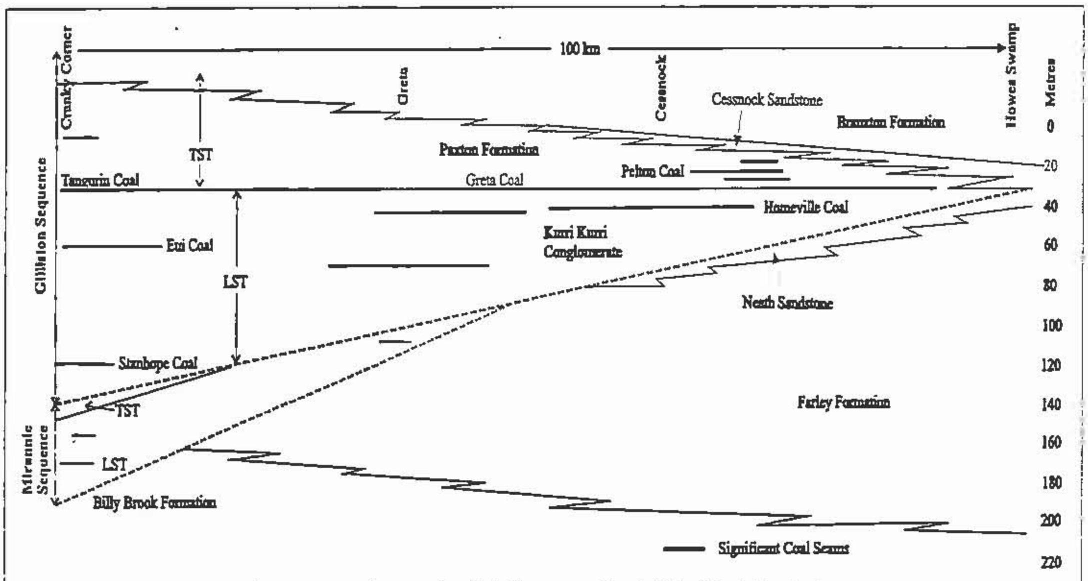


Fig2. Sequence Stratigraphic Section of the Maitland-Cessnock-Greta Coalfield and Cranky Corner Basin

sequence boundaries are recognised within the Greta Coal Measures (Fig.2).

The Mirannie sequence boundary extends from the proximal Cranky Corner Basin to the mid-distal Greta region. It appears to coalesce with the Gilliston sequence boundary which extends from the proximal to the distal edges of the study area. The prescence of incised valley fills can only be the case of conjecture as borehole and outcrop data is too widespread for localised facies correlation except in the South Maitland Coalfield.

The Mirannie Sequence comprises coarse clastic sedimentation with very minor, thin peat production. Regressive parasequences are topped with fine grained floodplain sediments. Electric logs show an aggradational to retrogradational parasequence stacking pattern. This is interpreted to represent a lowstand systems tract with a remnant transgressive systems tract formed in a high accommodation setting. Clastic sediment supply in the early-middle lowstand tract equals or exceeds the increase in accommodation. This sediment supply competes and overwhelms localised peat swamps. Any coal seams developed are thin, localised units with probably high ash contents (stony coals). As the accommodation rate increases the sediment supply relatively decreases and more continuous peat swamps develop. Rapid subsidence restricted the thickness of the peat swamps by drowning in the early transgressive system tract. Unloading of the thrust zone caused rebound of the Mirannie Sequence and the removal of the remainder of the sequence. This relative fall in base level formed the erosional unconformity represented by the Gilliston sequence boundary.

The Gilliston Sequence has a similar depositional style to the Mirannie Sequence. The lowstand systems tract is represented by progradational to aggradational coarse clastic parasequences. The parasequences terminate in sandy bartops with occassional floodplain sediments or very thin peat swamps. Localised thicker coal seams (Stanhope Seam, Eui Seam, Homeville Seam) show that the rate of increase in accommodation was more variable in the Gilliston Sequence than in the Mirannie Sequence. Generally the high increase in accommodation and large sediment supply precluded the development of thick, extensive peat mires (Fig.3.). If the sediment supply and/or accommodation increase was reduced localised, thick mires could develop. The very thick Greta and Tangorin Seams developed when a balance occurred between peat accummulation and the rate of change of base level. This situation occurs at the end of the lowstand tract when the increase in accommodation is less than the sediment supply and a bypass surface occurs. The top of the Greta Seam represents a transgressive surface.

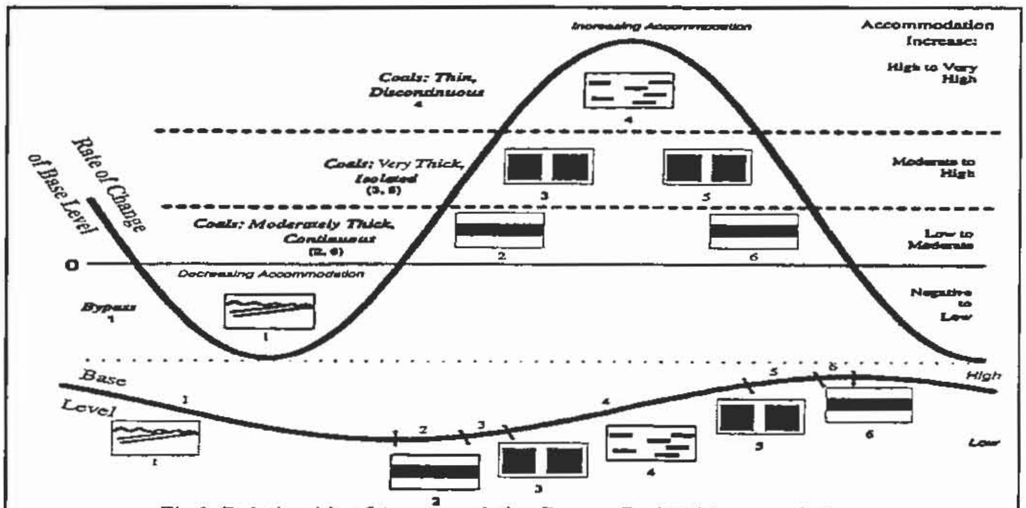


Fig.3. Relationship of Accommodation Rate to Coal Thickness and Geometry. Derived from Bohacs and Suter, 1997.

The upper portion of the Greta Coal Measures in the study area is contained within the transgressive systems tract of the Gilliston Sequence. Backstepping fluvial to estuarine parasequences contain thin, discontinuous, high sulphur peat mires (Pelton Seam). As the rate of base level rise increases fluvial sedimentation backsteps and retrogradational stacking patterns develop. Peat growth is unable to keep up with the increase in base level and the mires rapidly drown, often by the incursion of brackish water. The shoreline eventually transgressed over the fluvial sediments ending Greta Coal Measure deposition.

The Greta and Tangorin Seams are a high volatile, low ash bituminous coal with a moderate sulphur content. Proximate analysis results show an upward increase in volatile matter and ash in both seams. Cannel coals are found in the top portion of the Greta Seam. These show an increase in the rate of groundwater rise and subsequent drowning of the mire as the accommodation rate increases. An upwards increase in the sulphur content of both seams suggests that the drowning of the mire was caused by brackish water. The Tangorin Seam has a lower pyritic sulphur and higher organic sulphur content than the Greta Seam suggesting a reduction in available iron proximally. The high vitrinite content of both seams shows that groundwater conditions were stable both proximally and distally. The peat mire formed in a broad, flat braidplain with a constantly rising water table associated with a gradual rise in base level. Low vitrinite values near the base of both the Greta and Tangorin Seams are reflected by higher inertinite and liptinite values. This shows a sharp fall in the water table at some point in time probably due to tectonic adjustment in the hinterland. The two distinct inertinte populations are due to a greater allocthonous content of the proximal swamp. The nearby hinterland shed organic matter which had undergone oxidation before incorporation into the peat. Liptinite content also shows two distinct populations. Gammidge (pers.comm.1997) reports that the majority of the liptinite in the Greta Seam is composed of sporinite. In the Tangorin Seam, Marshall and Draycott (1954) note that cuticular material is common and spores form a very minor proportion. The significance of this is that the amount of leaf matter reduces significantly from proximal peats to distal peats.

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