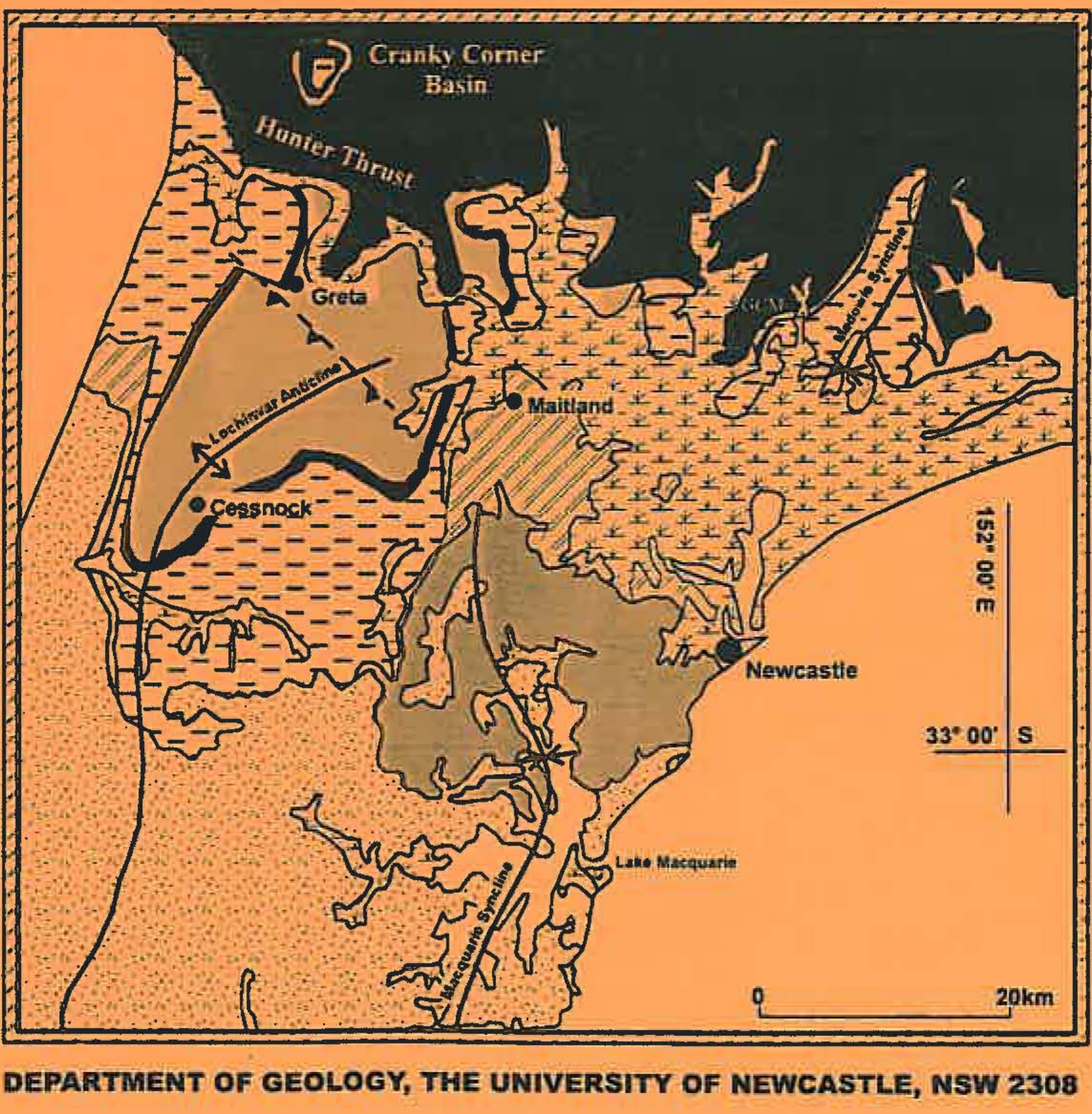
THIRTY FIRST NEWCASTLE SYMPOSIUM

on

ADVANCES IN THE STUDY OF THE SYDNEY BASIN

April 18-20

NEWCASTLE NSW AUSTRALIA



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DEPARTMENT OF GEOLOGY

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COVER: Outcrop geology of the Lower Hunter region, showing the Greta (black), Tomago (diagonal stripes) and Newcastle (medium grey) Coal Measures. Modified after Hawley, Glen and Baker (1994).

DEPARTMENT OF GEOLOGY
THE UNIVERSITY OF NEWCASTLE

PROCEEDINGS OF THE
THIRTY FIRST NEWCASTLE SYMPOSIUM

on

"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

NEWCASTLE BICENTENARY SYMPOSIUM

edited by R L Boyd and K Allan
The University of Newcastle

April 18 - 20, 1997
NEWCASTLE NSW 2308 AUSTRALIA

R L BOYD
CONVENER

INDEX

AUTHOR INDEX

POSTERS

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-first Newcastle Symposium. We have receive 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 First year, the Symposium theme is associated with the Bicentenary of Newcastle. Discovered by white settlers first in 1797, a central element in the early history of Newcastle was its association with geology. Shortland's original landing in 1797 established the presence of coal in what is now the cliff below Fort Scratchley (see Shortland's map on the cover of the 29th Symposium volume). The history of Newcastle has been intimately associated with coal and shipping ever since. In recognition of that association, we are pleased that the NSW Minister for Mineral Resources, Bob Martin will be officially opening our Symposium. In addition, our Keynote Address will be given by Dr. John Turner, a noted local historian who will examine the relationship between coal mining and the early development of Newcastle. An invited talk by Jeff Beckett and others will examine the parallel but later association of geology with the development of the Upper Hunter Valley. A second invited talk by Beau Preston and others will take us to the other end of the spectrum to show the newest developments in the Newcastle Coalfield with the exploration of the Wyong district.

In keeping with our normal program, in addition to the Bicentenary theme, we have sessions that will examine local geology, coal geology and marketing, Quaternary geology, environmental geology, and economic 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. I particular I would like to acknowledge the efforts of Geraldene MacKenzie in organisation over the last decade, prior to her retirement in 1997. She was responsible for much of the success of the event. This year we welcome Kathy Allan who has also played a central role in organisation and preparation for the 1997 Symposium. Other major contribution have come from Andrew Walker, Phil Seccombe, Richard Bale 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 $10 increase in registration. Our aim as ever is 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 31st Newcastle Symposium, and hope that you will have an enjoyable weekend.

Ron Boyd
Convener

FOREWORD

Welcome to the 31st Newcastle Symposium!

I am delighted that the Department of Geology is contributing to the celebration of Newcastle's bicentenary this year through having a historical theme for the Newcastle Symposium. The bicentenary is a timely occasion to reflect on the role of natural resources and the importance of geology to the early development of this part of our nation. We should also take the opportunity to examine our future directions, and reflect on the importance of a soundly-trained and experienced professional geological community to the continued well-being of the east coast region, not just in terms of mineral resource development, but also in understanding and managing aspects of our environment such as groundwater systems, engineering problems and seismic hazards.

In line with Australia's continuing high demand for geoscience professionals, the Geology Department is experiencing a steady growth in its number of undergraduate geology majors and postgraduate students. It is pleasing to see that all our graduates are readily finding employment in the mining and minerals exploration sectors nationwide. This year, with the appointment of a new academic staff member, Dr Tim Rolph, we are introducing Environmental Geology as a major third year course designed for geology majors, as well as for students undertaking Environmental Science programs. Tim has major expertise in areas of environmental geophysics and palaeomagnetism, so we look forward to developing research and training strengths in these areas.

At the end of last year, the Department of Geology achieved major successes in attracting research funding from the Australian Research Council. Industry and Federal government research funding in excess of $935,000 over three years will support the appointment of three postdoctoral research fellows, several new postgraduate students, and considerably enhance the work in our two major areas of research strength, namely "Sedimentary Basin Studies" and "Thermal, Deformational and Fluid Processes in the Crust". A very important aspect of our research profile is a continued strengthening of collaborative research with the minerals and energy industry and government agencies, both nationally and internationally.

A number of people have worked tirelessly to ensure the success of this weekend's meeting. I especially thank our convenor, Ron Boyd, who again has put enormous energy into organising the Symposium, especially its broad-ranging and stimulating programme. I also take this opportunity to thank Geraldine MacKenzie for her charming efficiency and major contribution to the success and smooth running of the Newcastle Symposium over a number of years. For many of you, Geraldine has been your point of contact for conference registrations, abstract submissions and other organisational details. Geraldine is now enjoying the pleasures of early voluntary retirement. Our new Departmental Administrative Assistant, Kathy Allan, has joined us part way through the preparations for this year's Symposium. It is a tribute to her skills that everything has worked extremely well this year - thank you Kathy!

I hope you find this weekend to be a scientifically productive occasion in which you not only catch-up with the latest developments in research dealing with the Sydney Basin, but also contribute through discussion to further advances in our understanding of geological processes in one of Australia's most economically important geological provinces. I hope we have also provided a venue in which you have plenty of time to renew acquaintances, make some new ones, and have an enjoyable time! As someone who is still relatively new to the Sydney Basin, I look forward to meeting you all and hearing of your work.

Stephen Cox
Head, Department of Geology

NEWCASTLE BICENTENARY SYMPOSIUM PROGRAM

"ADVANCES IN THE STUDY OF THE SYDNEY BASIN"

FRIDAY	**18 APRIL 1997**
9.30am - 5.00pm **EXCURSION**	AN OVERVIEW OF THE GRETA, TOMAGO AND NEWCASTLE COAL MEASURES *LEADERS :* Ron Boyd, Aldo Van Heeswijck, Murray Little, Ken Brown, Russell Rigby The excursion will visit exposures of all three coal measures in the lower Hunter Valley. In the morning there will be an opportunity to visit the Greta Coal Measures In Pelton Open Cut prior to its final closure in 1997. After lunch we will visit the Tomago Coal Measures in Bloomfield Colliery open cut and conclude with a visit to the lower Newcastle Coal Measures at Black Hill Quarry. Lunch will be provided. Safety boots and hard hat are essential. In the event of heavy rain the excursion will be cancelled.
6.30pm - 11.00pm	**UNIVERSITY OF NEWCASTLE GEOLOGY GRADUATES' SOCIETY** **SHEEP ROAST - UNIVERSITY UNION**

SATURDAY	**19 APRIL 1997 - LECTURE THEATRE B**		
08:30 - 09:00	**REGISTRATION** - Foyer of the Geology Department		
09:00 - 09:05 **Lecture Theatre B**	**WELCOME** by the Head of the Department of Geology Professor Stephen Cox		
09:05 - 09:10	**OPENING** of the 31ST NEWCASTLE SYMPOSIUM by the NSW Minister for Mineral Resources, the Hon. Bob Martin, M.P.		
TECHNICAL SESSION 1	**LECTURE THEATRE B** **Chair**	**Ron Boyd, The University of Newcastle**	
09:10 - 09:30 ***Invited Lecture***	*Keith Bartlett et al* *Coal Operations Australia Ltd*	Exploration of the Wyong Area	
09:30 - 10:00	*Rod Boyle* *Dartbrook Colliery*	Ettrema - The Dancing Queen Mine	
10:00 - 10:30 ***Invited Lecture***	*Jeff Becket et al* *NSW Dept Mineral Resources*	History of Mining in the Upper Hunter Valley	
10:30 - 11:00	**MORNING TEA**	in the FOYER OF THE GREAT HALL	
11:00 - 11:30	*Greg McNally* *UNSW - Applied Geology*	History of Wallamaine & Wallarah Collieries	
11:30 - 11:55	*Peter Fennell* *Coffey Partners Int'l*	Down-hole Camera Observations of the Yard Seam, Newcastle	
11:55 - 12:35	***Dr John Turner*** ***Newcastle***	**KEYNOTE ADDRESS**	The Rise of the Coal Industry in 19th Century Newcastle
12:35 - 12:40	*CHAIR*	VOTE OF THANKS	
12:40 - 13:50	**LUNCH**	in the UNIVERSITY UNION	

SATURDAY	19 APRIL 1997	
TECHNICAL SESSION 2	**LECTURE THEATRE B** **Chair** **Stephen Cox**, The University of Newcastle	
13:50 - 14.15	*PJ Hanna , ECS International & J L Cameron McElroy Bryan Geological Services Pty Ltd*	Computer databases & geological modelling Hunter Valley geology to meeting today's exploration & mining requirements
14:15 - 14:45	*Nikolai Kozyrev & Greg Skilbeck U.T.S.*	Origin of CO_2-rich gas from the Permian Coal Measures of the Northern-Sydney Basin
14:45 - 15:15	**AFTERNOON TEA**	In the Foyer of the GREAT HALL
15:15 - 15:45	*David McLintock & David Murray Douglas Partners Pty Ltd*	Slope Stabilisation Assessment & Remediation Works - F3 Freeway Cuttings, Wahroonga to Hawkesbury River
15:45 - 16:15	*MS Newton & J M Whitehead CPEU The University of Newcastle*	The development of innovative techniques for the use of biosolids and native seed treatment in coalmine spoilpile rehabilitation
16:15 - 16:45	*Carsten Matthai Sydney University*	The effects of Newcastle harbour dredge spoil dumping on surficial marine sediments
17:00 - 17:15	*CHAIR*	VOTE OF THANKS
19:00 FOR 19:30	**SYMPOSIUM DINNER**	**In the UNIVERSITY UNION**

SUNDAY	20 APRIL 1997	
TECHNICAL SESSION 3	**LECTURE THEATRE B** **Chair** **Phil Seccombe, The University of Newcastle**	
09:30 - 09.55	*J Enever et al CSIRO Petroleum Resources*	The current stress state in the Sydney Basin
09:55 - 10:20	*Hakan Kahraman & Charles Coin ACIRL Ltd*	Technical factors determining the comparative coking coal prices in Japanese market
10:20 - 10:45	*Judith Bailey University of Newcastle*	Coal gasification and PCI - New information from char
10:45 - 11:15	**MORNING TEA**	in the Foyer of the GREAT HALL
11:15 - 11:45	*Colin Ward UNSW*	Use of the electron microprobe in chemical analysis of coal macerals, with special reference to direct determination of organic sulphur
11:45 - 12:15	*Aldo van Heeswijck*	Reinterpretation of Greta Coal Measures
12:15 - 12:20	*Larissa Gammidge NSW Dept Mineral Resources*	Pyrite morphology of the Greta & Liskeard Seam
12:45 - 12:55	*CHAIR*	VOTE OF THANKS
13:00 - 14:30	**LUNCH**	In the UNIVERSITY UNION
14.30 - 16.30	Standards Association Meeting -	MN/1/5/1 Coal Petrography Working Group for Standards Association Australia

EXPLORATION OF THE WYONG AREA

B C Preston, K E Bartlett & J L Edwards
Wyong COAL Pty Ltd, PO Box 43, Wyong NSW 2259

INTRODUCTION

In October 1996 Coal Operations Australia Limited (COAL) was awarded Exploration Licences 4911 and 4912 covering approximately 250 square kilometres in the Wyong-Tuggerah Lake area. This area is a rapidly developing residential region because of its proximity to Sydney and ease of access. It contains zones of significant ecological and environmental interest, eg Tuggerah Lake, wetlands, State Forest and remnant rain forest. There are also areas of particular interest and significance to the local aboriginal population. The local community in general has no traditional ties to the mining industry. These factors and the need to carry out exploration in a cost-efficient manner requires modern techniques which are sensitive to the local environmental conditions.

EXPLORATION STRATEGY

A comprehensive exploration strategy for the Wyong areas was developed during the tendering process. The philosophy of the proposal was an extension of that outlined in "Guidelines to Evaluation of Open Cut Coal Reserves" prepared by the Coalfields Geology Council.

Aerial Surveys

Initially an aerial magnetometer survey was conducted to locate igneous bodies. An aerial survey was subsequently run to produce up-to-date photography at a scale of 1:10,000.

Grid Drilling

Drilling is being carried out in stages. Stage 1consists of drilling the deposit on a 2 km square grid. Stage 2 holes are then drilled on a 2 km offset grid at the centres of 2 km squares. The third stage of exploration involves drilling bores on 1 km centres to infill the grid pattern. All 2 km bores are fully cored. These and all subsequent bores are geophysically logged over their entire length. Tools run include calliper, gamma, neutron, density, resistivity, sonic, dip meter and deviation. Later stage bores employing both coring and non-coring of Triassic sediments above the target seam rely on geophysical fingerprints from fully cored holes for correlation of upper sequences.

COMMUNITY CONSIDERATIONS

A major consideration effecting the exploration of the Wyong area is the fact that it is not a traditional mining area. Mining to date has been limited to shallower seams to the north where some mining induced subsidence made spectacular press stories for local newspapers in recent years. With the extension of the F3 Freeway and upgrading of rail services, the Wyong area has become a dormitory suburb for Sydney. Many residents who have moved into the region in recent years are not interested in working in the area but are attracted here by its quiet lush valleys and extensive waterways. COAL therefore has a large responsibility to educate and inform the local community on what effects a new industry in the area may have. This was initiated by opening an office with an "open door" policy in the commercial centre of Wyong. This serves as a focus for contact with the local community. A Community Liaison Committee was established chaired by a representative appointed by the Minister for Mineral Resources. This group which is made up of representatives from local council, community groups and the company meets on a monthly basis. The chairman accompanies company representatives to meetings of local community action/interest groups to ensure that all concerns expressed by local residents are addressed in a timely manner.

As mentioned earlier the Wyong area is a growing residential centre. Drilling on private lands is only be carried out once approval has been granted by the owner. The exploration area covers approximately 250 square kilometres. Excluding suburban areas there are in excess of 1500 households occupying small to medium sized farms, small acreages, country retreats and small towns. COAL has attempted to identify all owners outside the suburban centres and circulate them with regular newsletters and information about the project.

An example of the type of information which needs to be communicated to the public is the concept of the depths at which any future mining may be conducted. In recent years open cut mining has been the focus of mining developments. People immediately think that there will be a huge "quarry" developed in their back yard or that their house will fall down a hole just below the surface. A number of posters have been developed for use at information meetings which display to scale the depth of mining compared to the height of Centre Point Tower in Sydney, a landmark known by most residents. The responses from those seeing the display vary from amazement to relief.

The Wyong area has an active Aboriginal Land Council (the Darkinjung) who are keen to preserve their cultural identity and history. A number of significant sites have been identified throughout the area and some areas are subject to land claims. It is imperative that any exploration activity be sensitive to the requirements of this section of the community. Potential drill sites in vacant crown land or state forests are inspected by company representatives with Darkinjung sites officers to ensure that no significant sites are disturbed. A good working relationship has been developed.

ENVIRONMENTAL CONSIDERATIONS

The Wyong area has some very important environmental factors to be considered when planning any new development. This exploration program has employed a number of procedures and equipment specifically designed for conditions encountered.

Lake Platform

One of the most conspicuous geographical features of the Wyong area is Tuggerah Lake. This is a shallow broad lake fed by Wyong River, and Jilliby Jilliby and Ourimbah Creeks flowing from higher country to the west and open to the sea at The Entrance. Two major watercourses feeding into the lake are the source of the regions water supply. The lake supports an active fishing and prawning industry and is used for recreational boating. Exploration activity was not to cause any pollution of this very important environment. Mitchell Drilling from Brisbane developed a drilling platform specifically for the project. The drill platform measuring 20 metres by 9 metres is supported on large pontoons enabling it to be towed onto sites in water as shallow as 1 to 1.5 metres water depth. Once on site, four legs are lowered to the bed of the lake and the platform raised to clear the water. It is generally stationed approximately 1 metre above normal water level. Because the lake is very shallow and broad, rough conditions can develop quite quickly but drilling operations are not hindered.

The platform has been designed to be totally self contained. Drill casing is lowered into the lake floor and sealed up to the platform. All drilling fluids then circulate through a series of tanks on the platform where drill cuttings are removed and placed into sealed 44 gallon drums for transport to shore. A dam included in the design around the outside of the deck is sufficient to contain much more than the total drilling fluid should any of the containers or sumps rupture. Consumable supplies, additional equipment, cuttings and core samples are lifted from the platform to tender vessels by a crane in specially designed cradles.

Oil Spill Kits

In any industrial workplace there is always the potential that pollutants may be accidentally spilled. To minimise risk to the environment of any incident at land or lake sites all personnel are fully trained in the use of oil spill kits. Two kits are maintained, the one for the lake rig having additional spill control booms to contain any spill.

Environmental Checklist

An extensive checklist system has been developed to ensure that minimum impact is caused by the exploration program. A separate environmental file is generated for each hole. Specific requirements are discussed with the landholder during access negotiations. These are noted and explained to the supervising geologist, land management contractor and drilling contractor. The file includes an environmental checklist to be monitored during the drilling operation. On completion of the bore the site is inspected with the landowner before the file is signed off.

Borehole Sealing

Of major importance on this project is the need to ensure that all boreholes are effectively sealed. Considerable effort and time was spent developing a cementing procedure which was both practical and sound. All bores are sealed with a cement grout by pumping cement to the base of the hole via drill rods. Lake bores can only have a maximum of 200 metres of hole sealed in any one operation; a mechanical plug is also inserted in these holes approximately 100 metres above the uppermost working section. Samples of each batch of cement are taken and a written record of cement mixes, volumes, intervals, and plugs are recorded on a specially developed report sheet.

During the sealing of one of the lake bores a problem occurred which it is felt should be drawn to the attention of all geologists responsible for sealing boreholes. A part of our sealing process involves confirmation that the grout has set and that it has filled the hole to the planned level. In the hole in question the grout was located 100 metres above the designed position. When the seal was drilled out the base of the hole was found to be filled with water. Careful investigation of the grouting process and computer modelling revealed that the plug of cement had floated in the rods and had never reached the bottom of the hole. A spreadsheet was

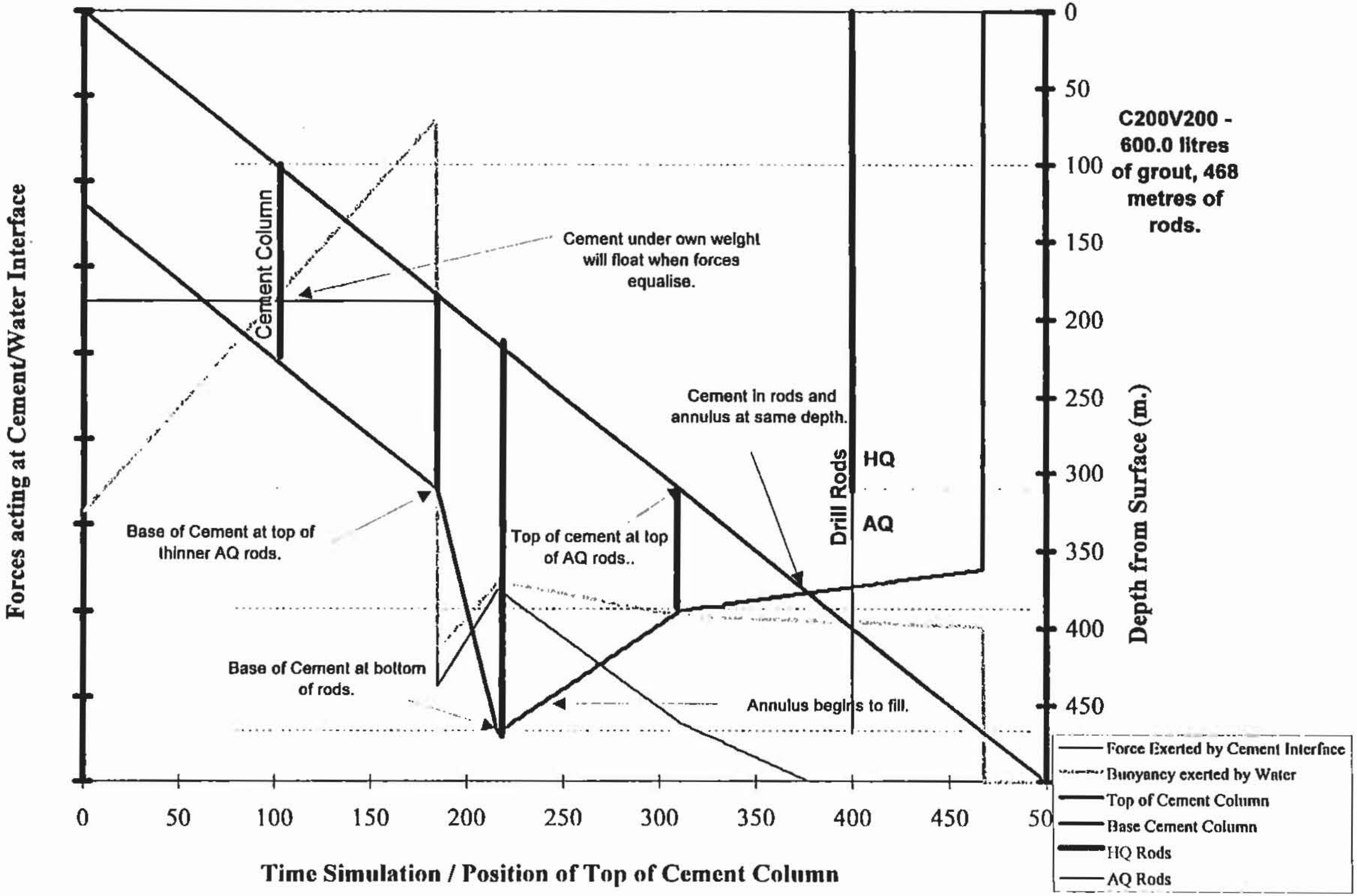

Figure 1. Simulation of forces acting on cement column during sealing.

developed to model forces acting about the grout column. The accompanying chart (Figure 1.) from that spreadsheet explains why the column floated and can now be generated immediately for any hole to a depth of 750 metres. It is now obvious that this problem could occur in any bore containing water if rods (some or all) are extracted before a critical amount of grout/water is pumped into the rods. Calculations of required cement volumes and follow-on water required to prevent flotation are included as part of the model and are prepared before sealing is commenced on any hole.

TECHNOLOGIES EMPLOYED

Data Transfer

To minimise the chance of data corruption and inaccuracies, wherever possible data capture is performed directly onto computer and transferred electronically to subsequent data processing systems. After delivery to a central core shed all logging is carried out directly onto computer using the ProLog program. Output is transferred by disk to the Wyong Office and stored on an NT Server for backup. Downhole geophysical results are e-mailed to the Wyong office and this data is also stored on the server. The application MEGSLog is used to display the lithological and geophysical data together so ply correlations can be added to the borelog. Before coal seams are sampled MEGSLog is also used to insert unique sample numbers into the data file and to output sample tags used by the laboratory. All laboratory results are stored and reported from an ACCESS database application. Data from this system is also e-mailed directly to Wyong. Coded borelog files, geophysical LAS files and analytical data files are then transferred directly to the Silicon Graphics workstation and loaded into VULCAN modelling software.

Core Photography

All bore core is photographed under uniform conditions in a frame permanently set up in the core shed. In addition to conventional prints all exposures are stored as digital images on CD-ROM. After photography is completed bore core is stored in racks for easy access.

Survey

Much of the area is covered by steep forested country and Tuggerah Lake. Site location and final survey in these areas by conventional methods would be both time consuming and very expensive. GPS is being used for all surveying in the project area, on lake and land. Initial sites are located to within 20 metres without a base station installed.

Precise locations are determined within millimetres with a base station installed.

Other Surveys

Additional procedures being undertaken on selected bores include:-
- Gas content testing
- Geotechnical testing
- Hydrologic investigations
- Placement of geophones for future in-seam seismic surveys

CONCLUSIONS

Exploration of the Wyong area is being carried out utilising five drill rigs. Enormous volumes of data are being generated. Without using modern computerised techniques it would be impossible to process and evaluate the quantity of data produced. All issues of significance to the local community are being addressed. Operational procedures are being developed and constantly improved to ensure that the exploration program causes minimal disturbance to the existing environment and that all relevant data is securely recorded for future reference. Already some interesting results are being generated, some of which will undoubtedly form the subjects of a number of presentations at future symposiums.

ETTREMA - THE DANCING QUEEN MINE

R Doyle
Dartbrook Coal, PO Box 517, Muswellbrook NSW 2333

ABSTRACT

This paper summarises the history of the Ettrema Mine. Despite being the subject of numerous geological investigations and some small exploitation, the ore bodies haven't been adequately explored. Since its discovery some 90 years ago, the ore bodies have experienced a variety of issues ranging through geological, environmental and political. Its proximity to the Morton National Park raises doubts about any future exploration.

Metalliferous ore bodies of mixed quality exist in two main veins including, zinc (15%), iron (15%), arsenic (6%), lead, (5%) and copper (2%). Associated with faulting the mineralisation is related to margins of the Eden-Comerong-Yalwal Rift Zone.

INTRODUCTION AND LOCATION

Small bodies of mineralisation occur throughout the metallogenic provenance of the Upper Shoalhaven area, with gold at Yalwal and Oallen, tin and copper at Wandandian and Tolwong, (the latter having a smelter erected alongside the Shoalhaven River) and galena at Yarramunmun to name a few. The purpose of this paper is primarily to detail the work conducted and highlight the potential of Ettrema, which has experienced a unique, albeit short lived mining history.

Situated some 40kms to the south-west of Nowra, Ettrema lies on the edge of the Sydney Basin. The Ettrema Mine is located on Jones Creek (formerly Rolfes Creek) which flows into the Ettrema Creek and then into the Shoalhaven River. The mine is at water level at the base of a gorge, which Jensen describes as 'narrow and awful'. The mine is adjacent to Morton National Park in an area defined as a Mining Reserve. Figure 1, shows the location of Ettrema Mine.

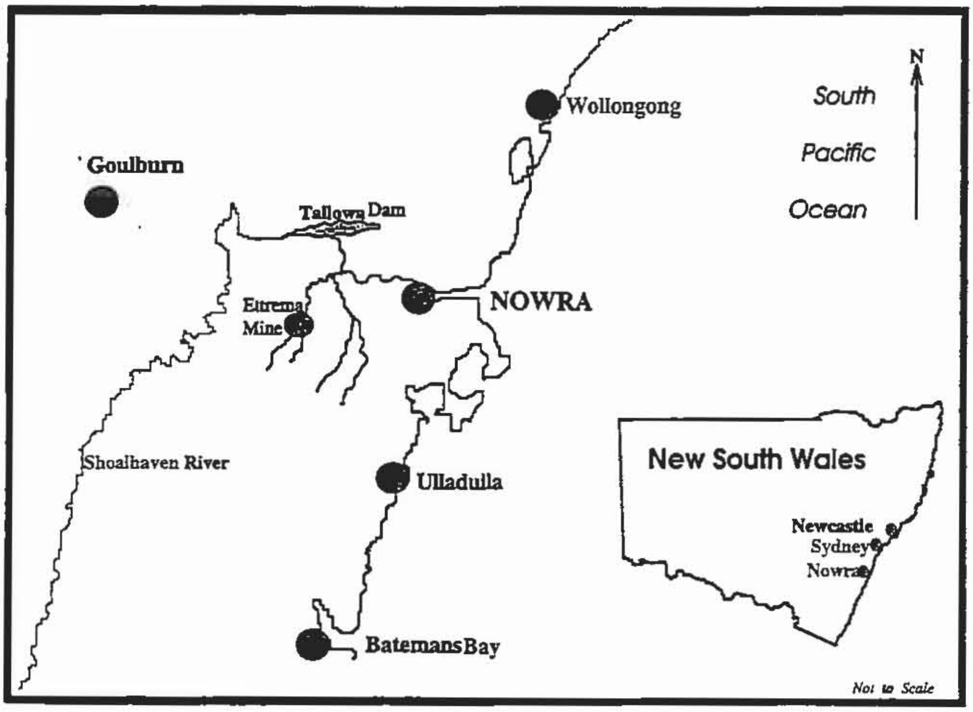

Figure 1. Location Map - Ettrema Mine

GENERAL GEOLOGY AND STRATIGRAPHY

The rocks of the Ettrema area include quartzites, siltstones, sandstones and limestone of Ordovician, Silurian and Devonian age. Which are in turn capped by massive marine sandstone and siltstone rocks of Permian age from the Shoalhaven Group. The surface of the land is relatively flat and contains numerous swamps. Figure 2 is an aerial photograph of the area, showing the prominent jointing present in the sandstone capping. Also evident in the photograph is the steep rugged nature of the Ettrema gorge. Table 1 shows the stratigraphy relating to the area mostly taken from McIlveen, 1975.

EXPLORATION HISTORY

On two occasions in 1908, for periods up to a few weeks, Jensen explored the area. He wrote a paper which he read before the Royal Society of NSW. It is a fascinating account which merges many aspects in a narrative of botany, geology, science and geography. He displays a high level of geological understanding of a complex area. He believed that the Sassafras tableland was a horst, having a north-south trending fault to the west, with Ettrema Creek rising in the heart of this horst.

Jensen described Tertiary basalt capping and the possibility of a rude columnar jointing where the basalt has been eroded to expose the underlying sandstone. He notes fossils found in the Devonian strata (Spirifer disjuncta and Rhynconella pleurodon) and notes the abundance of crinoid stems in the limestone.

ETTREMA - THE 'DANCING QUEEN' MINE

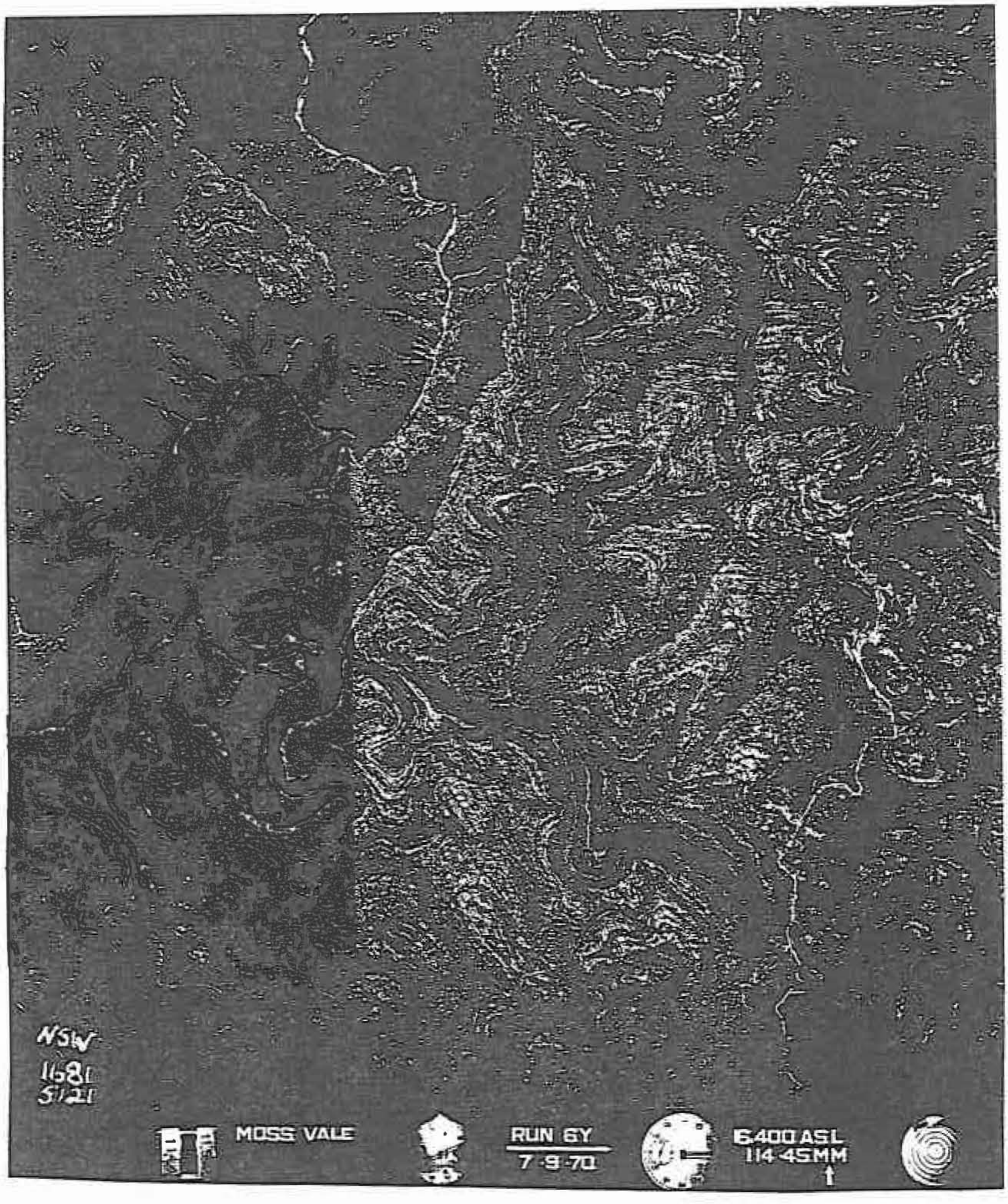

Figure 2. Aerial Photograph Covering Ettrema and Jones Creeks.

Jensen states that the Devonian rocks have undergone significant alteration and severe folding. The basalt capping he attributes to the period of faulting probably occurring in the Tertiary - which allowed for the intrusion and extrusion of the basalts. He described the thick nature of the marine sandstones and notes that they overly folded rocks of Devonian age.

He describes the ore bodies, linking their presence to the faults that have occurred acting as channels for the ascent of metallic solutions from below. He identifies several ore bodies, two main ones 20 and 8 feet thick. Although separate at exposure, he believed the ore bodies would join up at depth, their joint pipe still widening with the quality becoming more concentrated. The ore bodies contain galena, zinc-blende, and chalcopyrite amongst other more minor minerals. He believed the source of the mineralisation could have been a great laccolith intruded at great depth. (The presence of granites outcropping locally were found at a later date by other workers.)

Period	Formation	Rock Types
Tertiary		Basalt Flows
Permian	Shoalhaven Group	Sandstones
Carboniferous		Granitic Intrusions
Devonian (Frasnian)	Merrimbula Group Equivalents Ettrema Limestone Member	Sandstones, Shales & Quartzites Limestone Quartzites
Silurian		
Ordovician	Undifferentiated Metasediments	Phyllites & Quartzites

Table 1. Stratigraphic Column

In the Geological Survey No 7 Memoir of 1915 Harper briefly mentions the ore bodies describing them as metasomatic replacements in limestone. He did not consider the prospect promising. He believes that the Sassafras Plateau is not faulted as suggested by Jensen but is simply folded.

In 1949 Glasson visits the mine site to take samples and in his report refers to Dr Jensens report as well as Mine Department Records. He notes that there are 3 tunnels driven south in the creek bed and in each case they start in ore but after 40 feet there is no ore in the drives. He presents assay results from the DMR records and from the Lake George Mines Pty Ltd.

Thomson (1957) notes that the extensive Permian cover conceals the strike extension of the known mineralisation and that the lodes are only revealed by accidents of erosion. He noted that lodes 1 & 2 were the main bodies and made recommendations for 500 feet of shallow diamond drilling. He estimated tonnage per foot depth of the lodes and presented grades of samples taken. His examination of specimens suggested that minerals would be liberated at a fairly coarse grind. With galena possibly being concentrated by gravity methods, other sulphides may be separated by flotation.

In Kennedy's (1963) abstract he notes that the richness of the ores is offset by their irregular nature and the inaccessibility to the mine. He states that the ore bodies are unusual in that no secondary ore has developed. He lists the following ores as being present; arsenopyrite, sphalerite, smithsonite, chalcopyrite, galena, stannite, tetrahedrite, pyrite, native bismuth and tin in the form of sulphide stannite. Kennedy states that the No 1 lode, is vertical, some 30 feet wide with a proven length of 250 feet and of an unknown but possibly considerable depth. The gangue which is essentially a skarn, consists of calcite, wollastonite, diopside, epidote, garnet, quartz, fluorite, and secondary silica.

ETTREMA - THE 'DANCING QUEEN' MINE

Croft et al. (1970) undertook geological mapping of the Ettrema-Jones Creek Area, producing a report for BHP. The rugged terrain exacerbated the problems experienced with geological mapping. They note the rocks present in the area, similar to Jensen, locating unconformities. The conclude that the weakly mineralised limestone along Ettrema Fault suggests that an area for potential mineralisation exists between this fault and the Jones Creek mineralisation.

McIlveen (1975) states that the Eden-Comerong-Yalwal Rift Zone is a discontinuous meridional graben bounded by normal faults representing a transitional tectonic setting from volcanic rift to rift valley. Forming in an area of tension, the site of the graben then becomes a site of intensive sedimentation.

During the 1970's J.A.M. Doyle explored the Ettrema over several years, Figure 3, shows his hand drawn cross-section of his interpretation of the area. Table 2 presents the assay analysis of samples taken over the years by the many workers who have sampled the ore bodies.

YEAR AUTHOR	Pb%	Zn%	Cu%	As%	Bi%	Fe%	Au oz/t	Agoz/t	Comments
1907 DMR A.Report	50.0	39.0	6.0					51.0	
1899 CARNE	6.2	10.6	1.4	17.4				8.0	
	8.9	28.1	1.6	3.8				9.0	25' thick
		22.8	0.2					1.0	cuts across bedding
1908 JENSEN	20.0	50.0	6.0				0.4	62.4	
1909 DMR A.Report	16.0	20.0	3.0					20.0	Average of Results
1948 WILLOUGHBY	4.8	9.3	0.4	23					300'N of Jones Waterfall
	9.7	20.2	0.8	2.8					Down from 2nd Waterfall
	6.7	5.2	0.8	4.2					Bottom of Cave
	0.8	18.7	0.3	0.3					
	0.8	8.1	0.1	0.3					E side of Creek 8' sample
1949 GLASSON	1.8	17.4	0.2	0.6		7.0			20' across face W channel
	0.4	0.8	0.2	2.7		29.6			Sulphide ore above Waterfall
	20.7	4.6	3.4	11.3		21.0			Grab sample above lode
	13.3	18.6	2.8	11.2		15.4			Small Grab Sample E lode
1957 THOMSON	0.3	5.7	0.2					0.6	No 1 lode (200t/ vertical foot)
	0.3	24.2	0.6					0.8	No 1 lode (10t/ vertical foot)
	0.3	3.5	0.1					0.2	No 2 lode (50t/ vertical foot)
	9.0	21.2	1.2					8.0	No 3 lode
	4.0	8.0	1.4					6.0	No 4 lode
1963 KENNEDY	6.1	3.5	3.6	17.4				10.0	No 4 lode
	9.1	21.2	1.2					8.0	No 3 lode
	5.7	0.3	0.3		0.05				N. lode
	31.8		0.1					0.2	No 1 lode
1979 DOYLE J.	11.0	25						10	Robertson Research 1974
Estimated*	7.6	23	1.5	5.2		11.2		12.9	Lode 1
Average*	4.7	15	1.6	5.7		15.4		1.6	Lode 2
Assays*	8.4	17	5.6					6.3	Lode 3
Overall*	3.8	5	1.1	21.2				5.7	Lode 4
** Also by Doyle J									

Table 2 Assay Analysis from Ettrema's four Ore Bodies.

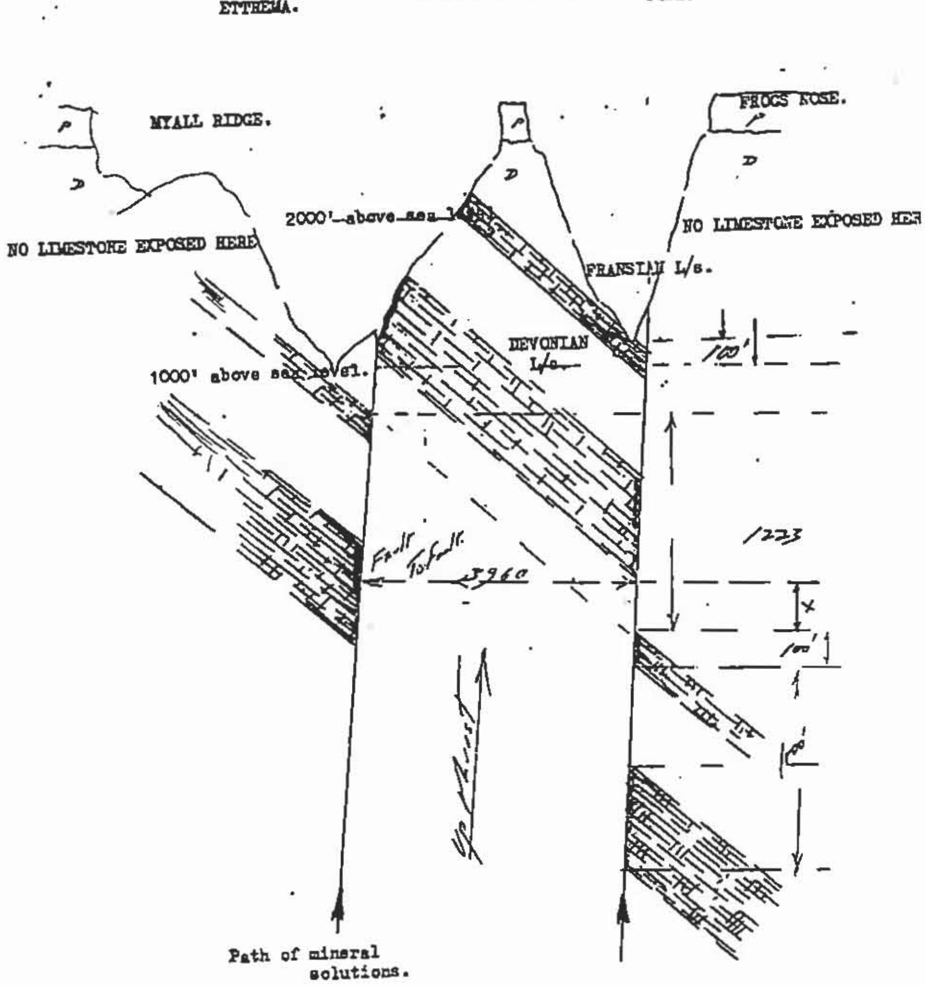

Figure 3. Cross-Section of the No 1 Ettrema Ore Body.

THE DEPARTMENT OF MINES ANNUAL REPORTS.

The Department of Mines annual reports have several entries over the years 1907-1911, 1914 and 1947, a brief summary is provided here. In 1907, it was suggested that assay results would justify the hope that an important mine would open. In 1908, a company, 'Ettrema Mines (Limited)' commenced mining operations, developing an aerial ropeway to remove ore. In 1909, '200 tons of ore were raised to grass'. It was suggested that, a large outlay on machinery and plant would have to be faced before the complex ore of which there is stated to be an exceedingly large quantity in sight can be successfully handled.

During 1910 work on the lease was directed to further exploration and opening up of the ore bodies. Driving and cross cutting totalled over 300 feet. The ore raised amounted to about 300 tons. In 1911, work was suspended owing to the capital being exhausted and efforts were made by one of the directors to proceed to Europe to raise capital. The outbreak of war made the task of raising money remote. The 1914 report notes that there are about 400 tons of ore at grass and that the adits, shafts and drives totalled 404 feet. No active work has been undertaken since. In 1947 mining leases were granted but no mining operations were conducted during the year. Then during the late 1970's an attempt to obtain a mining lease was made but the attempt met with considerable resistance from conservationists.

ETTREMA - THE 'DANCING QUEEN' MINE

WARDENS INQUIRY

During the late 1970's Doyle applied for mining leases over the Ettrema Mine area. Several groups of conservationists claimed that the granting of such a licence in a wilderness area would be against the public interest. They described the area as one of 'pure wilderness', (despite having been previously mined). Several of these conservation groups wrote letters objecting to the granting of mining claims over the area. Newsletters published their concerns to their membership. Doyle felt, that these objections were 'playing the individual and not the ball' and as a result he issued writes against several groups for deformation.

A Wardens inquiry examined submissions for and against a proposal to gain access to the Ettrema Mine. Upon conclusion of the ten day hearing, the Chief Warden presented his findings to the Minister the Mines, the Honourable R.J. Mulock. Mulock replied to Doyle stating that he had both received and considered the report from the Chief Warden, listing recommendations that he will make to the Governor, primarily they are;

- to make a Mining Reserve over the Ettrema area,
- direct that no claims, mining leases, mining purposes leases or prospecting licences shall be granted within the reserve.

His letter goes on to say that, "In specific instances, call upon persons or companies to apply for exploration licences to prospect within the proposed reserve area. *The mineral potential of this area should be ascertained*........Holders of such licences would be warned that the proposed reserve will prevent the grant of a mining title." In retrospect the Minister got one thing right, in that the mineral potential of this area is still unknown. Doyle considered that evidence existed that Mulock neither received nor considered the report, as a result Doyle took Mulock to court for denial of natural justice. He passed away prior to these issues being resolved and the matters were struck off.

CONCLUSIONS

The paper summarises work conducted in the past and acts as a simply reference guide to the material currently available. The paper attempts to outline the potential of the Ettrema as a mineral resource of the Shoalhaven area. The assays over the years show some variations reflecting various sampling techniques. Nevertheless, what they all clearly point out is that these ore bodies are worthy of further exploration. To ascertain the thickness and depth of the bodies drilling needs to be undertaken, to this day there are no exploration boreholes.

ACKNOWLEDGMENTS

This paper is dedicated to my late father, who had he started mining would have called the mine 'the Dancing Queen'., in honour of Queen Elizabeth II, Queen of Australia!

ROD DOYLE

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A BRIEF HISTORY OF COAL MINING IN THE UPPER HUNTER RIVER VALLEY

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INTRODUCTION:

The History of the mining of coal in the Upper Hunter River Valley is fragmented and poorly documented in comparison to the information available for the Newcastle or South Maitland - Greta Coalfields.

We are geologists, not historians, but like many geologists have a strong interest in the history of mining and geology. History, like geology is interpretive and the "truth" is often in the "eye of the beholder", (to mix a metaphor or two).

The search for a mineral deposit almost naturally begins with a review of past exploration and mining data. This search often reveals very useful data, but also sometimes provides extremely interesting insights into the technologies and social fabric of the times being researched. In the case of coal mining in the Upper Hunter Valley, our search of archival and historical data has provided an insight into some of the people and the social and economic background to the development of the mining industry Indeed, as in the case of Prof. David Branagan, or in the case of popular historical articles written by Jim Comerford, a retired miner from Cessnock, the history and the historian often become intertwined with time.

So, as well as presenting you with maps and tables of early mines and production figures which our research has established, we would also like to present some images of the people, the prospectors, geologists and miners, within the social framework of the time.

STAGES IN THE EXPLORATION AND DEVELOPMENT OF COAL MINING IN THE UPPER HUNTER RIVER VALLEY.

1. Early Reports of the Occurrence of Coal - 1820-1830
2. Local Domestic and Rural Industry - 1850-1920
3. Gas Production & Power Generation Industry - 1940-1970
4. Export Coal Industry - 1975-2000

STAGE 1. EARLY REPORTS OF THE OCCURRENCE OF COAL IN THE UPPER HUNTER VALLEY, 1820-1830.

The earliest reports of coal in the Upper Hunter River and its tributaries begin with the first exploration parties in the early 1820's and from the farmers and graziers who quickly followed.

Howe Expedition 1819 - 1820

In October 1818 the Chief Constable of Windsor, John Howe , with a party of 7 others, set out to explore the forbidding country northward.

On the 4th November the party reached a point where they looked down Doyles Creek at the Hunter River Valley between Denman and Singleton.

On the 5th November they reached the junction of Doyles Creek and the Hunter River.

"In the afternoon they made a course downstream in a generally easterly direction, picking up in the river some large pieces of coal, which the took back to Windsor."

Cunningham Expedition 1825

In March 1825 Allan Cunningham set out from Richmond with the intent of making the Hunter River at its nearest point and then to proceed further north to country that he had explored in 1823.

On the 11th April they reached the "extensive sheep farm of John Marquet Blaxland on the Wollombi". On the 14th April they passed through the farm of George Blaxland ,(Wollun Hills) which Cunningham noted as " the most distant land possessed and occupied on Hunter's River".

By the 16th April they camped at the Junction of Wybong Creek and the Goulburn River where Cunningham noted the *"luxuriant grassy flats and large masses of coal on the lower part of the river"*.

Henry Dumaresq, St. Heliers Vale, 1826

After " exploring the remoter parts of the Hunter River for 10,000 acres of good country", on 6th March 1826, Colonel Henry Dumaresq reported that he had secured land at St. Helier's Vale. By December 1826 a house was under construction on St Heliers Creek and Dumaresq wrote that *"The river and brook furnish fish and wild birds in myriads, and you get your coal from the banks of the former without more ado than to shovel them up."*

By the 1830's coal occurrences were being reported from many properties in the Hunter Valley, extending from east of Singleton through the Muswellbrook and Scone areas to Burning Mountain at Wingen.

In July 1828 the Sydney Gazette published a report by the Rev. C. P. N. Wilton which stated that *"I found specimens (of coal) in the Kingdon Ponds about seven* *miles from the (Burning) Mountain. This mineral has been found on Colonel Dumaresq's estate at St Heliers, at Mr Ogilvies at Merton, at Captain Wright's Bengula (Bengalla), at Dr Bowman's on the Foybrook (Ravensworth), at Mr Glennie's on the Falbrook and at Mr Scott's on the Westbrook (Glendon)*

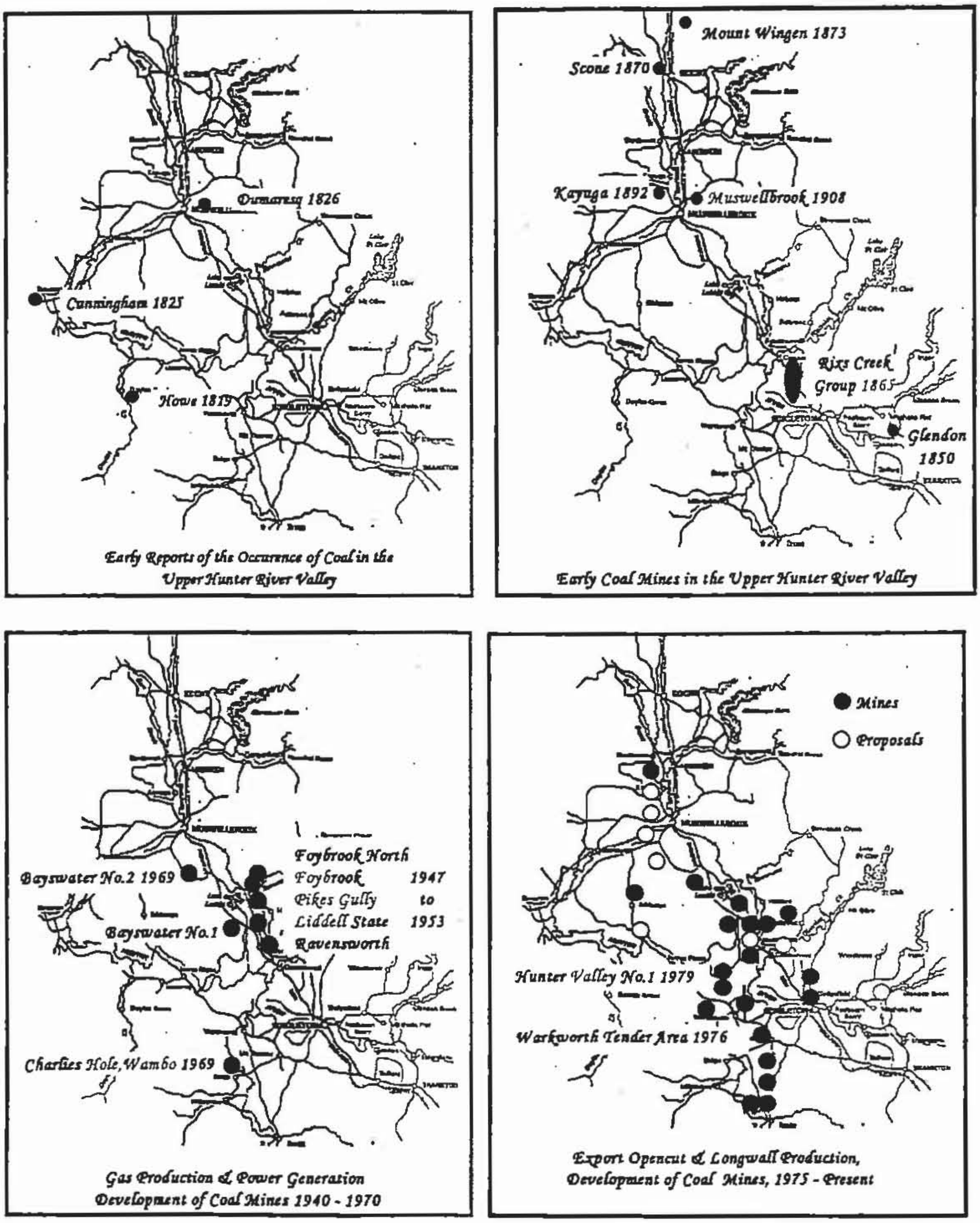

Figure 1. Stages in the exploration and development of coal mining in the Upper Hunter River Valley.

STAGE 2. DEVELOPMENT OF COAL MINING TO SUPPLY LOCAL DOMESTIC AND RURAL INDUSTRY, 1850-1920.

It may not comfort the Minewatch group a great deal to have to acknowledge that the first coal mines in the Upper Hunter Valley developed largely in response to the energy requirements of the early dairy industry.

Possibly the first coal mine in the Hunter, to the west of the (then undiscovered) Greta Coalfields, was some 10 kilometres up the river, just past the junction of Glendonbrook and the Hunter River. The Maitland Mercury of 6th July 1850 reported that excellent samples of coal from Glendon could be purchased in Singleton for 17/6d per ton

The Glendon Mine was developed on steeply dipping outcrop of the Bayswater seam at the southern end of the Mitchells Flat Fault. It provided coal for the boilers of the condensed milk factory on Corinda Property at Lower Belford, as well as domestic heating coal to the Singleton community.

In a similar manner the first coal mine at Muswellbrook, the Kayuga mine, provided energy for a local butter factory.

Mine	Location	Year Established	Year Closed	Total Tons Produced	Revenue Pounds	Average Employees	Owner
Glendon	Elderslie	?1850	?	?	?	?	?
Rixs Creek	Singleton	1865	1896	28439	£15,059	5	J. Elliot., E. Campbell.
Scone	Scone	1870	1872	260	£153		?
Mount Wingen	Murrurundi	1873	1879	320	£180	2	Rev. J. Nash
Singleton	Singleton	1879	1885	27403	£27,403	25	?
Ellesmere	Singleton	1880	1894	121032	£56,250	23	Longworth
Rosedale	Singleton	1885	1903	54687	£23,170	11	Minto, Nowland & Co., Longworth.
New Park	Singleton	1886	1903	238716	£89,415	46	Singleton Coal & Coke Co.
Quarry Tunnel	Singleton	1886	1887	3600	£1,330	5	?
Dulwhich	Singleton	1888	1903	41965	£15,838	8	Singleton Coal & Coke Co.
Kayuga	Muswellbrook	1892	1903	7961	£2,575	2	H. Hyronimous., Kayuga Coal Co.
Rose Hill	Singleton	1893	1894	1313	£376	4	?
Sunlight	Singleton	1893	?1894	74	£18	2	?
Granbalang	Singleton	1897	1903	10375	£4,770	10	J. Elliot
Muswellbrook	Muswellbrook	1908	Current			84	Muswellbrook Coal Mining Co. Ltd.

Table 1 Early Coal Mines in the Upper Hunter River Valley.

The early coal mines in the Upper Hunter Valley were mainly located around the newly growing towns of Singleton and Muswellbrook.

Singleton Area

There were up to 16 mines operating in the Rix's Creek and Nundah area. Records compiled from Department of Mines Annual Reports show dates and production from 10 of these mines for the period between 1865 and 1903, when the method of reporting apparently changed.

Production from other known mines, which included "Nundah Extended"," Whodathoughtit", "The Busted Onion" and the "Dog and Rat" is not recorded. Often these mines were amalgamated into the larger operations. The largest mines in the Rix's Creek- Nundah area, New Park and Ellesmere produced several hundred thousand tons of coal. Five others, Granbalang, Rix's Creek, Dulwhich, Singleton and Rosedale each produced tens of thousands of tons over periods of 10 to 15 years.

The story of William Longworth, one the main proprietors in the mines in the Rix's Creek - Nundah area provides an interesting example of the personal perspective that can be put on history. The first item below is a summary by Singleton Historical Society from information supplied by Jim Comerford, a miner whose affiliations were with the Miners Federation.

"William Longworth started life as a labourer at "Dulwich" and ended up a magnate and millionaire. Much of Longworth's wealth came from a business connection with Cobar Copper Mines where coke from his Rix's Creek Mine was used to smelt the copper ore. Mr A. Dangar from Baroona was a partner with Longworth in the Great Cobar Copper Mine.

The closing of the Rix's Creek Mine was sudden and absolute. The Miners Federation was in its infancy and most of its members were in the big coal producing areas. concern. Eventually the Singleton miners joined but when they were asked to go on strike over an issue in a Sydney mine and which did not concern them at all, Mr Longworth told them that if they went on strike he would close down the pit. When assured by the organisers that they had nothing to fear the miners walked out. A week or so later the strike was over and the locals returned to the pit to find it locked. It never reopened. Those were the days of no social service payments and the miners used to walk into Singleton to beg for food. Gradually the families left, the school closed and the houses were removed. The once prosperous village again became grazing land."

The second article, from a private publication of the history of the Glennies Creek area paints a much more benevolent picture of Longworth, who kept uneconomic mines open and compensated miners when the pits were closed.

"Things went well for Longworth who had started with nothing and by the turn of the century had become a millionaire. Then coal prices slumped and miners struck for more money and better conditions. Longworth agreed, gave them what they asked for and the

miners went back to work. Longworth although he made no profit, kept the mines open until the unions demanded even more money and better conditions, so he closed all his mines in 1921. He then compensated each man with a sum of money for each year of their employment."

Whatever the reasons, the final closure of the mines in 1921 ended an era. The Rix's Creek mines had enjoyed a 50 year prosperity since first mine opened in 1865. This period was associated with the expansion of the colony, major extensions to the railway, a market connection with copper mining at Cobar and the development of a major coal export industry. At the end of this period only one mine, Muswellbrook Colliery was left operating in the upper Valley. This may have been due, as is explained later, as much to political "influence" as to the high quality of coal.

The Upper Hunter mines, as well as the Newcastle mines, were by the turn of the century under increasing pressure from the much higher quality of coal being won from new underground mines in the Greta, Cessnock and South Maitland fields.

At the height of this period of early mining, Hutchison, 1896, wrote that

"The quantity of coal shipped in 1895 to foreign and intercolonial ports was 1,920,378 tons, valued at £678,217; and the largest quantity of coal taken by a steamer (May 30, 1895) was 5235 tons, by the "Port Stephens," and by sailing vessel, 4,558 tons, by ship "Royal Firth," on June 14, 1895.

Collieries at Work, &c., in the Northern District, viz., Newcastle, Fourmile Creek, Maitland, Greta, East Greta, Singleton, Curlewis, and Gunnedah.

In 1895 there were sixty nine collieries at work and opening out in the Northern District, which raised 2,631,221 tons of coal, valued at £813,997, and the number of men employed in and about the collieries was 6,777".

Muswellbrook Area

Two small mines, at **Scone**,(1870-72) and at **Mount Wingen**, (1873-79) produced several hundred tonnes of coal for local domestic markets. Difficult mining conditions led to the closure of both ventures which were located close to major faults. The attempt at mining at Mount Wingen was documented later, when the Scone Advocate of May 1906 reported that *" the Rev. Nash, a gentleman of some attainments in the field of geology proved the existence of coal in the Wingen area but considered the prospects of working could not have been encouraging, (perhaps he had some inside information). Mr Abbott put a shaft down some 30 feet to hit coal present near the Burning Mountain. Again it did not appear encouraging. Sometime thereafter a group approached Mr Abbott to sink the shaft further and it was increased to a depth of 70 feet and was successful in hitting a coal seam some 16 feet wide. Here the coal seam was dipping very strongly at some 65 degrees to the west to near vertical. They noted the existence of another seam some 8 foot thick some 70 feet away. This led to some confidence in the project and a main shaft 8'6" wide was sunk. Preparations for* *exploitation of the coal became more serious and the general surface infrastructure was put in. The erection of poppet heads, an engine shed, a boiler, a winch, a dam and other sundry work was completed and the Wingen Coal Mine was all but producing. The boiler is a 8hp Tangye with 100lb pressure with a two 6" cylinder engine.*

Ironically it was a lack of water that was holding up production as the boiler had no water to create steam - and it had not rained for some considerable time. There are plenty of orders on hand from both Murrurundi and Scone which will receive attention as soon as water is obtainable and a start can be made. (This was in May and the wet season is summer - it was rumoured that mining would be suspended for 12 months.

A request for a railway siding was made to the Department of Railways but was never constructed. It was hoped that coal could be won for some 8 shillings per ton."

The first successful mine in the Muswellbrook area was the **Kayuga Mine** which was opened in 1892, by a syndicate led by Mr Arthur Cox, with Mr Harry Hyronimus the first manager. The Kayuga Coal mine raised its coal to the surface by horse and winch and delivered it to town by horse and dray, for use in the butter industry and to produce gas at the local gas works which commenced in 1894.

All coal won in the mine was done so by hand. It didn't take long for progress to take over and the horse and dray were replaced by a steam traction engine. *"Not only did these machines create quite a bit of unaccustomed noise but they tore strips off the road surface as well causing considerable dust to be lifted into suspension"*.

Industrial action taken in the lower coalfields did not reach the Kayuga Mine essentially due to the tyranny of distance. This led the Department of Railways to offer to take as much coal as the mine could produce which saw a dramatic change in production.

Kayuga was essentially laid out with coal extracted in workings not dissimilar to the Welsh Bords. Long narrow roadways which were up to 100 yards long ran in a north-south direction, were widened out to about 8-10 yards. The colliery was abandoned on the 26/11/1907. The final record tracing is signed off as a true record by W. Humble. The mine was worked on several subsequent occasions by private parties when the Muswellbrook Mine was closed by strike action. The last reported sample was taken from the mine in 1921 to be tested for production of coke by BHP.

Part of the reason for the demise of the Kayuga Mine was the discovery of coal on Muswellbrook Town Common when drilling operations, being undertaken by Mr J. C. White of Edinglassie, to find water, passed through several coal seams which were reported in the Muswellbrook Chronicle on 3rd July 1907.

An interested spectator at the water boring operations, Mr Harry Jeans noted the evidence of the coal intersections during the drilling. In company with Mr A Weidmann, Jeans immediately travelled to Scone and with Mr A. Smith of the Scone Advocate the three made an application to the mining warden for mining leases. A syndicate including H. Jeans, A. Weidmann, A. Smith, J. Luscombe, J. Sparkes, W. Barrett, D. Flemming and W. Flemming was formed and made application to Muswellbrook Council on the 20th July 1907 to prospect and mine the Common. The members of council at that time included Luscombe,(Mayor), Sparkes, Weidmann, D. Flemming and Barrett. The potential conflict of interest between the council and the infant coal company was not raised and approval to mine the common was given with the proviso that operations maintained a stated distance from the continuing water bore operation.

The initial development of the Muswellbrook Mine followed much the same path as the Kayuga mine, with Bord and Pillar workings. Initial mining was undertaken by hand with subsequent introduction of mechanised techniques. It was a big mine to begin with, starting with 4 miners and a single horse drawn skip but averaging about 85 people in its first few years of operation. Clearly this was a mine with a committed management and workforce, good coal reserves and a market. The markets were firstly domestic, with the main supplies going to the railways and the gas plant. By 1923 the company had built a local power station which eventually supplied Muswellbrook, Aberdeen, Scone and Denman areas with electricity.

The recently closed (March 1997), No. 2 Underground mine at Muswellbrook ended a period of nearly 90 years of continuous underground mining which began when the No. 1 underground mine opened in 1908. The St Heliers Mine, which began about 1923 was amalgamated with the Muswellbrook Coal Co. and operated for about 40 years. Open cut mining at the Muswellbrook mine commenced in 1944 with Thiess Bros. initially contracted to commence the operation.

Other early mining ventures in the Muswellbrook area were less successful. In 1919 or 1920 a coal mine was opened at Overton, about 2 miles to the west of town. A rail spur and siding were constructed, connecting with the Denman - Merriwa line. The mine was short lived and was abandoned. The siding and rail spur long since removed. (This line was in a position close to where the Coal & Allied Mount Pleasant Proposal has recently been refused council support for the construction of a rail line and loading facilities for the proposed mine).

Another syndicate formed to mine the South Muswellbrook mining lease was even less successful. Test adits and drillholes done in 1922 showed that large areas of coal were intruded and cindered. In a shaft sinking exercise at Muscle Creek where the coal proved to be cindered it was later found out that this was already known. Its interesting to note a comment in The Muswellbrook Chronicle 8/03/1963 which states, "had they taken notice of the chart drawn by that great geologist, Sir Edgeworth David, showing the lay of the coal seams in the area, much time and money could have been saved." Is there any hope for us mere geologists if the mining engineers wouldn't even listen to T.W.E. David.

STAGE 3. GAS PRODUCTION & POWER GENERATION, 1940-1970

The 3rd stage of coal mining development in the Upper Hunter River Valley was also politically controlled. This period saw the direct intervention of the Federal and State Government, with major investment in the coal mining industry. The Joint Coal Board and the Department of Mines were involved in the exploration and development of open cut coal mining and in the declaration and development of State Coal Mine Reserves.

This era also included a period of extended industrial unrest, where *" Much attention was attracted to the district when the Australian Prim Minister Ben Chifley put troops into opencuts at Liddell and Ravensworth to end the post war industrial deadlock on the coalfields".*

During the period between 1947 and 1951 exploration was carried out by the Joint Coal Board, The New South Wales Department of Mines and Bureau of Mineral Resources in the Foybrook and Ravensworth areas. This led to the establishment of Foybrook, (March 1951), Pikes Gully, (March 1951) and Foybrook North (November 1951) open cut projects, with the original leases being issued to the Joint Coal Board.

At the same time the Liddell State Mine underground operation and the Ravensworth open cut project were developed on adjoining State Coal Mine Reserves. The Liddell underground commenced when;

"preparations for entry to the coal seam by means of two tunnels were commenced on 3rd September 1951, with the first consignment of marketable coal dispatched on the 26th June 1952."

Early in 1961, it was decided to install a treatment plant at the mine and to construct an independent railway siding. As a result a jig type Acco washery of a capacity of 140 tons per hour was installed and a railway siding constructed close to the mine. These came into operation in September 1961. Washed cobble coal now produced is sold to the Railways Department, whilst washed nuts and small coal are sold for export and to gas works".

The future of these mines was assured for a long period when in 1969 the Electricity Commission took the decision *" to build the largest power station in the Southern Hemisphere, at Liddell".*

STAGE 4. EXPORT COAL INDUSTRY - 1975-2000

The fourth or current stage of coal mining in the Upper Hunter Valley has been chosen on the basis of the Warkworth Tender Area No. 1 process which led to the establishment of major, multi million tonneper annum, open cut mines, with Warkworth and Hunter Valley No. 1 being two of the first of these current generation mines.

Warkworth Tender Area No. 1 was awarded in 1976 to a consortium which included Costain and Mitsubishi. This process which introduced new international players into the coal mining industry is still the main basis on which major coal allocations are made today.

Following the Warkworth tender, in 1978 the New South Wales Government awarded an area to the north of Warkworth to Coal & Allied. The allocation was originally for a limited amount of coal, 56 million tonnes of coal in three major coal seams, Vaux, Piercefield and Mount Arthur. Ultimately it led to two separate leases, one north of the Hunter River which would become Hunter Valley No. 1 Mine, and one south of the flood plain which would become Hunter Valley No. 2. More recently these mines have been amalgamated as a single entity, the Hunter Valley mine.

Hunter Valley No. 1 opened in November 1979. The markets for the initial production also underscored the change, in this period, to wholly export mines with a world wide market. Separate sales had been arranged with two major power utilities in West Germany for a total of over 400,000 tonnes annually for up to twelve years. Deliveries would commence in 1980 for a minimum of 500,000 tonnes annually to Israel Electric Corporation, and Ube Industries Ltd. would expand their contract to take Hunter Valley No. 1 tonnage. Kyushu Electric Power Co would take up to 270,000 tonnes a year.

This stage of development also saw a major reversal from the previous period of state owned mines and leases. Liddell State Mine is now Cumnock Colliery. The Swamp Creek lease has recently been sold to Peabody and the remainder of the Liddell State lease and the A238 (Ravensworth No. 3) exploration area divided amongst adjoining leases. The completion of Ravensworth South opencut mine in about four years will herald the end of state owned coal leases in the Upper Hunter Valley

At the same time, in the corporate area, we have seen the beginnings of the globalisation of the world export mines. Ownership changes have bought Peabody and Cyprus mining companies into the Upper Hunter Valley in recent years along with direct ownership by the major customers such as Sumitomo and Idemitsu. More recently the RTZ-CRA merger and the investment into NSW and the Hunter Valley by the South African based Ingwe Mining has resulted in the situation where the same company may be supplying coal from any of the major coal exporting countries of Australia, South Africa, Indonesia and the United States.

STAGE 5 ? THE FUTURE.

It will be more than 20 years before major dragline and truck & shovel opencut mines are eclipsed as the major form of production. However, the last major open cut deposits in the Hunter Valley at Mt Arthur North and Saddlers Creek are currently being allocated. The group of open cut mines proposed for the Muswellbrook area, Bengalla, Mt. Pleasant and Kayuga, along with the two tender areas, will be the last major open cut mines. Production will have to come increasingly from new underground, highly efficient longwalls such as the relatively new Wambo and South Bulga mines and the new Dartbrook Mine.

The miners of today have a privileged position as far as their income is concerned with respect to their older counterparts. This requires that the more modern mines of today are structured to minimise the number of employees utilised to produce volumes of coal, therefore producing large output on a tonnes per man basis. To be a productive modern mine requires the use of longwall machinery to get high productivity. Mines such as Wambo and South Bulga are amongst the most productive underground mines in the country. With both high tonnages and excellent safety records, these two mines tend to point the way of new modern Upper Hunter Valley mines. The more recently constructed Dartbrook Mine is currently producing of the order of 50,000 tonnes per week with a workforce of around 175 permanent employees and about 25 contractors.

In 1995 South Bulga was the most productive underground mine in Australia. It also had the distinction of being the safest. While these are both important benchmarks, the most critical one, the profitability of coal mines, is not widely publicised,

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TWO CENTURIES OF COAL MINING ON THE SWANSEA PENINSULA: A HISTORY OF WALLARAH AND WALLAMINE COLLIERIES

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For the purposes of this paper the Swansea Peninsula is the 30km^2 finger of land between Swansea and Catherine Hill Bay NSW, comprising the present Wallarah and former Wallamaine colliery holdings. It can boast the oldest continuously operating coal mine in Australia - Wallarah Colliery, opened in 1889 - and has links to the Ebenezer Mine worked at Coal Point, on the opposite side of Lake Macquarie, by the Reverend Lancelot Threlkeld in the 1840s. Swansea Heads may even have been the site of the first Australian coal discovery in 1791, by a party of escaping convicts led by William and Mary Bryant. However, the Hunter River mouth and Glenrock Lagoon are other likely contenders for this honour.

Coal mining can be said to have begun here in 1800, when Captain William Reid was sent by Governor King to investigate reports of coal seams. He landed at Swansea Heads, thinking it to be the mouth of the Hunter River (thus giving the nearby headland its alternative name: Reid's Mistake). Whatever his weaknesses as a navigator - he appears to have been unaware of his error until he returned to Sydney - Captain Reid was evidently a man not easily discouraged, for he collected a cargo of coal from exposures of the Pilot Seam at the base of the nearby cliffs. His 'mine' appears to have been located at beach level, west of the coast guard station - the same spot which Threlkeld was to use as a coal trans-shipment depot in the 1840s and the site of the 1950s Swansea Colliery.

The first recorded colliery on the Swansea Peninsula, working what was probably a lower split of the Wallarah Seam from two tunnels beside the shore of Lake Macquarie, was operated by the Murray brothers during 1863-64. The location of this mine is not known, but it was most likely about 2km north of Point Morisset. Output reached 400 tonnes per week before it was forced to close by transport costs, made higher by the need to trans-ship coal to oceangoing ships across the rock bar at Swansea Heads (the same problem which had defeated Threlkeld twenty years earlier).

The Murrays' mine was reopened in 1879-83 to supply fuel for steam dredgers and cranes on the Swansea channel deepening works, and was later known as the Morisset Colliery (closed 1902) (for mine locations see Figure 1). Another temporary mine opened about one kilometre south of Swansea in 1883, supplying coal for the same machinery. This was probably the original Swansea Colliery, which closed in 1890 and which should not be confused with a 1950s mine of the same name at Reids Mistake. The 1883 Swansea Colliery began as a breakwater stone quarry, coal being the standards of the time. The B Pit was apparently little worked from 1914 to the mid-1920s, but resumed development westwards under the present Pacific Highway until the early 1930s.

The E Pit commenced as a southern entry to the B Pit in 1906, but as the Wallarah mine developed towards the southwest between the world wars it came to dominate production, until itself displaced by a new mine - the present Wallarah Colliery - centred around the Crangan Bay entry in the early 1960s. The C Pit, like the A Pit, worked an outlier of the Wallarah seam, but was even smaller (2ha) and probably only operated for a year or two in the early 1890s.

The D Pit is something of a mystery; two shafts about 0.7km north of the jetty penetrate to the Great Northern seam and Wright (1973) notes a D Pit railway siding. The only surviving mine plan indicates that a few pillars had been formed up prior to 1898, but no real production appears to have eventuated. This may have been a short-lived reopening of the 1875-77 shafts sunk by the Lake Macquarie Coal Company, whose location is otherwise unknown. To judge by its location close to and below sealevel, it could have been a wet pit, and this is possibly why it was abandoned by both companies.

Danvers Power (1912) provides some details of the Wallarah company's mining methods and equipment in its heyday around 1910. At this time only the B and E Pits were in operation, and, though served by different entries, were connected underground, with the main pithead facilities at E Pit. The bottom 1.8m of the 3.8m thick Wallarah Seam was being worked by bord and pillar methods, though pillar extraction was limited due to the risks of flooding and of spontaneous combustion, both caused by the shallow depth of overburden cover. The mine seems to have been well ahead of its time in terms of mechanization, boasting no less than four types of coal-slotting machines. Thirty five years later little had changed (Elford and McKeown, 1947) and output was 850-950 tonnes per day from a mine workforce of 350.

In 1957 the Wallarah Coal Company was taken over by J&A Brown, Abermain Seaham (JABAS) Collieries, later to become Coal and Allied Operations Limited. This historic company is the descendent of that founded by the brothers James and Alexander Brown, who, along with Lancelot Threlkeld, broke the coal mining monopoly of the AA Company in the 1840s. The new owners extended the Wallarah workings westwards beneath Lake Macquarie, converted from rail to road transport to the wharf, but retained the 'Sixty Miler' colliers, and in 1958 constructed a new entry drift at Crangan Bay, west of the Pacific Highway. This is the access to the present-day Wallarah Colliery which, after more than a century, has finally ceased working the Wallarah seam and whose operations are now confined to the Great Northern.

A new mine, Moonee Colliery, was opened in the Wallarah Seam southwest of Catherine Hill Bay in May 1982. This had originated as an entry to the main Wallarah Colliery in the 1940s, under the name F Pit, but it was developed as a separate mine after the closure of E Pit in 1963. Moonee Colliery has experienced mixed fortunes, but is scheduled for re-opening as a longwall mine during 1997, now working the Great Northern Seam downdip from the 1870s New Wallsend Colliery.

Wallamaine Colliery

The Wallamaine colliery holding occupies most of the Swansea peninsula north of Cam's Wharf and Mine Camp, and abuts the Wallarah colliery holding in the south. Mining commenced in this area in the 1860s and continued spasmodically until the late 1940s, when a coal shortage led to a proliferation of small collieries and open cuts. About twenty small underground mines and open cuts are listed in Department of Mineral Resources records as having operated within this small area (about 12km^2) from the 1930s, but most of these were either renamed or minor extensions to existing collieries (see Table I). By the mid 1950s the Wallamaine holding collieries were in decline and no coal has been mined since 1975, though several proposals for new mines have been put forward over the past twenty years (Stone, 1973; Stone and Richards, 1974; Croft and Associates, 1981).

The earliest mines appear to have grown out of the Murray brothers' venture in the 1860s, in the vicinity of the present-day Youth Camp, 2km southwest of Swansea. The Morisset Colliery was followed by the North Wallarah (closed 1916), Wallarah Extended and North Wallarah No 1 (1931-47). In the late 1930s these mineworkings followed the Wallarah seam cropline along a ridge towards the southeast (North Wallarah Nos 2&3, Aberfield Colliery).

A second mining era began in 1943 when Mr WA (Art) Mawson took over the lease of the Northern Highway Colliery (1932-44), so named because it was beside the old Pacific Highway about one kilometre south of Swansea. The post-1994 Pacific Highway (Swansea Bends Deviation) actually cuts through a short section of these old workings, which are on fire updip though they pose no threat at present to the highway (McNally and Francis, 1996). During the construction old Wallarah seam pillars and goaf were exposed beneath a cover of only 2-3m!

In 1944 Mawson established a second mine (Northern Highway No 2, later Normaine Colliery) on the same site to work the underlying Fassifern Seam. These are typical of the mines of the period, hand-worked beneath shallow cover from outcrop and covering only about 0.5km^2, immediately west of the present day Swansea High School. This was also the location of an interesting bulk sampling exercise in 1969-70, when a 0.75m diameter cable tool hole was drilled to 158m depth to obtain coal from the Australasian seam. Geologist Dick Sanders was then lowered down to seam level, where he opened out the borehole to obtain the 12t coal sample (since no miner would do it!) (Sanders, 1982). Normaine Colliery closed in 1958 and remains the only mine to have worked the Fassifern seam in this area, though extensive new workings were proposed immediately to the south by the Newcastle Wallsend Company in the 1980s (Croft and Associates, 1981).

Abandoned workings of Wallamaine No 4 Colliery (previously Northern Rivers No 1 and Wallamaine Colliery) were also disinterred during the Swansea Bends project (Kopandy and Francis, 1991). In this case forty year-old mine roadways and pillars were found to be in excellent condition, and unaffected by oxidation-induced heating. The grouted-up mine workings, including a goaf about 30m wide, can be seen in the eastern side of the southernmost, and deepest, cutting on the job. At this point the Wallarah seam is immediately beneath the present roadway and is covered backfill, to further prevent any chance of ignition. The same coalbed is well exposed in the open cut below the Mawson lookout, about 500m east of this highway cutting. Subsidence cracks up to 200mm wide can be seen in the bush between the cutting and the lookout, above the old Wallamaine No 7.

Production in the Wallamaine holding was greatly increased after 1948, at the urging of the Joint Coal Board, to meet a postwar coal shortage. Exploration was carried out by the board and the Bureau of Mineral Resources in 1948-50, with the aim of identifying open cut resources in the Wallarah seam, whose outcrop skirts around the ridges south of Swansea. The Swansea Open Cut (1950-57) was opened to further lift output, leaving the unrehabilitated spoilheaps and bare pit floors which are so conspicuous from the Mawson lookout today. By 1953 the coal crisis had passed and production was scaled down.

Several small mines (Wallamaine Nos 4-8) are listed in Department of Mineral Resources records as operating during the late 1950s and 1960s. Wallamaine No 4 (1955-65?) was the first of the series, opened by Mawson in 1948 as Wallamaine Colliery. It was an eastward extension of the 1930s North Wallarah Nos 1-3 and Northern Rivers No 1, which they purchased at that time; presumably these were counted as the first three Wallamaines. Wallamaine No 4 was apparently also the site of experiments into hydraulic mining, using high pressure hoses to dislodge coal and flush the fragments downdip.

Wallamaine No 5 (1955-58) was a small southeastern extension of the Wallarah workings at Normaine Colliery, while Wallamaine No 7 (1960?-1968?) appears to have been the final development of Wallamaine No 4, just south of the Swansea Open Cut. Wallamaine No 6 was an extension of that open cut towards the southeast; it probably operated sporadically up to the cessation of mining in 1975. Wallamaine No 8 appears to have worked a very small outlier of the Wallarah Coal beside the Pacific Highway on the southern boundary of the lease in 1966.

Wallamaine Ltd (then known as Silver Valley Minerals) purchased the land and mineral rights from the Mawson group in 1968, and re-opened the Swansea Open Cut as Wallamaine No 6, with the aim of exporting Wallarah coal to Japan. A breakwater was constructed from the mine overburden at Spoon Rocks, where an entry to the Australasian seam was excavated, but no ship ever loaded here and the mining ceased in the holding about 1975.

Since the 1960s a number of proposals have been submitted to Lake Macquarie Council, and at least one has been approved, but no significant mining has eventuated. The proposals have included both underground and surface mining, residential development and even a large tourist resort. One of the main incentives for approving further mining has been a stipulation that rehabilitation of the 1950s open cut be included in the development plan. However coal transport remains a major problem, since the scale of the proposed mines is not large enough to justify dedicated road or rail facilities. The nearest existing rail loading site is at Morisset and offshore loading is impractical for modern deep-draught export colliers.

ACKNOWLEDGEMENTS

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Table I COLLIERIES OF THE WALLARAH AND WALLAMAINE HOLDINGS

Mine Name	Dates	Comments
A Pit (Wallarah)	1889-1895?	
Aberfield	Pre-1937	L:North Wallarah No 3
B Pit (Wallarah)	1896-1933?	
C Pit (Wallarah)	early 1890s	
Crangan Bay (Wallarah)	1958-Present	Operating mine
D Pit (Wallarah)	Pre-1898	F: Lake Macquarie?
E Pit (Wallarah)	1906-63	
F Pit (Wallarah)	1940s-Present	L: Moonee
Lake Macquarie	1875-77	L: D Pit?
Moonee	1982-Present	Operating mine
Morisset	1863?-1902	F:Murray Brothers?
New Wallsend	1873-77	
Normaine	1946-58	F: Northern Highway No2
Northern Highway	1932-44	
Northern Highway No2	1940, 1943-46	L:Normaine
Northern Rivers No 1	1945-48	L:Wallamaine, Wallamaine No 4
North Wallarah	?-1916	F:Morisset?
North Wallarah No 1	1931-47	F:Wallarah Extended
North Wallarah No 2	1936-42?	
North Wallarah No 3	1937-42?	F:Aberfield
Radar Hill O/C	?-1972	
Swansea (I)	1883-90	Normaine site?
Swansea (II)	1947-53	F: South Swansea
Swansea O/C	1950-57	
South Swansea	1937-39?	L: Swansea (II)
Wallamaine	1948-55	L: Wallamaine No 4.
Wallamaine No 4	1955-1965?	F:Wallamaine
Wallamaine No 5	1955-58?	
Wallamaine No 6 (O/C)	1968-75	F:Swansea O/C
Wallamaine No 7	1960?-68?	
Wallamaine No 8	1966	
Wallarah Extended	1920s?	L:North Wallarah No 1

Data from Dept of Mineral Resources mine card index (Cardiff) and mine records (St Leonards), and from Wallarah Colliery survey office.
F= former name, L= later name.

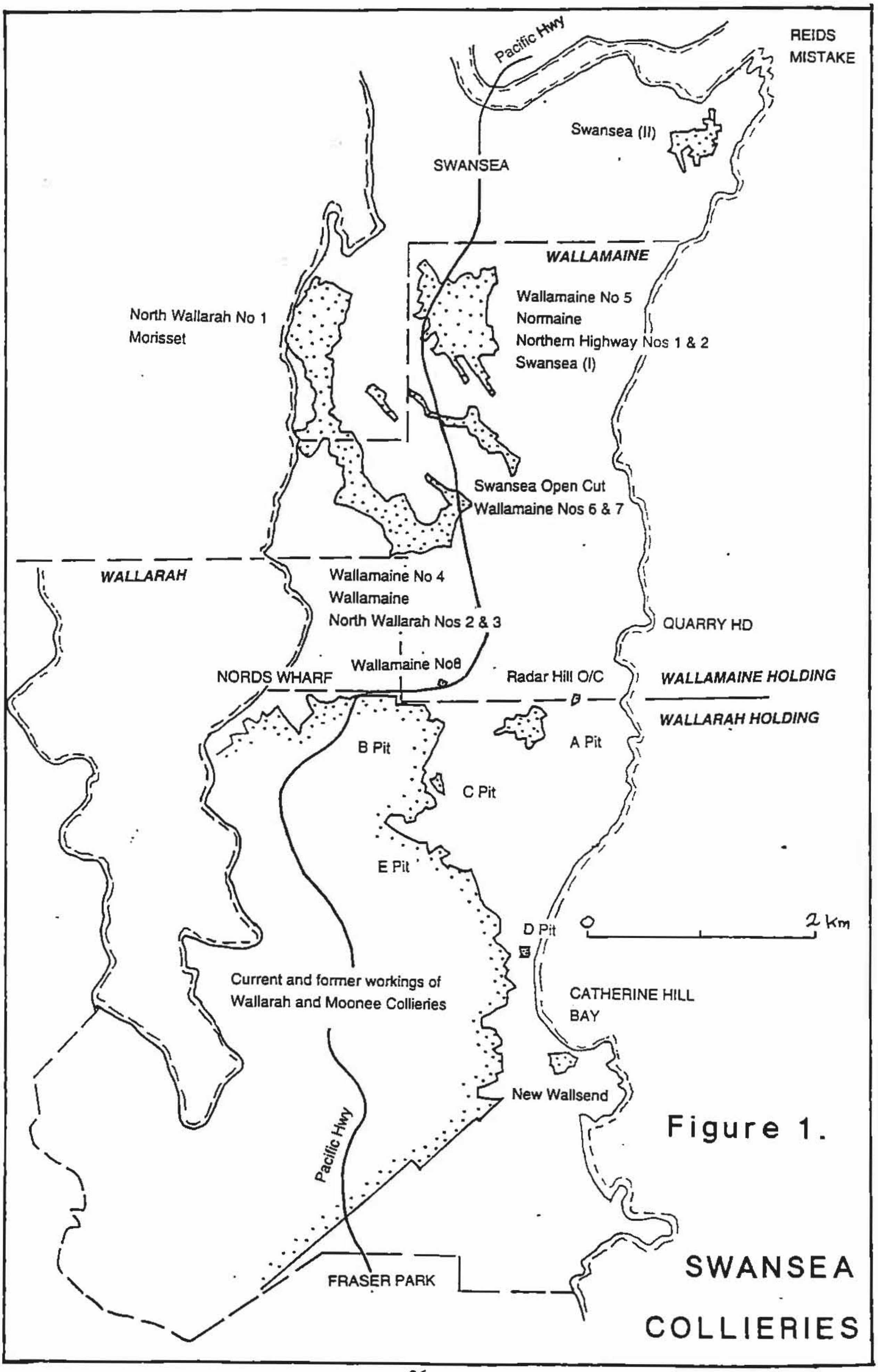

Figure 1.

SWANSEA

COLLIERIES

DOWN-HOLE CAMERA OBSERVATIONS OF THE YARD SEAM, NEWCASTLE

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1.0 INTRODUCTION

The new Telstra office building being constructed by McCloy Developments at the corner of Hunter and Darby Streets, Newcastle is undermined by abandoned coal mine workings within the Yard Seam of the Newcastle Coal Measures at a depth of roughly 23 m. The proposed development consists of a two storey concourse of shops and offices fronting Hunter Street and a three to seven storey tower block of commercial office space and car parking.

Prior to the approval of any 3 to 8 storey development on this site the NSW Mine Subsidence Board (MSB) and Newcastle City Council required that either the roof of these workings be supported or that all footings for the proposed development above three storeys be taken to rock below the Yard Seam. By either means it was envisaged that the risk would be mitigated of overstressing and crushing of coal pillars and subsequent mine subsidence.

The selection of a cost effective means of providing foundation support for the proposed development took place in early 1996. Contributors to this process included McCloys, MSB, Coffey, and structural engineers Low & Hooke. The implementation of the means of support relied upon information gathered from investigation work carried out between 1987 and 1989 on the Yard Seam workings before and during construction of the adjacent Australian Taxation Office (ATO) building. Prior to the construction of each of the ATO and Telstra buildings, little was known of the extent, orientation, or indeed existence of the workings beneath the respective sites. Down-hole camera observations at the Telstra site were presented with a central challenge: to map the workings beneath the site to sufficient detail to allow the progress of simultaneous construction work on support of the mine roof. The investigation was often only several days ahead of drilling for roof support work, a tight schedule given that disturbed sediments within the mine usually took several days to settle.

This paper describes the methods used to construct a map of the workings beneath the Telstra office building site and the technique used to support the roof of the Yard Seam beneath the tower section of the development. A video recording of underwater camera observations of the flooded workings accompanies this presentation.

2.0 BACKGROUND ON THE YARD SEAM WORKINGS

The Yard Seam workings were mined in the early 1800's by the "pillar-and-bord" method of extraction. Operated extensively by the Australian Agricultural Company the mine ceased operation in the early 1830's and was subsequently flooded. Only one plan held by the NSW Department of Mineral Resources at the time of the ATO building investigation in 1987 indicated the approximate extent of the workings in the area of the site (see Figure 1) as well as the typical pillar and bord layout in a small area well to the south of King Street.

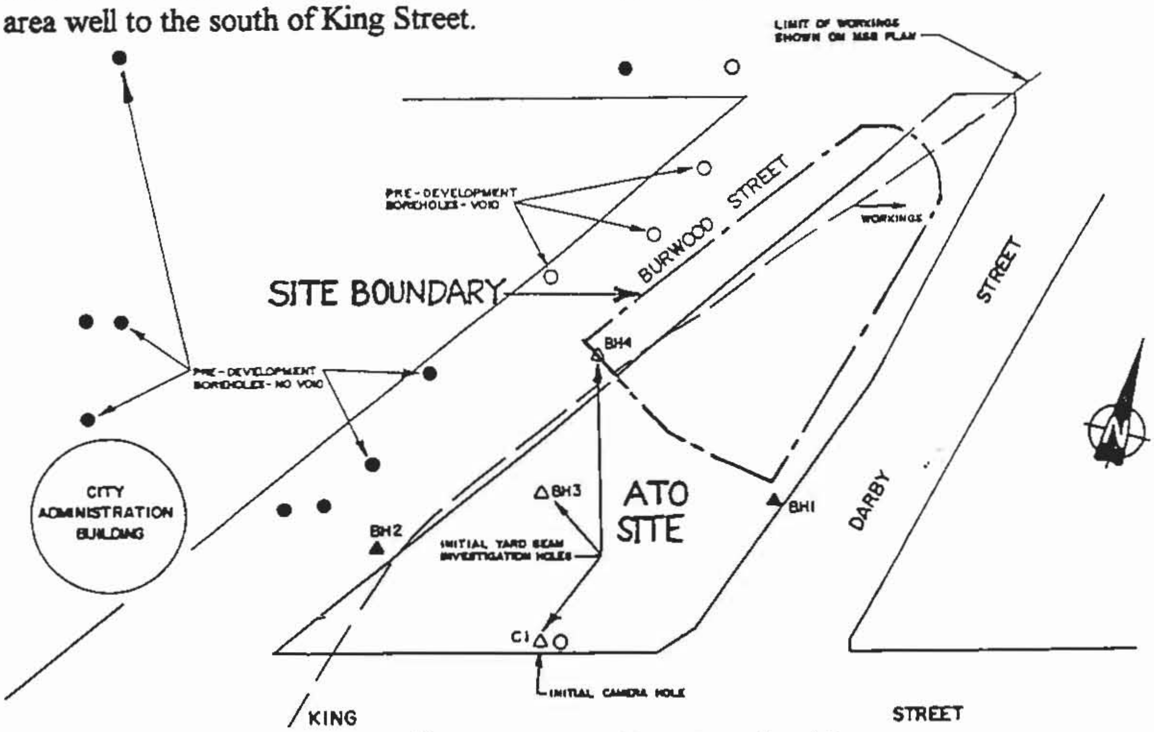

Figure 1 - Site Layout and Borehole Positions

The layout and approximate extent of the workings assessed from investigations at the ATO site were used as a starting point for the locations of pillars and bords beneath the Telstra site (Figure 2). Drilling within the Frederick Ash site and within Burwood Street prior to 1987 (shown in Figure 1 by open circles denoting voided ground and closed circles denoting solid coal at the level of the Yard seam) provided the only other indication of the extent of the workings near the Telstra site.

3.0 ROOF SUPPORT FOR THE WORKINGS

3.1 Support measures at the ATO site

Descriptions of the mapping technique and roof support measures used on the ATO site were reported in Pells et al (1988). The roof support method consisted of curtain grouting of the site boundary followed by bulk flyash and pressure grouting of the sealed workings (Figure 3). Drilling of curtain grout holes , together with the results of initial mapping from pre-construction investigations, provided enough information to create a map of the workings shown in Figure 2, and to therefore allow accurate drilling of flyash and pressure grout holes into the voided workings.

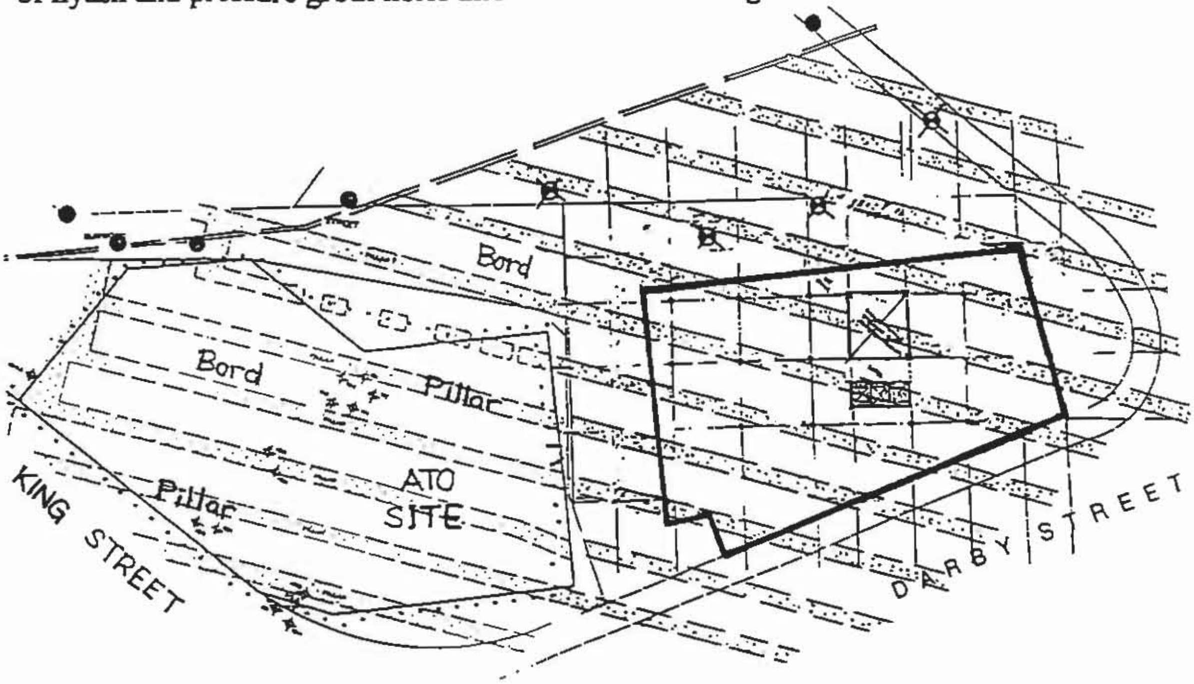

Figure 2 - Plan of Inferred Workings Beneath ATO Site

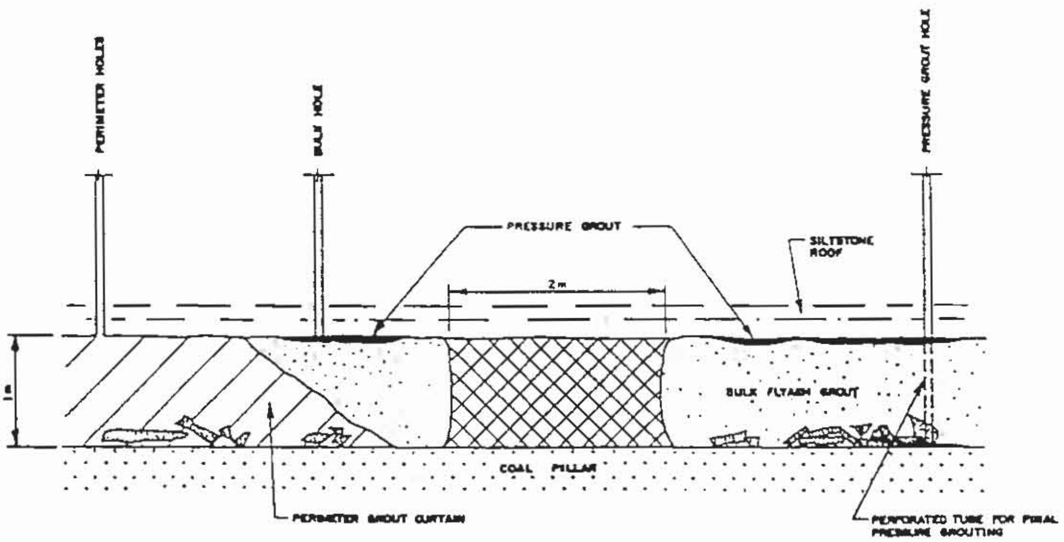

Figure 3 - Process Adopted for Filling of Workings Beneath ATO site

3.2 Proposed roof support for the Telstra site

A different approach to the solution of the same problem was adopted for the Telstra office development, where construction commenced in November 1996. It was argued that similarly suitable support of the roof of the Yard Seam workings could be achieved at a lower cost to the development by the placement of conical concrete columns at regularly spaced intervals along the bords (Figure 4). This would require the use of a concrete pump connected to a tremie pipe lowered into the workings.

It was initially assumed that 40 Mpa strength concrete placed at a slump of 60 mm would stand at a sufficiently steep side slope to produce within the workings a conical column having a floor contact of 3 m diameter and a roof contact of 1.2 m diameter. Calculations would show that columns of these dimensions spaced at 3 m centres along each bord would provide adequate support to reduce the risk of pillar crushing under surcharge loads. Full scale model testing by McCloys of the placement method showed that the slump should be modified to around 40 mm. Structural calculations indicated that columns achieving 1.5 m diameter roof contacts for a 3.6 m diameter floor contact would only be required at 4.5 m centres along each bord. This was the adopted design.

Bachy (Australia) was selected by McCloys to implement the intended support measures on the site. Construction of the roof support was proposed to consist of the following operations:

- Drilling through a layer of up to 5 m of granular fill and into weathered rock within a split of the Dudley Seam using 300 mm diameter hollow flight spiral augers.
- Injecting a bentonite-cement grout mix at the bottom of the drill string whilst withdrawing the augers, producing a grout column into which would be lowered an 8 m long 250 mm diameter steel casing.
- Drilling out the bentonite grout and then the underlying Permian Coal Measures comprising claystones, siltstones and sandstones using a pneumatic down-hole hammer drill rig. After breaking through the roof of the workings an air blast from this rig was also used to clean debris from the floor of the workings in preparation for concrete placement.
- Placing 40 Mpa concrete of 40mm-50mm slump using a 24 m long tremie pipe to form conical columns as described above.

Implementation of the roof support system was scheduled to be carried out between early November and the site close-down at Christmas 1996.

4.0 INVESTIGATION OF THE WORKINGS

4.1 General

The underwater video camera was chosen to investigate the workings on the strength of its performance at the ATO site, where much information was retrieved in a relatively short space of time.

The pillar-and-bord layout beneath the ATO site was extrapolated to the Telstra site with some minor rotations, and a grid of proposed boreholes was set out to intercept voided areas of the workings, as shown in Figure 2. Initial camera observations were made down four test holes drilled in late November 1996 at the northern end of the site, the area about which least was known of the workings. Bachy continued to advance boreholes to casing stage only at the southern end of the site, where the risk was assumed to be lowest of deviation of the assumed grid of holes from the actual line of bords.

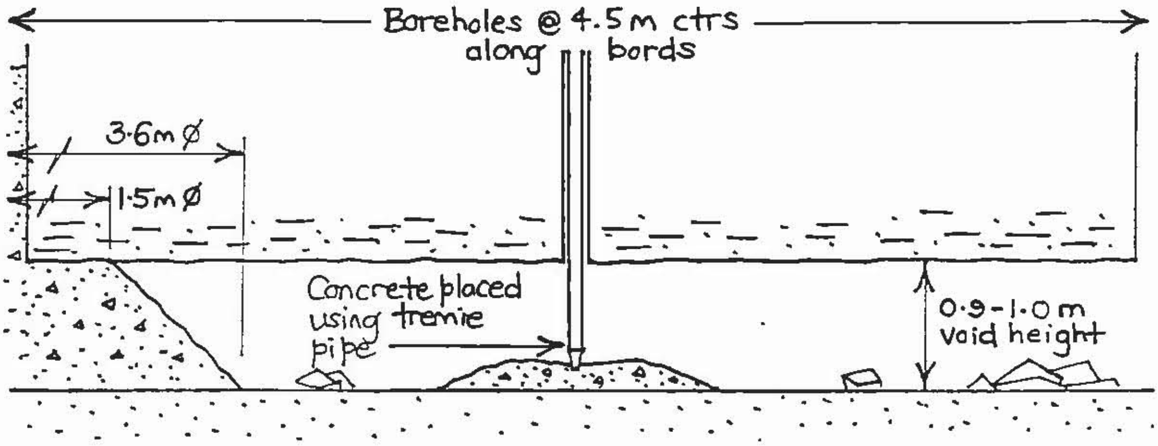

Figure 4 - Roof Support Process Adopted at Telstra Site

The aims of the underwater camera work were four-fold:

- To assess and reassess during construction the orientation of the workings beneath the site.
- To assess the condition of the mine pillars and of the roof of the workings.
- To assess the condition of the floor for concrete placement.
- To assess the performance of the concrete placement technique.

As the mine workings were a confined space judgement of dimensions was difficult. Basic precedents established from the ATO site investigation included:

- Pit props (timber roof supports) are generally spaced at 1.5 m centres across the bord and 1 m centres along the bord.
- Bord widths average 3 m but could be up to 5 m.
- Pillars are typically 1.7 m thick.
- The height of the workings is generally 0.9 m (hence the apt naming of the Yard Seam).

These features aided in the perception of distance and space within the workings. Underwater lights were used in a variety of combinations to highlight different aspects of the investigation. However, these proved ineffective when sediments within the mine were disturbed by vibrations from the camera or by ongoing above-ground construction work.

Some 80 holes were required to be drilled on the site along eight gridlines (M1 to M8, from east to west across the site) within the proposed footprint of the tower section of the development. Given the time constraints imposed on foundation preparation it was important to position each of the boreholes over the voided ground of the workings and as close as possible to the centreline of each bord.

4.2 Findings of the down-hole camera observations

Observations of the workings beneath the site commenced on 22 November 1996 with the lowering of a specialised underwater video camera down holes M5/11, M5/12, M6/9, and M6/10. Visibility to a distance of typically 2 m within the flooded workings was good, considering that some two days had elapsed since drilling had been carried out within the rocks underlying the site, although visibility was found to deteriorate with even minor disturbances within the workings. Each of these four test holes was judged to be closer to the pillar on its eastern side than to the pillar on its western side. It was therefore assessed that an adjustment to the assumed orientation of the workings would be made before drilling proceeded from the ATO building end of the site to the northern end. This adjustment, which included the redrilling of four new holes (M5/11A, M5/12A, M6/9A, M6/10A) only 1.5 m from their test hole counterparts, later provided four invaluable vantage points for the observation and assessment of the results of concrete pours.

Similar adjustments to the orientation of the workings, bord widths and pillar spacings were progressively made throughout construction. Viewing locations were chosen from the selection of holes made available at the time by Bachy. In all some 26 holes were used to make video observations of the workings over the period 22 November to 14 December 1996.

In accordance with the aims of the investigation the following features of the workings were noted:

- The pillars were judged to be in good condition (pick marks were still visible at many locations), with little or no crushing evident, as was found at the ATO site where coal extraction ratios of up to 80% were assessed. The average extraction ratio within the workings beneath the Telstra site was assessed to be about 60%.
- The roof of the mine was observed to be in generally good condition. Occasional areas of the floor were covered in rubble which was judged to be a result of isolated roof fall-in.
- The floor of the workings was typically clean, except as noted above. Large amounts of rubble were observed adjacent to some pillars, generally judged to be associated with nearby deepening of the floor and over-excavation of the roof, presumably to provide additional headroom for haulage roadways.
- As was found at the ATO site, construction activity on the surface, particularly use of the pneumatic down-hole hammer, tended to result in the release of considerable amounts of fine debris from the roof of the workings. To improve the chances of good visibility, camera inspections were carried out following extended periods of inactivity (typically 2 to 3 days) of the pneumatic drill rig.

The final assessment of the layout of the workings was made in early December. Figure 5 illustrates that the workings appear to deviate towards the east from their original north-easterly trend beneath the ATO site. Coal extraction operations may have encountered difficult ground conditions in the area under Burwood Street, where several pillar thickenings were evident. It would also appear from observations down hole M5/14 that the workings were terminated within the northern end of the site, just short of Hunter Street.

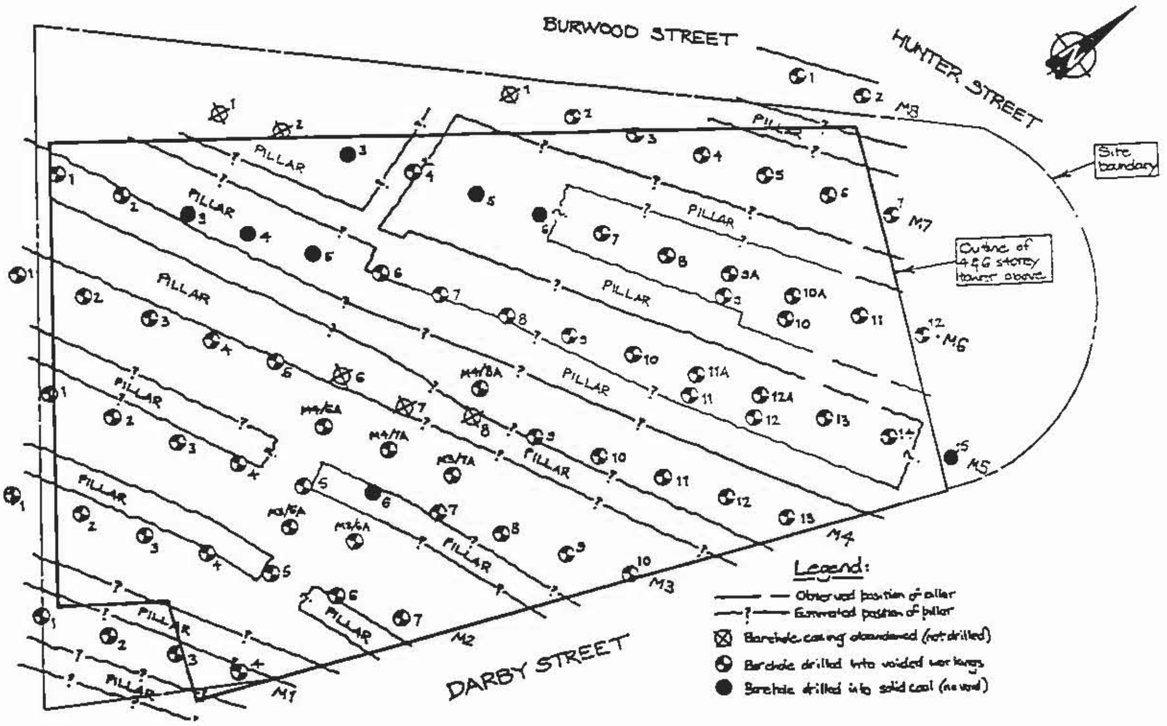

Figure 5 - Plan of Workings Created from Investigation

5.0 IMPLEMENTATION OF THE ROOF SUPPORT SYSTEM

Based on the structural design details for the roof support columns and the anticipated characteristics of the underwater concrete pours, each column was expected to take about 4 m^3 of concrete to achieve a minimum roof contact diameter of 1.5 m.

The underwater camera was used to assess the validity of this assumption, which proved to be overly optimistic. Rather than standing at an assumed repose angle of 45° the concrete was observed to sit at side slopes of about 14° (1 in 4). As a result the required volume of concrete to meet the design intent for each hole was recalculated as about 9 m^3.

The reason for such behaviour of the concrete was not established. A number of variables which could have had a significant effect were identified as follows:

- Inconsistency of concrete slump - placement of low slump concrete on top of that having a high slump may have amplified the already large spread diameter of the high slump concrete.
- Tremie nozzle flow characteristics - concrete pumped under pressure and striking the floor, like water from a hose hitting a perpendicular plane, tends to rebound and surge. The concrete, in its thixotropic nature, would respond to such vibrations by spreading. Such surges were observed at the concrete pump delivery pressure gauge.
- Sudden movements of the tremie pipe - these often occurred when pump refusal was met with the nozzle of the tremie buried in concrete, resulting in a sudden deceleration of the concrete column "slug" and the opposing inertial rise of the tremie, initiating thixotropy in the concrete. This related to work technique and was generally overcome by ensuring that the tremie was lifted as pump pressure consistently reached a pre-determined "safe" level.

6.0 CONCLUSIONS

Underwater video camera observations of the flooded Yard Seam workings allowed a suitably detailed map to be produced of the abandoned mine beneath the Telstra development. This map was found to relate well to the available information of the Yard Seam workings from investigations at the nearby Australian Taxation Office building and Frederick Ash building sites.

The mine roof support system was judged to provide a satisfactory means of rectifying the Yard Seam workings, allowing the founding of footings within rock strata above this formation to take place. Despite a small and often crowded site and the limitations of carrying out investigation work in conjunction with ongoing construction, the rectification was completed in accordance with the design intent within the specified time constraints.

7.0 ACKNOWLEDGMENTS

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THE RISE OF THE COAL INDUSTRY IN 19TH CENTURY NEWCASTLE

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In this paper, Dr Turner argues that there are several eternals in the history of the New South Wales coal industry and that these were revealed in the nineteenth century. Apart from the nature of the coal which was the controlling factor in the development of the industry, there was the availability of capital, the supply of labour, the prevailing private enterprise philosophy and volatile industrial relations.

Discovery of Coal and Early Mining

It is almost 200 years since soldiers, pursuing a group of escaping convicts, returned with news of the Hunter River and its coal. Enterprising Sydney merchants soon had labourers gouging coal from the cliffs at the Hunter where it was already exposed, and in 1799, the first export cargo reached India. Unfortunately, this surface coal was of such poor quality, that it could not be used for working iron and there was no other commercial export use for it. There would be no foreign trade until a new use was developed, or until improved methods of mining produced a coal comparable to the product of the long-established British coal industry.

There was to be no great improvement in mining techniques during the period 1804-1831 when the Colonial Government operated the mines using convict labour and consequently Newcastle coal mining had an unenviable reputation. In 1826, the editor of the "Australian" questioned government policy regarding the mines in these terms:

"How often have representations been made of the shamefully inadequate manner in which the mines were worked and the scandalous loss that was suffered by the public? How often has the miserable petty fogging work been condemned, of employing only twenty to thirty men, where a hundred or two should have been constantly engaged? How often has the insufficiency of the supply of coals been made the subject of complaint to the Government?"

Complaints such as these, led the British Government to hand over the Newcastle coal mines to private enterprise, and in 1830, with considerable encouragement from the Crown, the Australian Agricultural Company began to implement more efficient mining methods. Steam power was employed to keep the pits clear of water, coal of better quality was located, and in place of bullock waggons, the company constructed an inclined plan to facilitate delivery to ships lying in the river. However, miners were very scarce in the colony during the first half century. They were not often transported as convicts and those that were trained in the Newcastle mines usually did not remain in the industry after the expiry of their sentences. This scarcity enabled them to obtain relatively high wages and to negotiate with their employers from positions of strength. Even the convict miners were far from being powerless and in 1836 the prisoners on assignment to the Australian Agricultural Company mines refused to work overtime. This led directly to the introduction of immigrant coal miners in 1840, but the AA Company which was hopeful that the labour shortage was ending, was shocked by the mood of these miners. They were so aggressive that they sued their employer in the law courts and interfered in its dealings with its agricultural workers in what was surely one of the earliest examples in Australia of co-operation between employees in two such different industries.

The Export of Coal

It was the arrival of the steamship in Pacific waters that stimulated the export demand for Newcastle coal. The first to arrive in Australia was the "Sophia Jane", a paddle-wheeler, which reached Sydney in May, 1831, and soon afterwards made her first trip to the Hunter River. A few years later, steamers went into regular service on the opposite side of the Pacific, between Peru and Chile, despite problems arising from their elementary design and the isolated routes sailed. In the same period, coastal steamers began to ply in Dutch East Indian and Philippine waters creating a new demand for steam coal, and inspiring a search for local sources of supply. The first orders arrived from the Philippines in 1846 when Newcastle was already supplying British naval steamers operating in New Zealand waters during the Maori Wars, but it was the arrival in 1850 of a small fleet of ships seeking coal for steamers engaged in gold rush services in Californian waters, that really confirmed the great export potential of Australian coal.

Many countries on the Pacific seaboard did not possess good quality coal and the slow development of Chinese, Indian and Japanese coal gave New South Wales exporters a big advantage in the mid-19th century. However, they were to meet serious competition from the United Kingdom in every foreign market. Not only did Britain have great reserves of excellent coal, she also possessed a vast merchant marine which was of great value to her vital export trade.

English historian J.H. Burley has shown that Western Europe's ability to feed itself declined substantially during the 19th century creating a great grain import trade, mainly from North America, but later on, from Australia. There were also changes in taste, bringing tea, sugar and rice into wider world demand and adding to the need for ships to carry bulk cargoes to Europe. In return for these goods, Europe usually exported manufactures which were less bulky, so that more vessels were required for Europe's imports than for her exports. British coal filled many vessels bound for ports where bulk cargoes waited, but there was still the problem of ships which discharged European cargoes in Australian or other ports, where cargoes for Europe were not available. Faced with the prospect of profitless voyages in ballast, many shipowners carried Newcastle coal cheaply to ports where better paying cargoes could be obtained. Accordingly, coal was carried competitively to San Francisco where grain awaited export, to Hawaii for sugar cargoes, and to China for nitrates, guano, cotton and wool for Europe. In these ports, coal was in demand for industrial and domestic purposes and the export of New South Wales coal soon developed from its haphazard origins to become a well organised and fairly systematic trade.

After the opening of new mines at Minmi, Wallsend, Lambton and Waratah, about 1860, the supply of coal outran demand and this led some coal owners to make speculative voyages which introduced Newcastle coal into foreign markets. Such voyages helped spread the reputation of Newcastle and from these small beginnings, the export trade was to grow so large that it absorbed about one third of all coal produced in New South Wales between 1860 and 1914.

Only 44,000 tons of coal were exported from Newcastle in 1859 but already the town's maritime importance had been recognised. As one naval officer noted one June midnight in 1856: "it's adieu to these shores of sand and coal dust. Newcastle is a port of the utmost importance, but it certainly has no attraction for the visitor." It was still small, only 3,500 people, but the coal export trade had already put its stamp upon the town.

The Asian market was most important in the early years of the export trade, particularly during the 1860's, when considerable tonnages of coal went to Hong Kong and Shanghai mainly for refuelling the tea steamers which arrived in the first half of each year. British coal was the most important competitor in this market, but as early as 1871 cheaper Japanese and Formosan coals were becoming available. These coals were not considered very suitable for use in the steamers, as they burned so quickly that extra bunker space had to be provided. However, by 1879, the quality of Japanese coal from the Takasima mines had improved and less Australian and British coal was being imported.

The North American trade, which commenced in 1850, proved more important that the Asian market, taking more coal over a longer period. San Francisco, the main market, was a great grain exporting port and ships in need of cargoes for Europe often carried Newcastle coal there. In the 1860s, New South Wales was the principal source of coal for San Francisco though it soon yielded that position to British Columbian mines. Substantial shipments continued right through the century, reaching a peak in the late 1890s before declining in the face of competition from North American coal and oil. Fortunately for the NSW mining community, the South American market was expanding in this period and Valparaiso became the centre of a great coal trade. Imports of New South Wales coal increased gradually in the 1890s. In the early 20th century coal imports assumed the proportions of a flood: in 1912 Newcastle alone shipped 982,000 tons of coal to Valparaiso.

Such an expansion is impressive, but it should always be remembered that the overseas trade was less stable that the interstate or intrastate markets for New South Wales coal. Not only were there fluctuations in the demand for coal for certain markets and certain uses, but there were considerable variations in the total amount shipped abroad each year. Whereas the interstate and New South Wales coal consumption tended to grow steadily between 1850 and 1914, the export trade had a far more uneven pattern of development. Any disturbance to the pattern of shipping in the Pacific usually had its effect. The Maritime Strike in Australia in 1890, for example, caused a sharp drop in coal exports, whereas the outbreak of the Boer War stimulated exports from New South Wales by reducing the availability of shipping for exporting British coal.

Such fluctuations could be extremely severe, as in 1880, when total Newcastle exports fell from 450,000 tons in 1879 to only 175,000 tons. Variations of this kind could have severe effects on miners, colliery proprietors and the mining towns.

Total exports from New South Wales fell from 550,000 tons in 1879 to only 325,000 tons in 1880, but they did not affect the industry evenly. The southern and western coal fields were little affected because their share of the foreign trade was comparatively small; the northern district was par excellence, the exporting district. In 1901 for example, only 19,000 tons were shipped to South America from Sydney and Wollongong, whereas Newcastle sent 462,000 tons.

The outbreak of war in 1914 brought a serious interruption to the overseas coal trade but the war was not responsible for the disappearance of the trade in the 1920s. War so interrupted the normal pattern of shipping in Pacific waters that Australian coal shipments to foreign markets were severely restricted, but the trade did recover to something like its pre-war level in 1921. Thereafter it rapidly fell away to be less than a million tons in 1929 and only 25 percent of exports in the peak year, 1908. What was responsible for such a drastic decline? There can be no simple answer, but any discussion would have to take the increasing price of New South Wales coal into consideration.

Monopoly and Price Regulation

For the first five decades Australian coal mining was in the hands of a monopoly: the New South Wales Government was the sole supplier from 1804 until 1830 and from then until mid-century the AA Company produced almost all the coal raised in the colony. This arrangement offered many advantages to the infant industry.

While the monopoly lasted there was a possibility of controlled exploitation of the colony's coal reserves and its ending had profound implications for all those who depended upon the industry. Thereafter, with one or two brief intermissions, there were far too many mines and far too many colliers. Prosperous conditions invariably encouraged investment in improved plant and new mines with the result that the supply far exceeded the demand. As the newcomers struggled for a share of the coal trade, prices and wages, which were related, fell sharply, sometimes by as much as 50%, and the income of the mining community dropped correspondingly.

During the 1870s all but one of the principal Newcastle collieries co-operated in a 'vend', a device designed to fix the price of coal and share out the demand between them. By this means prices were doubled and wages went up while production also increased. Of course, the higher price of Newcastle coal stimulated the development of the southern and western fields of the colony but the northerners were more than satisfied. Their prosperity also produced such harmonious industrial relations that the miners' union presented the retiring chairman of the colliery owners' association with an illuminated address thanking him for his fairness and co-operation, and the prospects of the district seemed good . However, the Vend contained the seeds of its own destruction.

The Scottish Australian Mining Company, whose general manager believed in "the great laws of natural selection" and was determined to ruin some of his competitors, refused to join the Vend and captured an increasing share of the market by reducing his prices. When the other companies threatened to return to unrestricted competition, the miners' union tried to force the Scottish Australian Mining Company to join. However, it met resistance from that company's miners, who had been receiving so much work that Lambton, their village, was said to be "a land of Goshen in the midst of the troubled district around it".

Conflict between the supporters of the Vend, both unionists and coal owners, and its opponents, was so severe that a state of emergency was declared after shots were fired during a demonstration at Lambton. A contingent of soldiers and police was posted to the village to keep the peace and the Scottish Australian Mining Company managed to maintain its independence. However, a return to competition and the halving of the coal price eventually forced that company to join a revived Vend in 1881.

So great was the prosperity achieved by the Vend that the 1870s were long remembered as a golden age. This had great significance because prices and wages were not restored to that level for several decades and the mine owners were strongly criticised as a result. With prices lower and profit margins reduced in the 1880s, the employers resisted the union's efforts to improve conditions. Increasing investment in the industry was another factor which threatened both miners and proprietors in this period. The investment boom of the late 1880s led to the formation of many new mining companies, and with labour continuing to flow into the industry, intermittency again became a serious problem for both miners and the proprietors. Eighteen new mines were being opened out in the Newcastle region in 1888 at the same time as the southern coalfield was being expanded and connected with Sydney by railway. These developments caused over-capacity and the price of coal gradually declined.

Industrial Relations

From the beginning of coal mining in the Newcastle area in 1801, the industry made unusual demands upon its labour force. Hand mining was by far the most common method of production for the first one and a half centuries, though the first machine cutters had come into use in the 1890s. It required not only skill and strength but the capacity to endure the dirt, heat, discomfort, and danger that marked the colliers' working life. The presence of water in the pits, the long distances to be walked to and from the coal face, the often inadequate ventilation, the ever present danger of falling coal or stone, and the often cramped work spaces made it hard to achieve high productivity, but the miners were proud of their strength and prowess.

Before 1856 there were no unions as we know them, on the New South Wales coalfields. There had been combinations at various times, but their leaders were not given official titles and their identity was deliberately obscured to avoid retaliation by the employers. Thus the miners resorted to 'round robins' and signed their rare public statements 'The Miners of Newcastle'.

The labour shortages and the economic development that followed the gold strikes in New South Wales and Victoria in 1851 strengthened the miners' position and in 1856 the first unions appeared. Initially these were limited to the employees of a particular mine but in 1860 the workers at the four principal collieries combined to form a district union "for mutual protection". Known as the 'Coal Miners' Association of Newcastle, New South Wales', this body immediately took up two key issues, the need for improved ventilation in the mines and the reduction of inequalities in miners' incomes.

The need to ensure adequate ventilation of the mines is an issue on which the miners have always been agreed. First, they asked the colonial government for an act that would control working conditions, but the Legislative Council procrastinated. Then the union took up the cause and before long Alexander Brown, the owner of the Minmi mine, was complaining:

"the men themselves are in such a position now, that if the mines were not well ventilated they would have a meeting and stop working. We are completely at the men's mercy, and have been for some years."

Happily, Australian coal mines benefited from the experience of the British industry and its worst features were not reproduced in the colonies. The union could always appeal to the laws protecting mine labour in the United Kingdom and this was a help in securing safety and health measures. Women were never employed in Australian collieries as they were in Britain, but the first government investigation into the industry in 1861 revealed that boys often spent twelve hours a day operating ventilation doors in the mines.

One of the earliest concerns of the union was to share the work more evenly between the collieries by imposing a limit on the daily earnings of its members. Those who earned more than 11s 4d a day were obliged to pay the excess to the union and it was the effectiveness of this rule that finally forced the employers into action. They formed a colliery proprietors' association which, in the long run, proved to be just as important as the miners' federation.

In 1861 the associated colliery proprietors challenged the power of the miners' union and their contest has been a feature of the industry since then. It is true that the fierce struggles between capital and labour in 1862, 1888, 1895 and 1909 were ostensibly fought over wages and working conditions, but there was more at stake. In its early days, the union claimed powers that the managers refused to yield and it has continued to question the record of the proprietors as custodians of the nation's coal.

The coal industry was irrevocably altered by the experiences of the 1890s. Historians often disagree about the significance of this decade for the labour movement generally but there can be no doubt about the impact on the mining community of the depression, the consequent breakdown of the Vend and uncontrolled competition. Prices fell rapidly and the union was hard pressed to resist the wage reductions which followed. Thus by the middle of the decade, the railways were buying coal at 2s 6d per ton and miners who had been accustomed to a base hewing rate of 4s 2d were offering unsuccessfully to work at 2s per ton.

The mine owners were powerless and the union was incapable of effective action, yet they blamed each other and industrial relations had never been worse. The politicians tried to act as intermediaries but had no success and bitter critics decried the state of the industry.

"The present awful condition of affairs all over this continent is the direct result of 50 years of the uninterrupted rule of the mining speculator, the land boomer, and the bank boodler - who might be termed the 'Trinity of Corruption'. They are learning by bitter experience what a gruesome and disastrous failure 'private enterprise' - the god of Individualism - has made of our coal industry...."

A minority of miners reacted by advocating some form of socialism but the remainder merely wanted a return to the higher wages and shorter hours of earlier times. All were critical of their deteriorating conditions and blamed the employers for the sad state of the industry, but only a few favoured radical changes in society.

The policy of the union had not changed since its inception and was still based on the idea that the masters and the men should prosper together; that co-operation between the mine owners could sustain high coal prices which would in turn permit more rewarding wage rates. However, a new generation of mine leaders was emerging.

At the turn of the century, as labour and capital and the arbitration courts sought to resolve a seemingly endless series of strikes arising from the rapid development of the South Maitland coalfield, there seemed little prospect of real improvement in the state of the industry, but in 1906 the employers, with union support, revived the Vend. Prices were raised, and wages too, but the disputes continued and many of the miners' leaders, convinced that arbitration was a total failure, favoured a more militant union and the use of direct action as a means of improving the lot of their members. Arguing that the working class and their employers have nothing in common, they proposed a policy based on the ideology of the International Workers of the World. They hoped to eliminate "hunger and want" by organising all Australian workers into a national organisation which would make every sectional dispute into a general strike.

Peter Bowling, who became president of the northern miners in 1906, was much influenced by this philosophy and led the union into perhaps its most severe general strike. However, the New South Wales Government intervened actively on the side of the proprietors, gaoling Bowling and other leaders, and after eighteen weeks the strike was broken. The defeat weakened the case for direct action and turned the unionists back to the task of achieving affective political support for their cause.

"Yes Sir, capital and labour are two mighty giants, who, when travelling hand in hand, the sunshine of prosperity will shine on both, but, the moment they clash, then, like the proverbial Kilkenny cats, they will eventually eat each other up."

Thus wrote 'One of the Weavers' to a local newspaper in Newcastle, New South Wales in 1877. He was commenting on the current problems of the coal industry but his remarks may well have been made much earlier or much later with equal relevance. The Australian black coal industry was notorious for the spectacular industrial disputes which periodically disrupted the life of the nation between 1850 and 1950.

COMPUTER DATABASES & GEOLOGICAL MODELLING OF HUNTER VALLEY GEOLOGY

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INTRODUCTION

In 1997 Australia is unlikely to discover any significant new coal deposits. However, coal geologists have been kept busy more than ever, delineating resources that 10 years ago were found to be uneconomic and considered unrecoverable. What this implies is that more difficult resources are being investigated by geologists and that mining companies want to mine them, irrespective of the geological problems.

As geological conditions become less favourable, the level of knowledge required for risk management increases. The geologist can no longer be solely responsible for one area, such as exploration, quality control or in-pit mapping. Today, management expects to be informed of all hazards to mining so that 5 year plans and budgets can be justified and adhered to. Interruptions to production are extremely expensive and employees are now far more accountable.

Thus coal geologists are under considerable pressure to satisfy a company's exploration and mining requirements. Their expectations can be stated simply:

a sound mine plan and risk management

and, as we know, a major factor affecting a sound mine plan is **geology**.

THE GEOLOGICAL FACTOR

Hunter Valley coal geology comprises of most geological factors known to mankind that affect mining. These include: seam splitting; reverse and normal faults; bedding plane faults; dykes; sills, devolaterised coal; weathered coal; high sulphur coal; mixed gases; gas migration; gas regimes; aquifers; contaminated water; poor roof and floor conditions; highwall instability; spontaneous combustion; washouts; high ash coals; low energy coals; carbonate bands; seam rolls; high stress regimes; to name a few!

These factors will obviously affect the productivity of a mine which has a direct affect on company profit. They can also have a significant effect on the quality of the product, which again, affects the level of profit. But more importantly, these factors can affect people's livelihoods and, in some cases, their lives.

Geologists, therefore, need not only to store, retrieve and interpret geological data, they also need to present and communicate these geologically related factors to planning engineers, pit foremen, washplant operators and management.

COMMUNICATING GEOLOGY

A geologist should understand and be aware of all the parameters that may affect or control the mine plan for the next 10 years and beyond. They must be aware of structure, intrusions, coal quality, geotechnical issues, gas regimes, joints/cleats, principle stress direction, etc. They must have some understanding of all of these issues, and be able to liaise and communicate with mining engineers. If the mining engineer has little understanding of geology, the onus should be on the geologist to educate and assist the mining engineer. The geologist must have the technical knowledge, know where to get assistance by specialists, right through from exploration to feasibility to a mining operation. The geologist must have management skills, as well as good P.R. skills to negotiate with landowners. The geologist must also understand how to budget and understand the 5 year business plan.

A common complaint from geologists is a lack of funding. They need to understand the risks management are prepared to wear, and communicate the need for capital to minimise the risks to acceptable levels. Thus they must justify the need for exploration. He/she must have a clear understanding of likely risks that may be encountered, how to communicate solutions and how to maximise results for their expenditure.

It can never be assumed that mining constraints imposed on a deposit during exploration are anything like those with which the deposit will actually be mined. Careful thought is required at all stages of exploration to gather sufficient detail in appropriate areas without expending the entire budget on a single aspect. Selection of working sections, in particular, should be done in consultation with mining and/or geotechnical engineers. Sufficient detailed analysis over probable working sections is required as mining engineers will invariably change their mind. For example, if the maximum extraction height for an underground operation was 3.0m and a single composite section was sampled and tested for washability and other properties, and the working section height was reduced to 2.5m in order to minimise higher ash material or downstream processing, the entire analytical test results may be inappropriate for the revised working section.

Structural features, such as synclines, should be identified as hazards and in advance of underground operations. With retreat longwalling, these may not appear to be an immediate problem as such features are likely to be encountered during development and thus provide advance warning. If they were known even further in advance, monies could be budgeted for water management schemes, some of which could cost up to $500,000.

Geologists should have a clear understanding of the quality of their product and the issues surrounding its marketability. They need to understand likely mining conditions and communicate them as there will be a major investment in equipment, the choice of which is largely determined by geological conditions.

When data is collected, an understanding of geotechnical issues is required so as not to miss key issues such as cyclic loading, trafficability, highwall stability, floor and roof conditions, etc. The relative importance of traditional geological data, such as grain size, colour, hardness, etc., pales into insignificance when weighed up against such features as strengths and powder factors, slakeability and trafficability, secondary mineralisation and coal quality, seam gas and gas migration, slickensided planes in roof/ floor for both open-cut and underground operations.

As an understanding of what is likely to affect a mining operation evolves, so should the type and concentration of data be accumulated. The way this data is stored in a database requires an understanding of the final output requirements. The traditional way to view a database is one of "load it all up, that's what it's for!". The database itself needs to be structured, and allow selection of data from a multitude of sources to communicate everything the geologist suspects or knows about a problem. It needs to be flexible and may require numerous revisions to structure the data in such a way as it can be properly accessed. For example:

- Ash, sulphur and other coal quality maps should be colour shaded with appropriate ranges and colours that highlight poor quality and good quality areas.
- Seam floor dip maps should accompany structure contour maps, colour shading dip ranges where equipment, such as draglines and longwalls, will have trouble.
- Cross-sections should illustrate mining benches, longwall panels and fault positions.
- 3D structure floor perspectives should include detailed pit outlines (both open-cut and underground) to aid in the planning and positioning of pumps.
- Large detailed plans over small areas e.g. a longwall panel, should show boreholes, critical structure dip areas, both delineated and possible faults, areas of weak floor and roof, underground mapping features, and so on.

These and other examples will be illustrated in the presentation.

The catch-cry of "I knew it was there, but nobody asked me" is inexcusable. Not only does it mean the geologist failed to communicate what he/she is employed to find out, but it could cost vast quantities of money to fix after the fact, it may lead to a cessation of operations or, in the extreme, may cost lives. The role of the geologist has changed.

ORIGIN OF CO_2- RICH GAS IN THE PERMIAN COAL MEASURES OF THE NORTHERN SYDNEY BASIN, NSW

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INTRODUCTION

Areas where CO_2 is present in high concentrations (6-100%) are considered to be less attractive for coal bed methane (CBM) exploration. In the Sydney Basin CO_2 as a proportion of the total gas can range from 0.1% to in excess of 90% (Smith *et al.*, 1985), and so geographic and stratigraphic variability of CO_2 in coal seams, along with parameters such as methane content and coal permeability, have become of prime importance for successful CBM production. Before a full-scale CBM project can be undertaken in the Sydney Basin, reasons for high CO_2 content and the controls on its distribution need to be identified. In this paper we report the results of a study (Kozyrev, 1996) conducted to determine a) in-seam and inter-seam distribution of CO_2 and b) source of CO_2 particularly where it is present in high proportions, in exploration leases held by Pacific Power in the Sydney Basin (Figure 1).

The data for this study were collected mainly from 3 exploration wells drilled by Pacific Power, Elecom Hunter Llanillo DDH 1 (EHL-1), Elecom Hunter Randwick Park DDH1 (EHRP-1), both of which are located in PEL 4, and Hawkesbury-Bunnerong DDH 1 (PHKB-1) in PEL 5. Additional information was collected from Ellalong Colliery, approximately 10km south of Cessnock and from Dartbrook Mine, 10km north of Muswellbrook, both in the Hunter Valley. The locations of all are shown on Figure 1.

STRATIGRAPHY

The boreholes EHL-1 and EHRP-1 were both spudded in outcropping Wittingham Coal Measures and reached total depth in the upper part of the underlying Maitland Group (Figure 2). The Denman Formation was the uppermost unit intersected by EHL-1 whereas the Jerrys Plains SubGroup is the uppermost unit in EHRP-1. In both boreholes, the first gas was encountered at a depth of about 120m. The Wittingham Coal Measures is the unit being mined underground at Dartbrook. At Ellalong Colliery the Greta Seam is being mined underground. In both mines gas with a significant proportion of CO_2 is encountered. In Borehole PHKB-1 gas and coal samples were collected from the Illawarra Coal Measures (Figure 2) which underlie 800m of Hawkesbury Sandstone and Narrabeen Group. First gas was encountered near the top of the Coal Measures at a depth of 805m.

KOZYREV, N. and SKILBECK, C.G.

COAL GAS COMPOSITION, ISOTOPE GEOCHEMISTRY and ORIGIN.

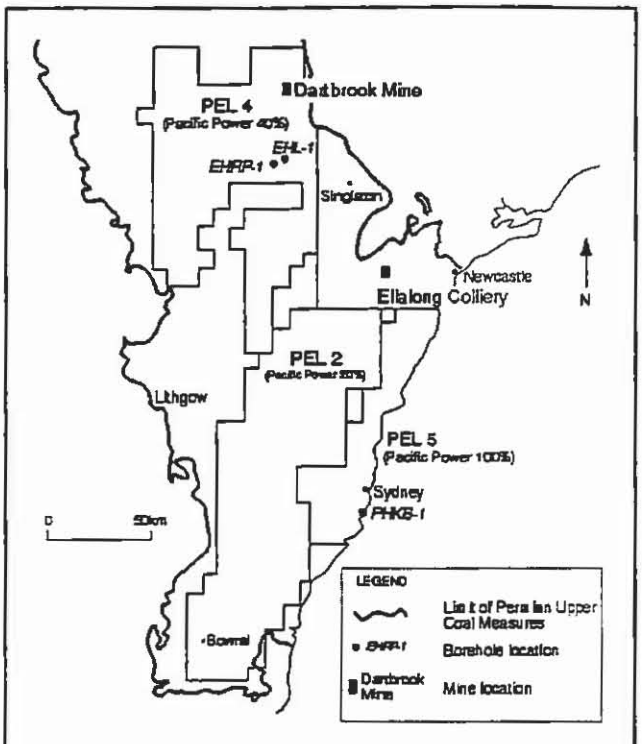


Figure 1: Locations of Pacific Power boreholes and Coal Mines used in this study of CO_2 distribution.

Gas analyses for samples collected from EHL-1, EHRP-1, PHKB-1 wells and Ellalong Colliery and Dartbrook Mine are given in Table 1. The results show a significant variety of chemical and isotopic compositions. CO_2 as a proportion of the total gas stream ranges from 0.1-74.0% of the 20 samples analysed and methane ranges from 26.0-99.3%. Up to 6% CO_2 in coal gas is considered to be the maximum amount that can be produced by normal thermogenic degradation of organic material (Rice *et al.*, 1988) and so for amounts in excess of this alternative explanations must be sought.

Variation in the ratio of the stable isotopes of carbon (C^{13}:C^{12}) can be used to determine the origin of both methane and carbon dioxide. The ratio changes according to the relative ease of breaking a C^{12}- bond compared with a C^{13}- bond (James, 1983). Methane in coal seams can be produced either directly from decaying organic matter by thermal or biogenic (i.e. fermentation) pathways, or can be produced by bacterial reduction of CO_2 from any source. CO_2 can be present in coal gases as a result of introduction from a juvenile source, or can be produced from organic or inorganic (carbonate) sources. Possible modes of origin for both CO_2 and CH_4 are summarised in Figure 3. In general terms, gases of biogenic and thermogenic origin distinguished by the ^{13}C concentration. Methane with $\delta^{13}C$ values more negative than $-60^{0}/_{00}$PDB are considered to be biogenically produced whereas those more positive than $-50^{0}/_{00}$ PDB are thermogenic in origin - between $-60^{0}/_{00}$PDB and $-50^{0}/_{00}$ PDB mixing of the two types cannot be excluded (Schoell, 1983). The story is more complicated for CO_2, but possibilities from several sources are shown on Figure 3.

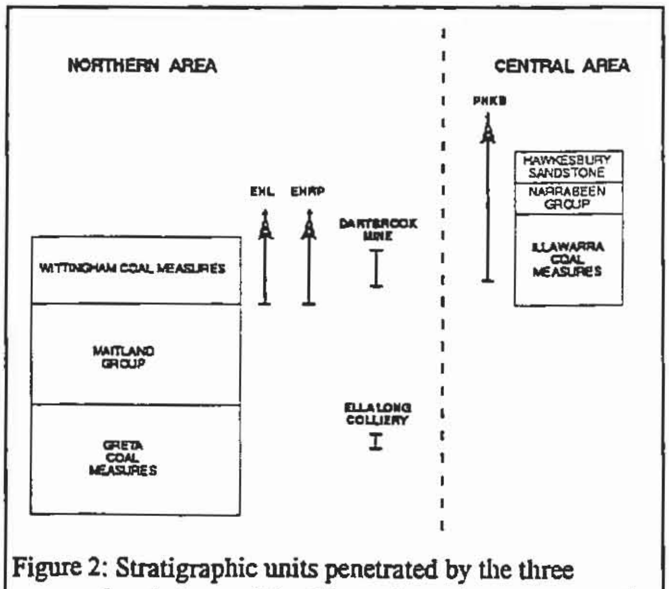


Figure 2: Stratigraphic units penetrated by the three boreholes used for this study, and seams exposed at the two mines.

Stable carbon isotopic composition was determined for all 20 samples examined in this study and the results are given in Table 1. According to the above classification, methane from PHKB-1 is interpreted to be of thermogenic origin with $\delta^{13}C(CH_4)$ values ranging from -35.2 to -43.7$^0/_{00}$PDB.

	SAMPLES	CH_4 (%)	CO_2 (%)	$\delta^{13}C(CH_4)$ (ppm)	$\delta^{13}C(CO_2)$ (ppm)	$\delta^{13}C(CO_2)$ - $\delta^{13}C(CH_4)$ (ppm)
well EHL	M410	58.6	37.2	-69.8	-3.9	65.9
	E1	79.6	20.4	-67.6	-3.1	64.5
	A314	48.9	51.6	-55.0	-3.9	51.1
	M409	78.1	22.3	-64.4	0.7	65.1
	A606	47.8	50.6	-53.2	7.1	60.3
well EHRP	A706	94.9	5.1	-68.8	-1.2	67.6
	A705	87.1	12.9	-68.4	-0.6	67.8
	A707	85.0	15.0	-58.4	4.3	62.7
	A700	92.2	7.8	-61.6	-1.1	60.5
	M137	92.2	7.7	-52.8	1.3	51.5
	M347	97.1	2.9	-51.9	-5.6	46.3
well PHKB	M424	98.7	1.2	-43.7	*10	53.0
	M408	99.3	0.7	-35 / -45	-10 / -15	20 / 30
	M422	97.0	0.1			
	M401	94.4	2.7			
Darkbrook Mine	NK1	31.3	68.7	-66.5	1.2	67.7
	NK2	26.0	74.0	-65.5	4.3	69.8
	NK3	68.4	31.6	-65.2	-0.5	64.7
Ellalong Colliery	NK4	49.4	50.6	-70.1	-1.4	68.7
	NK5	55.3	55.3	-73.5	-6.1	67.4

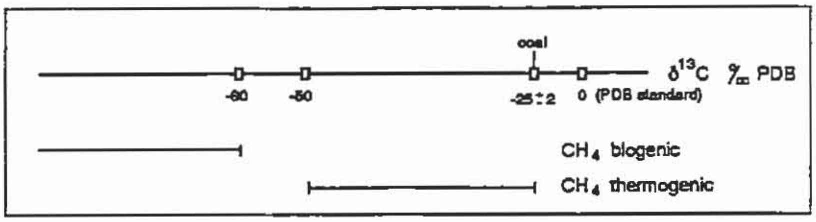
Table 1: Chemical and isotopic composition for coal seam gases analysed for this study.

The $\delta^{13}C$ values for methane produced by carbon dioxide reduction are strongly correlated to the $\delta^{13}C$ of the carbon dioxide substrate with the isotopic fractionation, $\delta^{13}C(CO_2)$ - $\delta^{13}C(CH_4)$, between the two gases at about 70±10$^0/_{00}$PDB (Rice et al., 1993). Isotopic analyses for wells EHL-1 and EHRP-1 therefore suggest that CH_4 and CO_2 are involved in the process of carbon dioxide reduction by microbial activity. In addition, gas samples NK4 and NK5 from Ellalong Colliery are also thought to represent the process of CO_2 reduction: fractionation between CO_2 and CH_4 for NK4 and NK5 is 68.7% and 67.4% respectively.

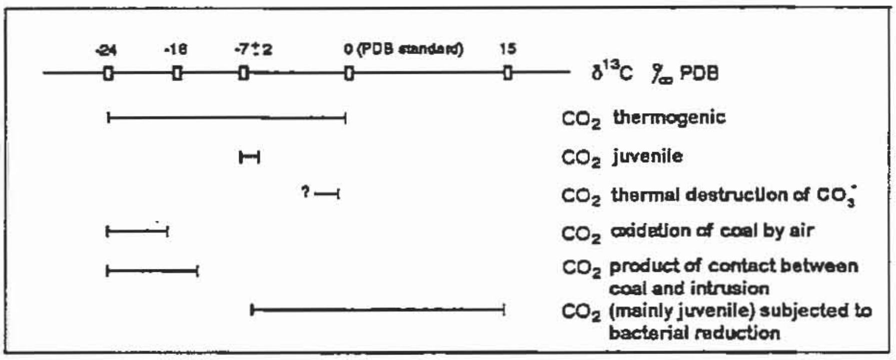
In natural gases, including coalbed gases, there is a strong direct relationship between the maturity of organic matter and the C-isotopic composition of indigenous thermogenic methane (Stahl, 1979): with increasing Ro, $\delta^{13}C(CH_4)$ also increases. If the $\delta^{13}C(CH_4)$ value and Ro of coal from which the sample was collected fall on or near the line representing this relationship (Figure 4), then the methane can be considered as indigenous (or thermogenic) to the coal. Otherwise, it is believed to have migrated in or been subjected to secondary process (Schoell, 1983). Figure 4 shows the genetic classification of natural gases in the coal seams of the Sydney Basin. This scheme

$$\delta^{13}C\ PDB = \frac{{}^{13}C/{}^{12}C\ sample - {}^{13}C/{}^{12}C\ PDB}{{}^{13}C/{}^{12}C\ PDB} * 10^3\ ‰\ PDB$$

FORMULA



METHANE PRODUCTION



CARBON DIOXIDE PRODUCTION

Figure 3: Formula for calculating $\delta^{13}C$ values and $\delta^{13}C$ ranges for various production pathways for methane and carbon dioxide. Data from Gould & Smith, 1980; Schoell, 1983; Smith & Gould, 1980; Smith & Pallasser, 1996; Smith et al., 1982).

is based on data from Pacific Power's 3 wells. The $\delta^{13}C(CH_4)$ data for the three wells indicate that gases from well PHKB-1 are of thermogenic origin, whereas the $\delta^{13}C(CH_4)$ values of the wells EHL-1 and EHRP-1 fall below the theoretical line and are probably biogenic in origin. In addition $\delta^{13}C(CH_4)$ values for the latter two wells are becoming more positive with depth (Figure 4). This feature could be explained by an increasing admixing of thermogenic methane with depth.

INTER-SEAM GAS DISTRIBUTION

Figure 5 is a schematic geological cross-section including EHL-1 and EHRP-1 showing the variations in gas composition in relation to structure. As CO_2 is highly soluble in water, it migrates within aqueous solution where formation water is saturated. CO_2 migrates towards structural highs more readily than CH_4 because CH_4 degases at higher temperature and pressure than CO_2 and can therefore be absorbed by the coal at greater depths (Faiz and Hutton, 1992, 1995). Figure 5 shows a sharp CO_2 decrease in gas composition for EHRP-1 below the interval 128-136m (at the Munro Middle Split the proportion of CO_2 is 82.1% and in the underlying Munro Lower Split it drops to 10.1%). It is assumed that CO_2 migrates vertically upward through permeable strata, and along faults, joints and shear zones, where it intrudes coal seams and subsequently migrates laterally to structural highs. In the lower section of EHRP (533m) $\delta^{13}C(CO_2)$= -5.6$^0/_{00}$PDB value for canister A347 could mean invasion by "fresh" juvenile CO_2 ($\delta^{13}C(CO_2)$= -7±2$^0/_{00}$PDB) which is mixed with the indigenous and existing juvenile CO_2 which had already been subjected to bacterial reduction. In such a case the fractionation effect between the two gases would be destroyed ($\delta^{13}C(CO_2)$ - $\delta^{13}C(CH_4)$ = 46.3 $^0/_{00}$PDB) (Figure 6, Table 1). During subsequent lateral migration, gases are subjected to bacterial CO_2 reduction and isotopic fractionation is stabilised (EHL-1 $\delta^{13}C(CO_2)$ - $\delta^{13}C(CH_4)$ = 60.3-65.9$^0/_{00}$PDB).

ISOTOPIC ZONALITY

In Ellalong Colliery some $\delta^{13}C(CO_2)$ zonality appears to exist within the coal seam section adjacent to a sub-vertical fracture system cutting through the Greta Seam (Figure 7). In its central part, the fracture system is thought to be a channel for migration of juvenile CO_2 because the $\delta^{13}C(CO_2)$ value is close to -7±2$^0/_{00}$PDB (sample NK5), further away from the fracture system, $\delta^{13}C(CO_2)$ and $\delta^{13}C(CH_4)$ values become more positive as the process of CO_2 reduction progresses (sample NK4).

CONCLUSIONS

High proportion of CO_2 in coalbed gases (>6%) of the Sydney Basin are interpreted to be mixtures of CO_2 derived by three different pathways: (1) CO_2 generated during normal maturation; (2) CO_2 of juvenile (magmatic) origin; and (3) a mixture of (1) and (2) that has been subjected to the process of bacterial reduction resulting in generation of CH_4. The influence of (1) and (2) are judged to be minimal because the

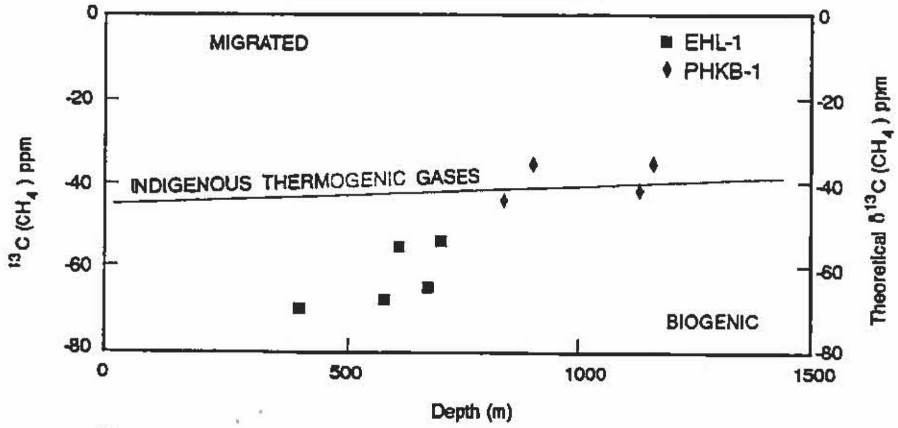


Figure 4: Plot of $\delta^{13}C(CH_4)$ against depth for EHL-1 (diamonds) and PHKB-1 (squares), showing the relationship with the theoretical $\delta^{13}C(CH_4)$ against depth relationship of Stahl (1979), generated from Ro and $\delta^{13}C(CH_4)$ values.

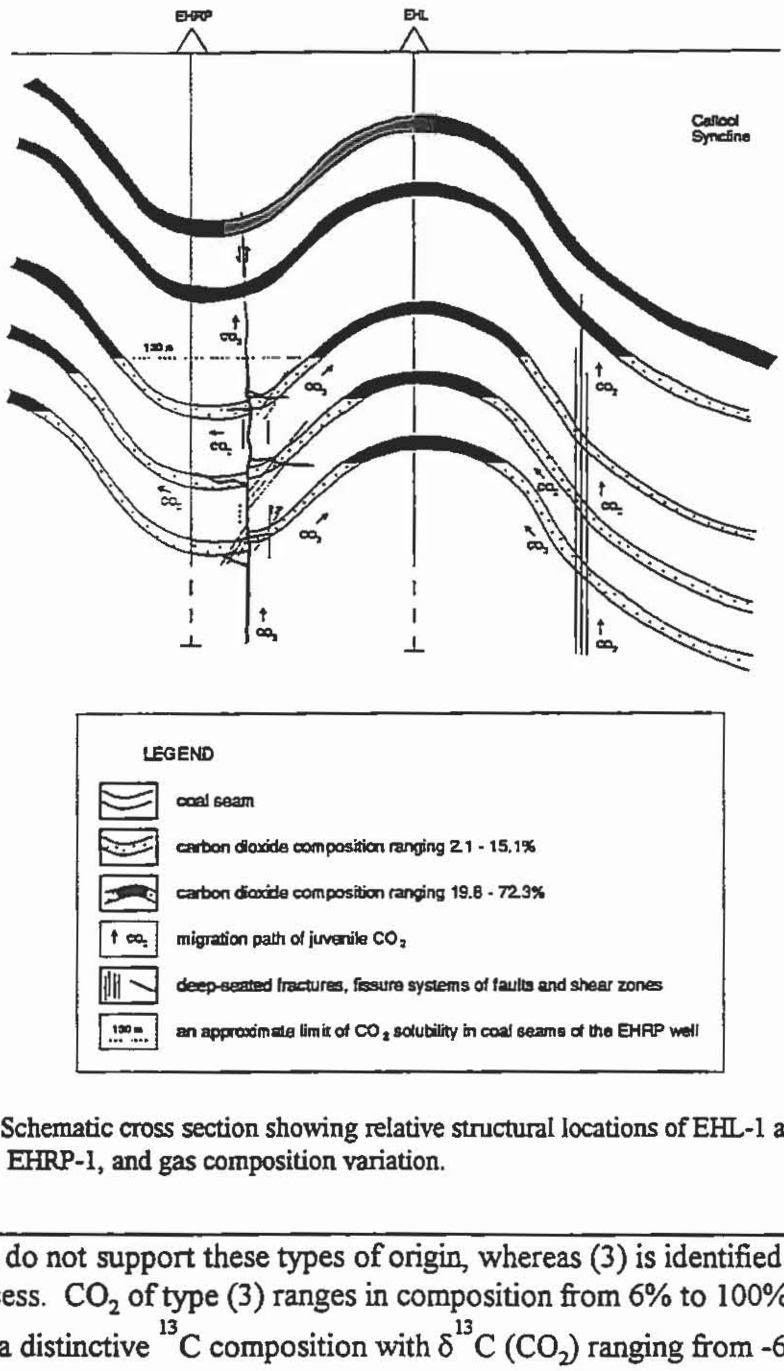


Figure 5: Schematic cross section showing relative structural locations of EHL-1 and EHRP-1, and gas composition variation.

isotopic ratios do not support these types of origin, whereas (3) is identified as the dominant process. CO_2 of type (3) ranges in composition from 6% to 100% of coalbed gases and has a distinctive ^{13}C composition with $\delta^{13}C$ (CO_2) ranging from $-6.1^0/_{00}$PDB to $7.1^0/_{00}$PDB. The proportion of CO_2 in the gas stream can be enhanced up to 100% by lateral migration to structural highs.

ACKNOWLEDGMENTS

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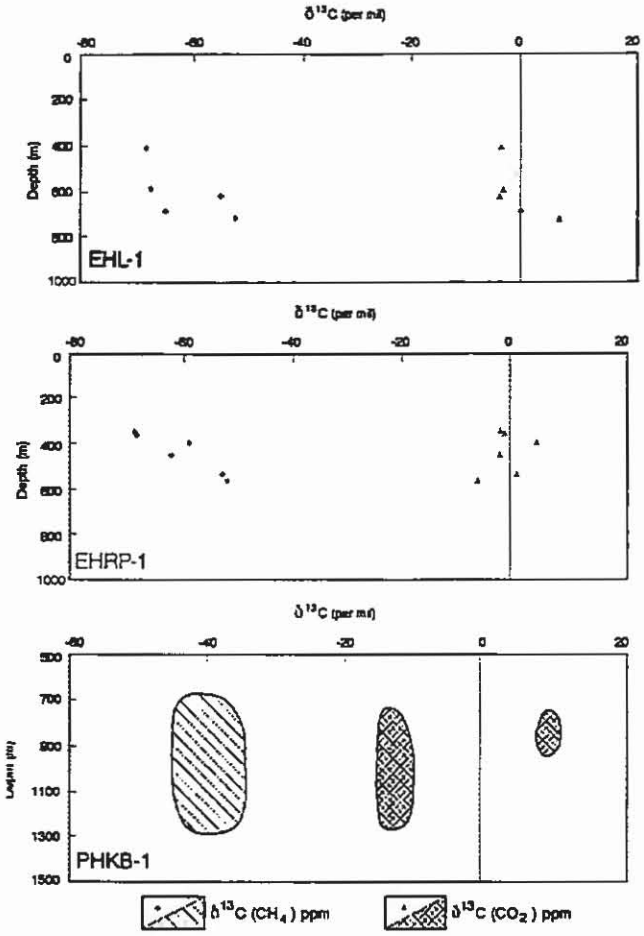

Figure 6: Downhole isotopic distribution of CH_4 and CO_2 for EHL-1, EHRP-1 and PHKB-1. Fields rather than individual values shown for PHKB-1 for proprietary reasons.

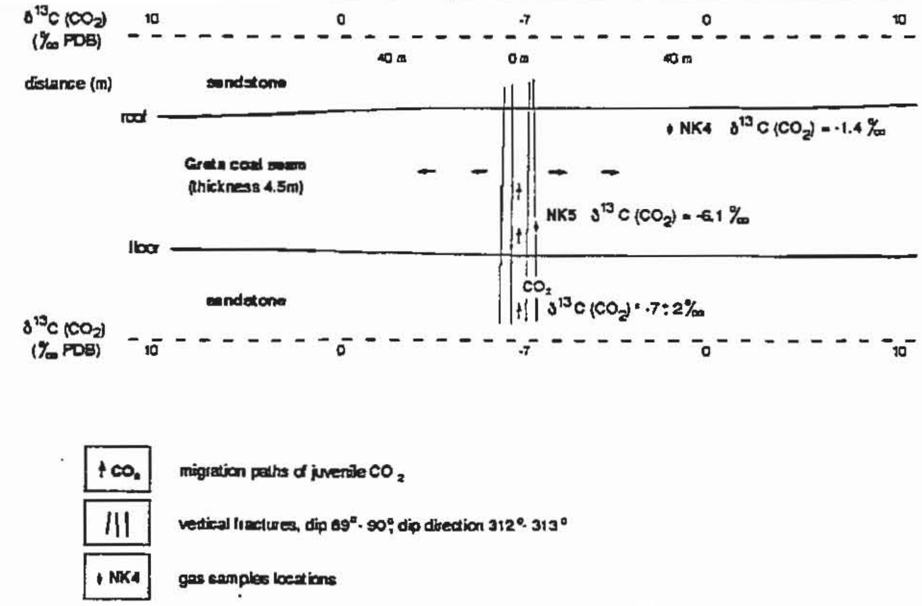

Figure 7: Carbon isotopic zonality for CO_2 of juvenile origin (the $\delta^{13}C(CO_2)$ value is close to -7± 2‰ PDB) in the Greta Coal Seam.

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SLOPE RISK ASSESSMENT AND REMEDIATION OF NEAR VERTICAL CUTS IN HAWKESBURY SANDSTONE F3 FREEWAY

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SUMMARY

A slope risk assessment analysis was undertaken on a total of 83 high angle road cuts in Hawkesbury Sandstone along a 20 km length of the F3 Freeway, north of Sydney.

Details of individual cut features and methods used to prioritise cuts for remedial works are given along with remediation measures, together with a discussion on risk assessment as part of the design process for future freeway works.

INTRODUCTION

The F3 Freeway forms the major transport link between Sydney and the Central Coast and Newcastle regions located some 100 km to 150 km northwards, with traffic movements of the order of 15,000 vehicles per day (1989).

Within the study area, the route of the freeway lies within a geological setting of rugged terrain dominated by the near flat lying Hawkesbury Sandstone of Middle Triassic Age. Local relief is in the order of 100 m - 200 m.

Construction of the Freeway was largely undertaken in the late 1960s to replace the older, two lane Pacific Highway, with a further southern extension constructed during 1986-87. Excavation methods appear to have been largely by drilling and blasting.

The resulting roadway from both periods of construction is characterised by alternating cut and fill sections with the cuttings typically steeply excavated in medium to high strength sandstone with some mudstone interbeds and occasional volcanic intrusives.

Some cuttings have intermediate benches, although most are continuous with slope angles up to 80° and heights ranging up to 70 m.

During 1994, Douglas Partners were engaged by the Roads and Traffic Authority of NSW (RTA) to undertake a Slope Risk Priority investigation on cuttings along the southernmost 20 km of the F3 Freeway, between Wahroonga and the Hawkesbury River.

During 1996-97 remediation of some higher risk cuttings was undertaken, including removal of boulders and blocks as well as stabilisation, involving the installation of rockbolts and the application of shotcrete.

This paper presents a brief chronicle of methods used to prioritise cuts for remedial works and a review of remediation works carried out. Discussion on features of the cuts posing a potential hazard to Freeway users and risk assessment during future freeway design are also presented.

TYPICAL FEATURES WITHIN THE CUTTINGS REQUIRING REMEDIAL WORK

The Hawkesbury Sandstone formation dominates the landscape within a 100 km radius of Sydney. It is a quartz sandstone with a maximum thickness of 250 m. The formation contains numerous thin mudstone interbeds but sandstone exceeds mudstone interbeds by about 20:1. (Herbert, 1980). Sandstone facies of the formation are both of the sheet or massive types. The sandstone has high in situ horizontal stresses which are relieved on excavation.

The Freeway cuttings have resulted in large exposures of all facies of the formation. The exposed strata is generally of medium to high strength and is moderately to slightly weathered. However, numerous bedding horizons of lower strength, highly weathered strata also occur along the Freeway route. During excavation, horizontal stress relief movement occurred along these bedding planes.

The formation in the area of the Freeway is also often characterised by steeply dipping, semi-orthogonal joint sets which can, upon intersection with the cutting faces, create slabs, blocks and wedges of rock, some of which are unfavourably orientated.

Some of the principal features of the weathered rock faces that are considered hazardous include:

- individual loose boulders or dilated joint blocks,
- zones of loosened joint blocks caused by weathering-out of horizontal bedding planes and/or joint zones,
- weathering and slaking of low-strength clayey sandstone beds, forming undercuts to the slope or rock above,
- dilation of joints running at an acute angle to the rock face; the 'feather edges' of such blocks are potentially subject to progressive tensile or shear failure,

- the presence of surface rubble or boulders on the natural slope above the crest of the cutting which could be undermined by strong overland rain-water flow,
- vegetation, particularly trees which can force joints open, due to 'root jacking'.
- stress relief between blast holes and blast damage, including areas where rock material has not been removed outside of the pre-split line, has also resulted in loose blocks or slabs,
- slot forming, weathered out of dolerite dykes or sheared zones.

It is considered possible that vibration from the traffic may also have contributed to slight general loosening of the cutting faces by encouraging further stress relief movement along bedding planes.

SLOPE RISK RATING SYSTEM & INITIAL CLASSIFICATION OF CUTTINGS

Douglas Partners undertook an initial assessment of 83 cut faces along the 20 km section of the freeway in August, 1994, using the RTA Scientific Services "Slope Risk Rating System Guide" (version 1). This guide presents a recommended procedure for assigning a risk rating to slopes above roads based on quantitative levels for both the probability of occurrence and the severity of the consequences of slope failure.

The term, 'risk', is deemed to combine both potential for as well as consequences of slope failure.

The work was undertaken to supplement an earlier assessment of the cutting stability by the RTA Materials Services Branch in May, 1993.

Field observations of each cutting were recorded on Slope Inspection Reports (SIR), then used to establish an order of priority which reflected the need for further detailed geotechnical investigation; remedial or preventative action based on each observation being given a weighted score and recorded on a Slope Instability Score Sheet (SISS).

The instability score assigned to each slope allowed the slope to be placed in one of five classes which qualitatively represent the instability conditions. The five classes and corresponding ranges of instability score are given in Table 1.

Table 1. Classification of Slope Instability

Instability Class	Instability Score Range
Very high (VH)	> 100
High (H)	75 - 100
Moderate (M)	50 - 75
Low (L)	25 - 50
Very low (VL)	<25

Source: RTA (1994)

A Consequence Assessment was also undertaken for each slope which qualitatively indicated the possible effects on road, traffic, human lives, services and property that could be caused by failure of that slope.

Road Class and traffic volume was a most important consideration in the Consequence Assessment. It is most likely that potential for disruption to traffic and services and loss of life would be highest on roads with the highest traffic flow.

A further consequence consideration involved assessment of potential disruption of services or loss of life resulting from the slope failure affecting occupied buildings above or below the slope.

A brief description of Road Class and a classification of Consequences Class are given in Tables 2 and 3 respectively.

Table 2 - Description of Road Classes

Road Class	Road Type	Daily Traffic Volume
1	Freeways, Tollways, National or State Highways	>10,000
2	National or State Highways State Roads	5000 - 10000
3	Regional Roads (Main or Trunk)	2000 - 4999
4	Rural Roads , Local Roads	<2000

Adapted from RTA (1994)

Table 3. - Classification of Consequence.

Consequence Class	Description of Consequence
Very High (VH)	High risk to life and/or total closure of a Class 1 road, resulting in an extended period of disruption to traffic and/or services and high cost of remedial works
High (H)	High risk to life and/or partial or total closure of one carriageway of a Class 1 road or total closure of a Class 2 road resulting in an extended period of disruption to traffic and/or services and high cost of remedial works
Moderate (M)	Moderate risk to life and/or partial or total closure of one carriageway of a Class 2 road, resulting in a temporary period of disruption to traffic and/or services and moderate cost of remedial works
Low (L)	Low risk to life and/or partial or total closure of a Class 3 road, resulting in a temporary period of disruption to traffic and/or services and low cost of remedial works
Very Low (VL)	Very low risk to life and/or partial or total closure of a Class 4 road, resulting in a temporary period of disruption to traffic and/or services and very low cost of remedial works

Initially, a High consequence rating was proposed for all cuttings as a result of the Freeway being a Class 1 road. However, some of the cuttings are only very low (<3 m high) and in their present condition were considered to present only a moderate risk to life, regardless of traffic volume. A downgraded Consequence Class, where applicable, was given to those cuttings.

When Instability and Consequence classes are combined, a Slope Risk Rating can be given based on Table 4.

Table 4. - Slope Risk Rating

	CONSEQUENCE				
INSTABILITY	Very High (VH)	High (H)	Moderate (M)	Low (L)	Very Low (VL)
VH	1	1	2	3	3
H	1	1	2	3	3
M	2	2	3	4	4
L	3	3	4	5	5
VL	3	3	4	5	5
Source:	RTA, 1994				

Numbers 1 to 5 in Table 4 indicate risk categories in order of priority for further investigations or implementation of remedial, preventative or maintenance works as follows:

Risk Rating 1 - Immediate action

Risk Rating 2 - Urgent action

Risk Rating 3 - Regular maintenance, action as soon as possible

Risk Rating 4 - Regular maintenance, frequent inspections

Risk Rating 5 - Periodical inspections and maintenance

On the basis of Consequence Class and Instability Class, a Slope Risk Rating was calculated for each of the 83 cuttings.

The results indicated that 19 of the cut slopes inspected were considered to warrant a Slope Risk Rating of 1. The bulk of these slopes were located within cuttings along the older northern section of the Freeway although five cut slopes from the newer, southern section were also included due to specific features.

In general, the findings were consistent with those presented in the RTA Material Services Branch Report, with similar features noted.

Several cuttings were allocated a high Slope Risk Rating due to the removal of undergrowth in bushfires that swept through much of the area in January, 1994. These fires had exposed large colluvial boulders on natural slopes, above the cut faces, which dipped towards the freeway. These problem areas may not have been easily identified during normal vegetation conditions unless a detailed walk-over inspection had been undertaken.

COMMENTS ON THE SLOPE RISK RATING SYSTEM

Some general comments should be made regarding the workability of the draft RTA system as used for the investigation.

Whilst the Slope Inspection Reports allow for considerable detail of field observations to be recorded, the Slope Instability Score Sheets were often insensitive to specific details of defects.

For example, on each SISS a specific score was allocated to the slope, dependent on total height. However, no allowance was given for the height upon the slope where various defects occur.

Similarly, whilst much information was recorded on the SIR regarding size and location of loose debris, boulders or blocks, there was little variation in allowable scores on the SISS.

Furthermore, it is considered that scores may be allocated on the SISSs for components that may not be applicable for the slope type. This was evident during the investigation when scores were allocated for degree of seepage, which was largely weather dependent and not considered to be a major stability factor for these slopes.

DETAILED SLOPE STABILISATION ASSESSMENTS

A second phase of the slope risk priority investigation involved recommendation of specific stabilisation measures on five selected cuttings that had been identified as having a Slope Risk Rating of 1 during the earlier phase.

Initially each cutting was photographed from the top of the opposite cutting, using a 35 mm SLR camera. This was carried out on an overcast day, to reduce shadow effects. Following development and printing of the films, a photomosaic was prepared for the full cutting comprising multiple plates with transparent plastic overlay.

The photomosaic was then taken into the field by a two man team of engineering geologists.

The cutting was taped longitudinally to identify horizontal chainages. It was also taped vertically at a number of points to allow heights of individual features to be estimated.

Following the taping, the cutting was carefully inspected from carriageway level, from the top of the cutting and from the opposite side of the cutting, noting various features which were considered hazardous and noting the necessary treatment. These features were directly highlighted on the photomosaic overlay and checked from various angles.

In the office, the recommended stabilising measures were transcribed onto the photomosaics and a table prepared describing the measures and giving a priority rating to each feature. These annotated photomosaics and the table were then independently reviewed by the Principal Engineering Geologist.

The recommended stabilisation treatment for the potentially unstable features noted included:

- scaling and cleaning of sections of the rock face and upper batter slopes,
- removal of vegetation from the rock face and from a 5 m wide zone at the top of the cutting,
- removal of individual dilated rock or joint blocks on the face,
- subhorizontal rock bolting across open feather-edge blocks,
- pinning by vertical dowels of undercut sandstone blocks at the top of the cutting,
- pattern bolting, meshing and shotcreting areas of rock being loosened by weathering-out of joints and bedding planes,
- scaling and then shotcreting of fretting low strength clayey sandstone and shaly beds,

- construction of a rock fence near the crest of the cutting to arrest any larger debris which may fall from the natural slope above.
- pattern bolting, meshing and shotcreting of dolerite dykes or sheared zones.

Based on experience, the priority of treatment was subdivided into six classes, namely 1, 1-2, 2, 2-3, 3 and 4.

Features with a priority of 1 or 1-2 were recommended to be treated in the near future. Features with a priority of 2 or 2-3 required treatment within two to three years, whilst features with a priority of 3 or 4 required treatment within five to ten years.

A brief report was prepared for each of the nominated five cuttings. Each report incorporated full colour photocopies of the photomosaics with the accompanying table listing all features to be treated on that cutting.

GEOTECHNICAL SUPERVISION OF REMEDIATION WORKS

Geotechnical input has been provided by Douglas Partners during both the tendering process and construction phase of remediation works undertaken on the cuttings.

In some instances, nominated priorities for various features to be stabilised have been changed during the course of the work following closer inspection from a cherrypicker and from on site discussions between representatives from Douglas Partners, the RTA and the contractor. On some cuttings all work has been undertaken by contractors, whilst on others, especially where scaling down quantities are not easily assessable in advance scaling down works have been undertaken by RTA day labour. The supervisor on site has usually been able to authorise variations to the work undertaken with minimum delay.

For example, where closer inspection indicated that rock slabs or blocks nominated for scaling were too large or awkwardly placed to be safely removed, bolting or dowelling the block or slab in place was given as an alternative. Similarly, blocks nominated for bolting may, upon closer inspection, be removed in preference.

DISCUSSION AND CONCLUSIONS

A slope risk assessment of high angle cuttings along the F3 Freeway, undertaken by Douglas Partners was carried out as part of the RTA management and maintenance programme for the safe operation of the freeway.

This ongoing maintenance is expected to continue for the foreseeable future and will require the long term allocation of funding, given the magnitude of the area to be assessed and the potential recurrence of certain defects even after remedial work has been undertaken (for example, regrowth of the trees).

Given this high cost of controlling or managing the risk to road users associated with rock slope failures on steep cuttings, some consideration needs to be given to the proportion of capital fimding allocated to protective measures on cuttings for future roadworks or for reducing slope angles during the construction phase.

Additional funding for benching cuttings or additional shotcreting or bolting may be more preferable than a "wait and see what happens" philosophy given the increasingly litigious nature of society.

Where potential risk of future slope instability is foreseen as a result of design of future roadworks, the degree of risk should be ascertained considering instability class and consequence of failure of the feature. Features identified as having an unacceptable level of risk should have remediation work implemented during the construction phase.

ACKNOWLEDGMENTS

I would like to aacknowledge the Roads and Traffic Authority for permission to reproduce extracts from the "Slope Risk Rating System Guide". I would also like to thank John Braybrooke for his support and valuable conversations.

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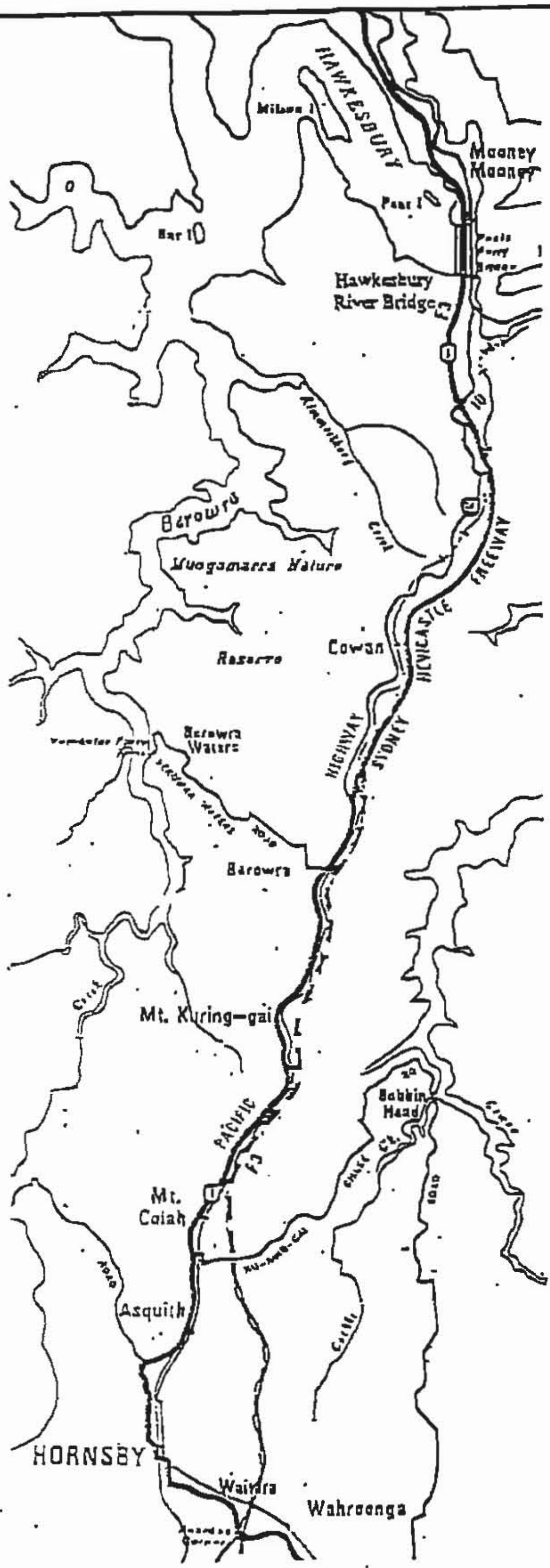
HAWKESBURY
Mooney Mooney
Hawkesbury River Bridge
FREEWAY
NEWCASTLE
Cowan
SYDNEY
HIGHWAY
Mt. Kuring-gai
PACIFIC
Bobbin Head
Mt. Colah
Asquith
HORNSBY
Wahroonga

THE DEVELOPMENT OF INNOVATIVE TECHNIQUES FOR THE USE OF BIOSOLIDS AND NATIVE SEED TREATMENT IN COALMINE SPOILPILE REHABILITATION

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INTRODUCTION

Cooranbong Colliery is located at Dora Creek, 50 kilometres south-west of the city of Newcastle, New South Wales, and is a major supplier of coal to Eraring Power Station. The Colliery is operated by Powercoal Pty Ltd, which is a wholly owned subsidiary of Pacific Power. The mine was developed in 1979 by Newcom Collieries Pty Ltd and commenced production in April 1981. At the end of January 1997, the mine has produced 17.9 million tonnes of coal with 9.5 million tonnes of recoverable coal remaining. As a part of the current lease holding, the mine operates within the Great Northern Seam at depths between 20m and 125m and produces approximately 1.5 million tonnes of coal per year.

Clause 4 of Powercoal's Environmental Policy involves "ensuring that any land affected by mining is rehabilitated to a condition appropriate to its subsequent use". A five hectare abandoned coal stockpile area, situated on site, requires rehabilitation to improve the aesthetic appeal and reduce contaminated runoff.

The stockpile area was designed to store coal in case of a coal handling plant malfunction or conveyor breakdown, as coal is only transported from the site by a single conveyor line to Eraring Power Station. However, it was very rarely used for coal stockpiling as this was an inefficient process in the operation of Cooranbong Colliery in regards to both time and cost. Instead, the area was used for the placement of reject material from the Coal Handling Plant (shale, sandstone, conglomerate and low grade coal) and for coal fines collected from the desilting of dams located on the mine site.

AIMS OF THE STUDY

The primary aim of the Cooranbong Colliery study is to determine the suitability of the minespoil substrate for the establishment of a range of native trees and to analyse whether the application of biosolids has beneficial advantages in the success of rehabilitation.

A number of secondary aims have been developed, which include:

1) to establish pollutant levels in both surface water and minespoil substrates as a result of the application of biosolids
2) to determine the effectiveness of engineering works and soil stabilisation techniques in reducing contaminated runoff from the site
3) to investigate innovative seed treatments and their impact on seed germination rates.

planting or sowing with native seed. The establishment of native trees using the latter method is the focus of the study on the Abandoned Coal Stockpile area at Cooranbong Colliery.

Revegetation of the stockpile area at Cooranbong aims to restore the area with tree species that are endemic to the surrounding area. A selection of the tree species is shown in Table 1 which also lists their proportional representation by weight in the seed mix to be applied.

Species	Proportion	Total Percentage
Angophora costata (Smooth - Barked Apple)	5%	
Eucalyptus eugenioides (White Stringy bark)	5%	
Corymbia gummifera (Red Bloodwood)	5%	50%
Eucalyptus umbra (Bastard Mahogany)	10%	
Eucalyptus maculata (Spotted Gum)	10%	
Eucalyptus haemastoma (Scribbly gum)	15%	
Acacia longifolia (Sydney Golden Wattle)	25%	50%
Acacia falcata (Sickle Wattle)	25%	

Table 1. Proportional representation by weight of species in the seed mix to be applied.

The seed mix comprises 50% *Acacia* spp (Shrub Layer) and 50% of upper canopy layer tree species. The *Acacia* spp *longifolia* and *falcata* are common in the area and have been selected as they provide a quick cover and will shelter the substrate until the Eucalypts become established.

The mix of upper tree species aims to introduce to the spoilpile a wide species variety that is endemic to the surrounding bushland. The proportions of each species within this 50% was determined largely on the seed quantities available from the seed company. However, *Eucalyptus haemastoma* which is found on the poorer soils around the area which are typical of the immediate bushland, was applied at a higher rate due to the poor condition of the stockpile.

The tree species have been sown on the stockpile area using the direct seeding method. Manderson (1985) considered that the success of any seeding operation on mine spoil rehabilitation, depends on three key factors always being present: seed source (good quality seed), good seedbed preparation (including the removal of competitive species) and good seasonal conditions. In consideration of these factors seed has been purchased from a supplier and applied at a rate of 6 kg per hectare on a seedbed that has biosolids applied to meet plant nutrient requirements.

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. The quantity of biosolids produced from sewage treatment plants is continually increasing as wastewater treatment plants are operated at higher efficiencies to produce higher quality effluent. The constant improvement in wastewater treatment technology has been a direct response to considerable community pressure calling for cleaner effluent discharge to rivers and oceans.

As the quantity of biosolids produced increases, much research has been undertaken to determine the environmental benefits of utilising biosolids in disturbed land reclamation as opposed to disposing of it to landfill. Studies so far suggest that the use of biosolids is beneficial as they:

- improve soil structure by increasing organic matter and water retention capability
- provide both nitrogen and phosphorus as a source of plant nutrients
- promote the re-establishment of microfauna and micro-flora which are essential for nutrient cycling (Phillips 1994).

The major benefit of utilising biosolids as a source of nutrients is that it acts as a slow release fertiliser for nitrogen where within the first year, 20% of organic nitrogen is mineralised. Nitrogen is available to plants in beneficial amounts for a further five years (Hunter Water Corporation 1996).

Guidelines have been developed to ensure that the utilisation of biosolids in disturbed land reclamation affords an environmentally acceptable method of disposal. The draft guidelines entitled Environmental Management Guidelines for the Use and Disposal of Biosolids Products have been developed by the Sewage Sludge Subcommittee of the Hazardous Chemical Advisory Committee, chaired by the NSW Environment Protection Authority in October 1995. The committee consists of representatives of a number of organisations, which include the Department of Health, NSW Agriculture and State Forests. One of the objectives of these guidelines is to encourage the beneficial use of biosolids where it is safe and practicable to do so, and where it provides the best environmental outcome (Environment Protection Authority 1995).

There are two steps involved in using the guidelines. The first is to determine the Contaminant Grade and Stabilisation Grade of the biosolids product and the second step involves the determination of the Maximum Allowable Biosolids Application Rate as well as establishing management factors for biosolids application. The contaminant and stabilisation grades are determined on organic chemical contaminants and levels of metals as well as the type of stabilisation treatment process used to reduce pathogen levels, vector attractants and odour. The Maximum Allowable Biosolids Application Rate is determined by calculating the Contaminant Limited Biosolids Application Rate (CLBAR). The maximum total nitrogen load allowable (Total Kjeldahl Nitrogen) is 1200 kg N/ha, which equates to approximately 50 dry tonnes of dewatered biosolids per hectare.

Contaminant	Maximum Allowable Soil Contaminant Conc. (mg/kg)	Measured in situ soil Contaminant Conc. (mg/kg)	Allowable Capacity of soil to assimilate contaminants (mg/kg)	Biosolids Contaminated application Conc. (mg/kg)	Contaminant Limited Biosolids Application Rate (dry tonnes/ha)
				Edgeworth Biosolids	
Arsenic	20	2.5	17.5	9.6	1822
Cadmium	5	0.5	4.5	18	250
Chromium	250	6	244	58.3	4184
Copper	375	13	362	556	651
Lead	150	27	123	256	480
Mercury	4	0.025	3.975	3.3	1204
Nickel	125	9	116	28.2	4112
Selenium	8	13	-5	11.7	-427
Zinc	700	100	600	1698	353

Table 2. Proforma Calculation Table for Contaminant Limited Biosolids Application Rate for Non-Agricultural Land, Powercoal Biosolids Application Trial, Cooranbong Colliery.

Biosolids applied to the rehabilitation site at Cooranbong Colliery was sourced from Edgeworth Sewage Treatment works which produces a product classified as Restricted Use 3, contaminant grade D and stabilisation grade B. The biosolids produced at Edgeworth treatment works was chosen as it had a lower selenium concentration than insitu values on the rehabilitation area. Hunter Water Corporation (HWC) have predicted that the lower selenium levels in the biosolids will in fact alleviate the sites selenium concentration through a dilution effect.

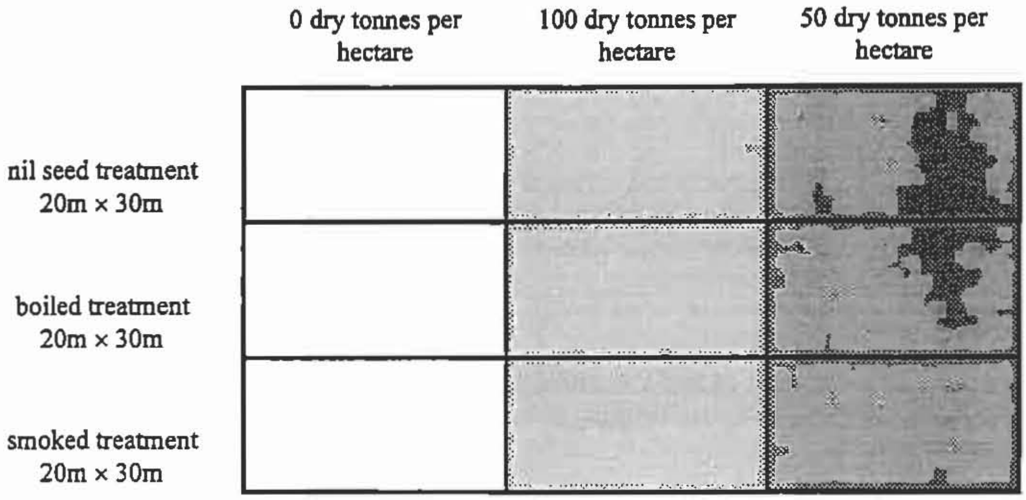

Figure 1. Cooranbong Colliery trial plot design.

One of the main aims of the research project is to determine whether the application of biosolids has beneficial advantages in the success of rehabilitation using native tree species. Figure 1 shows the design of the trial plots on the rehabilitation site. The plots are similar to those used by Phillips (1993) in the utilisation of sewage sludge on the Rix's Creek Mine Trial. The main aim of the trial was to investigate the logistics of incorporating sewage sludge into a normal rehabilitation program of an operating minesite. A series of 24 plots were designed to investigate a number of issues that included the implications of applying sewage sludge at 50 and 100 dry tonnes per hectare, the effect of applying topsoil and topsoil combined with sewage sludge and the effect of applying fertiliser and fertiliser combined with sewage sludge on the growth of pasture species.

Phillips (1993) concluded from the trials that all 18 treatments that utilised sewage sludge, superior dry biomass yields were recorded compared to that of non-sludge treatments. However, due to high transport costs, sewage sludge as a fertiliser substitute was not financially feasible, as is the case with topsoil if topsoil is not available on the mine site.

A series of nine treatments have been designed at Cooranbong Colliery to determine the effect of applying biosolids at 50 and 100 dry tonnes per hectare and applying innovative seed treatment techniques on the growth of native tree species that are endemic to the surrounding area. Unlike the trials conducted by Phillips (1993) on Rix's Creek Mine, topsoil and fertiliser applications have not been trailed. Instead, it is expected that, because topsoil is not available on site and that the only cost involved in the application of biosolids is that of spreading, biosolids will be a very cost effective substitute for both topsoil and fertiliser, with the advantage of introducing a product containing no seeds of competing species or weeds. As Cooranbong Colliery lies within the transport range already used by HWC for the disposal of biosolids they have agreed to transport the biosolids to Cooranbong Colliery free of charge.

Due to the high application rate of 100 dry tonnes per hectare of biosolids being applied to a trial area within the study, it is expected that the maximum allowable nitrogen loading rate for a one off application (1200kg N/ha) will be exceeded. The Environmental Protection Authority decided that a Pollution Control Licence is not required and that the project could proceed subject to their Environmental Management Guidelines for Use and Disposal of Biosolids Products (EPA 1995) which includes the monitoring of the site's runoff for contaminants and nutrients outlined in the guidelines.

The biosolids were applied on the site at Cooranbong by a tractor and spreader. To achieve an accurate spread, loads of biosolids were applied which comprised $80m^3$ (5 x $15m^3$ skip loads) for the 50 dry tonne per hectare plot and $160m^3$ (11 x $15m^3$ skip loads) for the 100 dry tonne per hectare plot. The biosolid plots cover an area of $1800m^2$ which are further divided into $600m^2$ plots for determining the effect of seed treatments. As the biosolids were applied, a D6 Dozer was used to incorporate the biosolids into the spoil material by deep ripping using tynes and running along the contour. A period of two weeks was then allowed before the area was direct seeded by hand.

SEED TREATMENTS

Two seed treatments and a control treatment (non-treated seed) were used prior to the application of native species of tree and shrubs to the area by direct seeding. The treatments involved boiling and smoking seeds, both designed to promote the germination of seed.

Boiling Seed

The dormancy of seed is chemically imposed by a seed coat (Baker 1989). Boiling of the seed provides a physical method of breaking the seed coat, promoting seed germination through breaking seed dormancy.

Smoking Seeds

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 Garden's plant science facility in Western Australia. After numerous smoke trials conducted under nursery and disturbed bushland conditions using seeds selected from the natural soil seed bank, it was often found that where smoke treatment was not applied, little or no germination was recorded (Dixon 1996).

Burning has been a method widely used in promoting the germination of native species as the heat and ash have been considered important to germination. However, it is now clear that smoke is crucial as it has been discovered by the scientific team at Kings Park that, in many instances, smoke promotes germination to the same or indeed greater extent than burning of bushland (Dixon 1996).

Research at this stage has found that over two hundred species of Australian native plants respond positively to smoke application, particularly those species that proliferate after a bushfire or that shed their seeds into the soil seed bank. Even *Hakea* and *Grevillea* species that are difficult to germinate, respond to smoke application. However, those species that retain their seed in capsules on the plant, such as Eucalypts and Banksias, appear to have a lesser requirement of 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 it is isolated, only the smallest concentrations will be required to treat hectares of bushland. Further research is being undertaken in the development of bonding and binding agents that will be used to facilitate the slow release of the smoke chemical to the dormant seed bank by adhesion of the chemical agent to the soil grains (Dixon 1996).

The use of smoke has many applications, these include use in Bushland Management, conservation of rare species, horticulture, farming and, in particular, in the mining sector. Smoking has the potential to be beneficial to minesite rehabilitation by promoting the diversity of species returning after mining or promoting the germination of broadcast seed. In her study of the effect of smoke and heat on seed germination in mine rehabilitation, Read (1996) results shows a 266 per cent increase in seed germination compared with a control group.

Research is continuing into developing the methods of applying smoke. Currently two main methods are used which include the application of aerosol or liquid smoke. Liquid smoke was used to treat broadcast seed for the recolonisation of native species on the rehabilitation area at Cooranbong Colliery. The methods of both liquid and aerosol smoke involve the burning or smouldering of native litter which is endemic to the area in which the native species being germinated exist (Lanham 1997 pers comm). This is important as it is believed that the chemical agent that promotes seed germination is a product endemic to the area. Commonly, aerosol applications involve channelling this smoke into a tent which contains nursery trays sown with seed, or the use of a tarpaulin in larger applications such as on farm lands. However, this method requires that the chemical agent be watered into the substrate containing the seed bank to promote germination. The project at Cooranbong Colliery involved the use of liquid smoke whereby smoke was bubbled through water to capture the germination enhancing chemical. Seeds were then soaked in this solution for 6 to 24 hours before seeding.

RESULTS

To determine the effect of applying biosolids and utilising different seed treatment techniques, results of biomass production, germination rates and relative success of different species will be determined. To establish the potential polluting effect of applying biosolids, surface water runoff will be collected from the discharge of the western dam located on the site and will be tested for the following:

Nutrients:	Ammonia-N, Nitrate-N, Nitrite-N, KN-N, Total Phosphorus
Other:	pH, Conductivity, Faecal Coliforms

As there is a high rate of application of biosolids, the concentration of heavy metals outlined in Table 2 will also be determined in the runoff water. Phillips (1993) found that the sewage sludge trials at Rix's Creek Mine did not materially affect the waters of the adjacent sediment dam except in nitrate and phosphorus levels. These nutrient levels increased initially in the months after the commencement of the trial but fell back to normal levels recorded prior to the trails after a few months.

The project is ongoing and the detailed results will be the subject of a further report on completion.

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THE EFFECTS OF NEWCASTLE HARBOUR DREDGE SOIL DUMPING ON SURFICIAL MARINE SEDIMENTS

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INTRODUCTION

The Port of Newcastle is located at the mouth of the Hunter River, approximately 120 km north of Sydney in central NSW, and it is the world's second largest coal exporting harbour, handling approximately one third of Australia's international export of coal (Department of Mineral Resources, 1994). The lower Hunter River estuary supports one of Australia's largest industrial bases for iron, steel and petrochemical industries, placing it under considerable environmental stress. Shipping channels in the harbour experience a high siltation rate which make maintenance dredging a requirement for uninterrupted shipping operations, a practice that has been continuous since 1859 (Frankel, 1996). The majority of the harbour dredged material has been dumped offshore to a spoil ground currently located approximately 5 km south-east of Nobbys Head (Fig.1). The Maritime Services Board of NSW (MSB) is required to study the mobility of dumped spoil material and assess its environmental significance to periodically obtain dumping permits from the Federal Government.

At present, work done offshore at the designated dump site has been mainly of a sedimentological nature, and very little trace metal contaminant data is available (Hunter Ports Authority 1992; EPA 1995). The purpose of the current study is the assessment of the spatial trace metal distribution in surficial sediments at the Newcastle spoil ground and an evaluation of the effects of long-term dumping on the trace metal contaminant concentrations. The sampling design allows for an an assessment of temporal and small-scale spatial variability of trace metal contaminants in the surficial sediments.

METHODS

A total of 73 surficial sediment samples were collected on two sampling occasions in February 1996 (34 samples) and July 1996 (39 samples), using a Smith-McIntyre grab sampler with a stainless steel sampling bucket. All samples were homogenized, wet-sieved through a 63μm nylon mesh to remove the coarse fraction components, and oven-dried at $60^{0}C$. The coarse fraction was subsequently dry-sieved through a 2mm nylon sieve to separate the sand (63μm-2mm) and gravel (>2mm) fractions (Ackermann *et al.* 1983; Klamer *et al.* 1990).

The geochemical analysis for eight trace elements (Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn) of both the mud (<63μm) and sand (63μm-2mm) fractions, following a 2:1 concentrated $HClO_4$-HNO_3 acid digestion, was conducted using flame atomic absorption spectrometry (FAAS) (Birch 1996; Birch *et al.* 1997). Quality control and quality assurance (QC/QA) for the analytical work was ensured by the repeat analysis of certified standard reference material Mag-1 as well as an internal laboratory standard and analytical blanks. Trace element recovery for all elements falls between 85% (Ni) and 106% (Pb) of the recommended values for Mag-1, with a precision of better than 10% relative standard deviation (RSD) for all elements, except for Mn (11%) and Ni (15%).

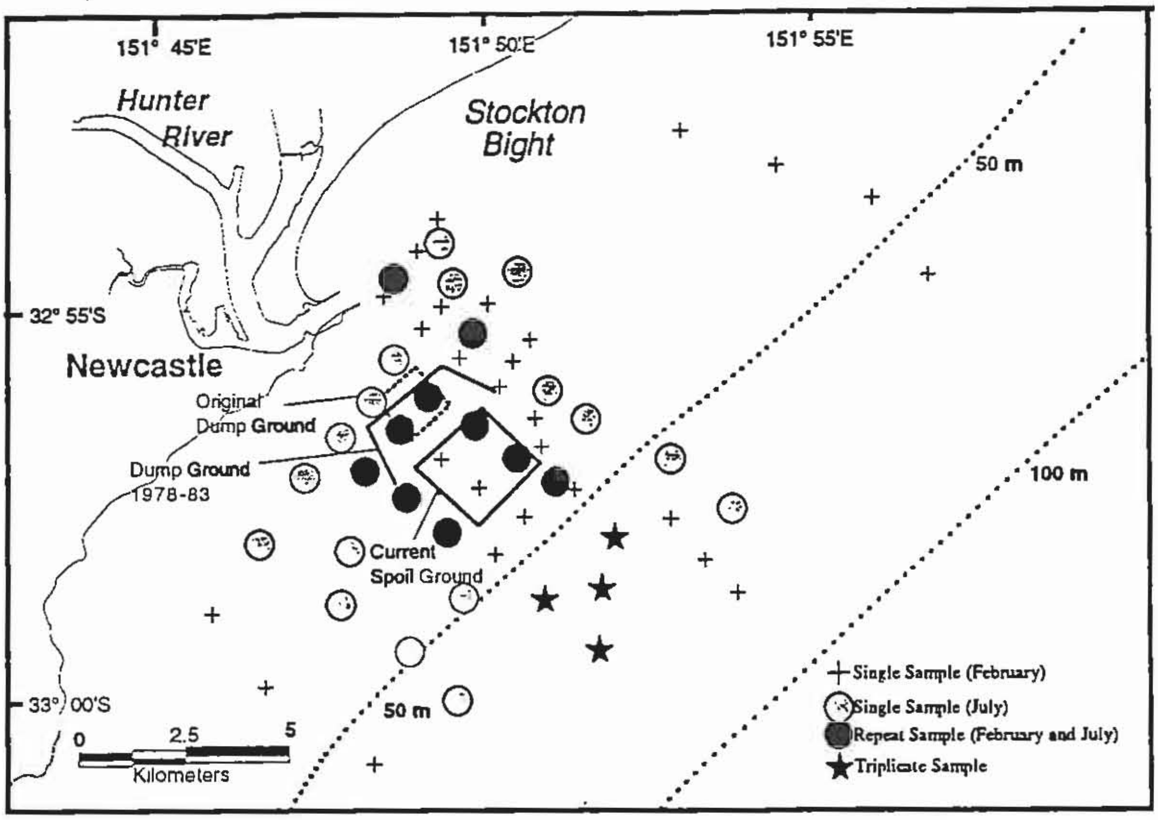

Fig.1: Sample location map for samples collected in February and July 1996. Note the presence of four triplicate sample locations on the inner to mid shelf boundary at 60 m water depth.

RESULTS

The sediment texture of inner shelf sediments off Newcastle is predominantly sandy, with slightly iron-stained, quartzose sands dominating in water depths of less than 60 m. Gravel-size components generally constitute less than 2% of the total sediment, but can locally reach up to 30%. They are mainly composed of mollusc carbonate fragments and rock fragments. Inside the existing and previous spoil grounds, lithic rock fragments and siliciclastics are found more commonly, with locally up to 50% of the surficial sediment comprised of these detrital components. Mud concentrations in inner shelf surficial sediments are generally less than 1%, with elevated mud concentrations of up to 7% found inside the spoil ground and up to 70% east to southeast of the harbour entrance, which is in agreement with the findings of Frankel (1996). Mud clasts of up to 2 cm in size, containing greater than 50% mud-sized components, can be found at a number of sample locations within the spoil ground and in the near field. The clasts are decreasing in size to microclasts of less than 5 mm in diameter to the southwest of the spoil ground, indicating their efficient dispersion and reworking on the high energy inner shelf environment. The geochemical composition of the clasts is similar to the fine fraction composition of the surficial sediments, as shown in Fig.2, with the largest differences between sediment and clast fine fractions observed for samples collected inside the current spoil ground. This is possibly associated with the larger small-scale spatial variability of trace elements in sediments inside the spoil ground.

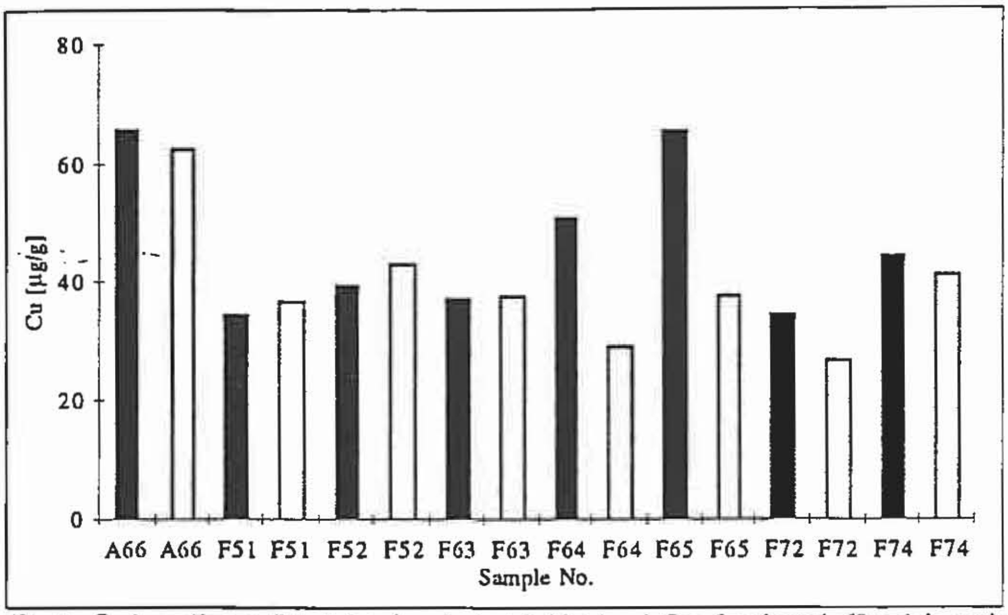

Fig.2: Cu in sediment (black bars) and clast (white bars) fine fractions (<63µm) in µg/g. Samples A66, F64 and F65 were collected inside the current and previous spoil grounds.

The mid shelf, at water depths of greater than 60 m, displays a sharp textural change from predominantly sandy (<1% mud) to muddy sandy, with mud concentrations reaching greater than 60% (Fig.3). This accumulation of sedimentary fines on the mid shelf is part of a larger regional textural feature, the mid shelf 'mud belt', reaching from Jervis Bay to north of Port Stephens (Davies, 1979; Matthai, & Birch, 1996b). The mid shelf is regarded as a depositional environment of modern fine sediment accumulation, which makes it a potentially important sink for anthropogenic contaminants (Bickford *et al.* 1993).

Gravel-free bulk sediment trace metal concentrations on the inner and mid shelf strongly correlate with the mud content of the sediments, generally increasing with greater distance from the shore. In contrast, elevated trace element concentrations are found off the harbour entrance and inside the spoil ground at levels above which would be expected from baseline levels found elsewhere in the study area (Fig. 4). Elevated trace metal levels at these localities were also found in an extensive temporal study by the EPA, as part of the Hunter Environmental Monitoring Program 1992-1994 (EPA, 1995).

A size-normalized (<63µm) trace metal distribution indicates an inner shelf enrichment of the sediment fine fraction clearly above mid shelf baseline values. Concentrations of all elements are highest inside both the existing and previous dump grounds and off the harbour entrance, as exemplified by the Zn distribution in Fig.5. A clear gradient of decreasing trace metal concentrations with greater water depth is indicative of the existing anthropogenic source relationship. The approximately shore-parallel distribution of elevated fine fraction concentrations, with a maximum between the harbour entrance and the current spoil ground, indicates that very little dumped sediment is dispersed to the southeast towards the mid shelf. A shore parallel fine fraction sediment contaminant transport is more likely to occur, correlating with findings of shore parallel sewage effluent and sediment fine fraction dispersal off Sydney (EPA, 1996; Matthai, & Birch, 1996a). An inferred southeasterly offshore dispersion pathway, as suggested by the Hunter Ports Authority (1992) and Frankel (1996) is thus questionable on the basis of the fine fraction trace metal distribution.

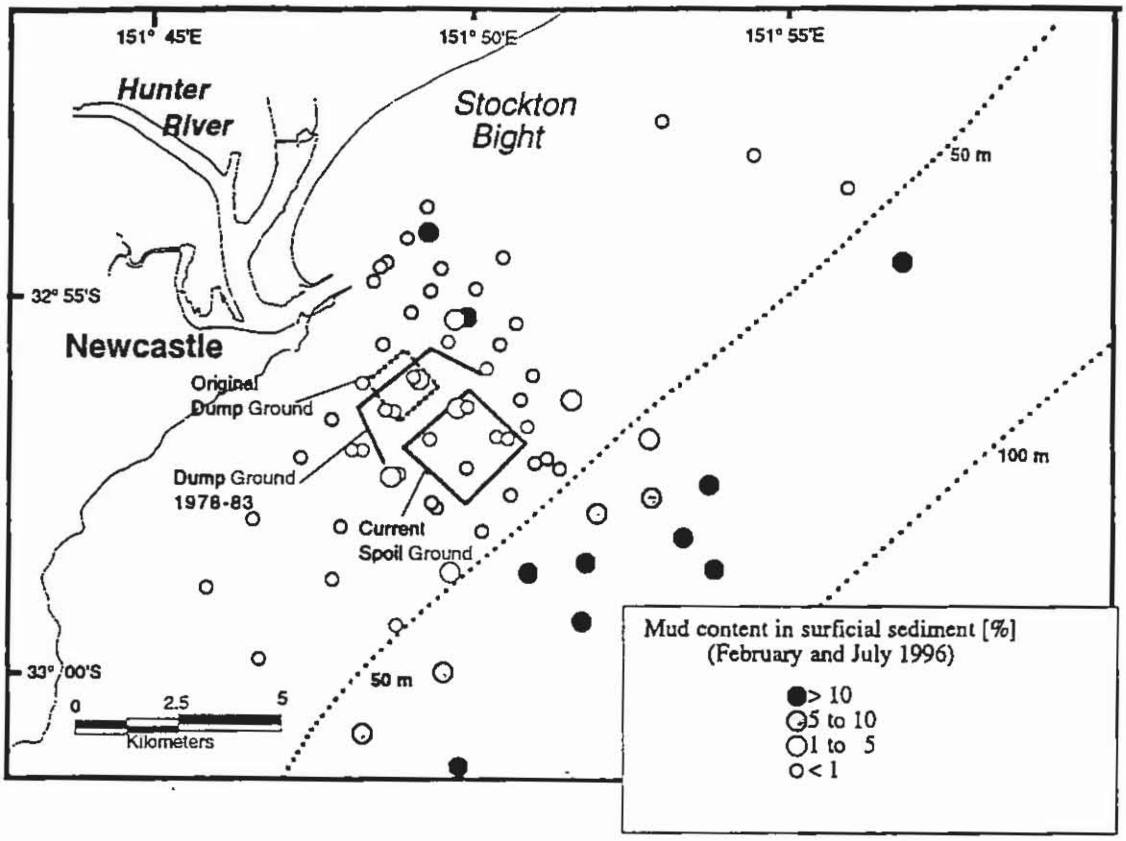

Fig.3: Distribution of mud fraction in surficial sediments.

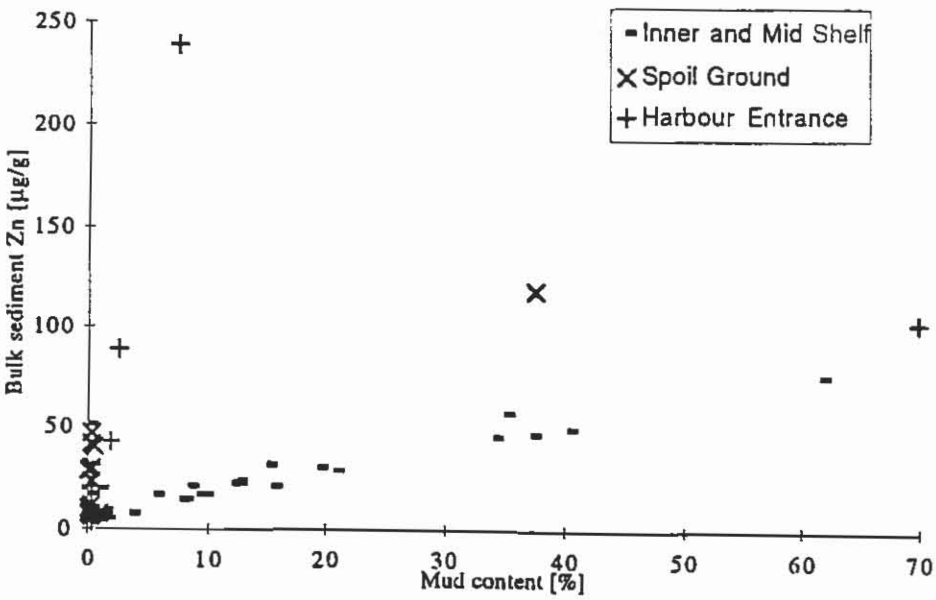

Fig. 4: Mud:Zn scatterplot for 73 samples from the Newcastle continental shelf.

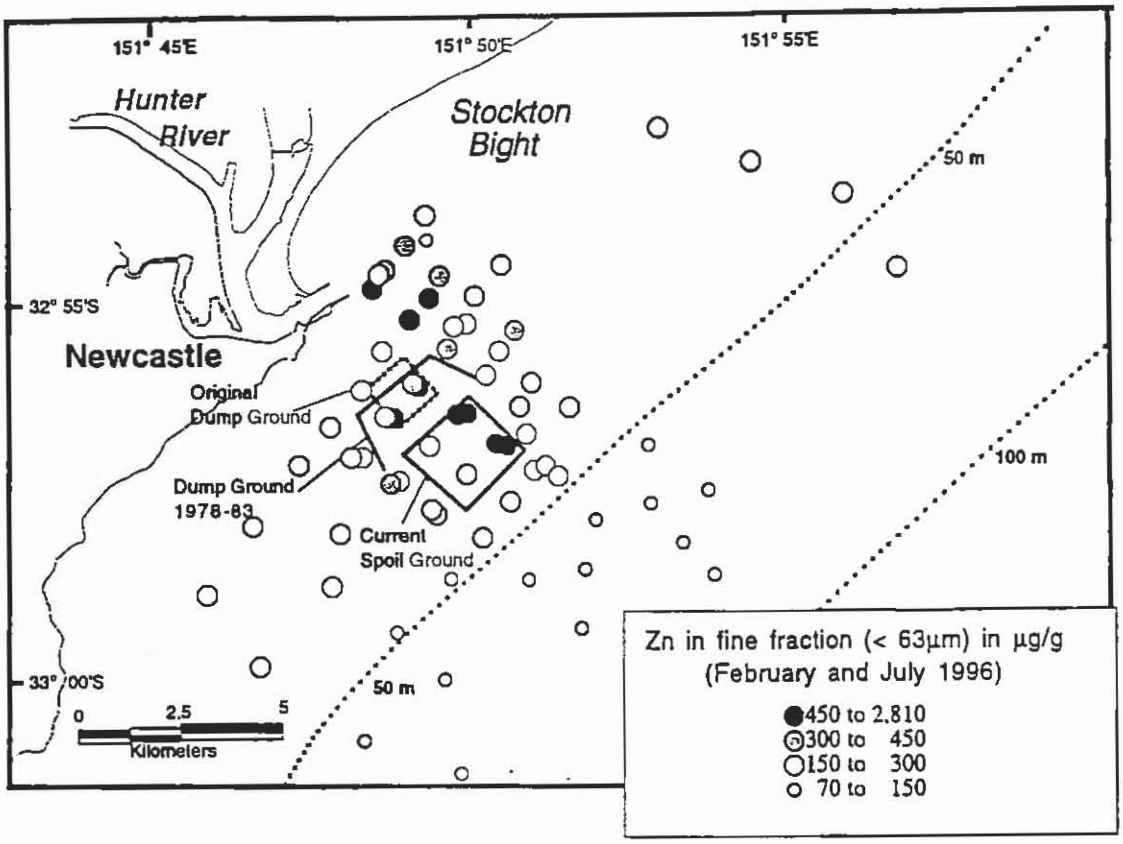

Fig.5: Spatial distribution of Zn in the fine fraction (<63µm) of surficial sediment.

The temporal trace element variability in the sediments was assessed by re-sampling 10 sample locations in February and July 1996. Sediment fine fraction trace element concentrations were found to correlate strongly, without displaying a temporal change in element concentrations, whereas the total sediment concentrations displayed greater differences, mainly as a result of textural variability (Fig.6a and 6b)

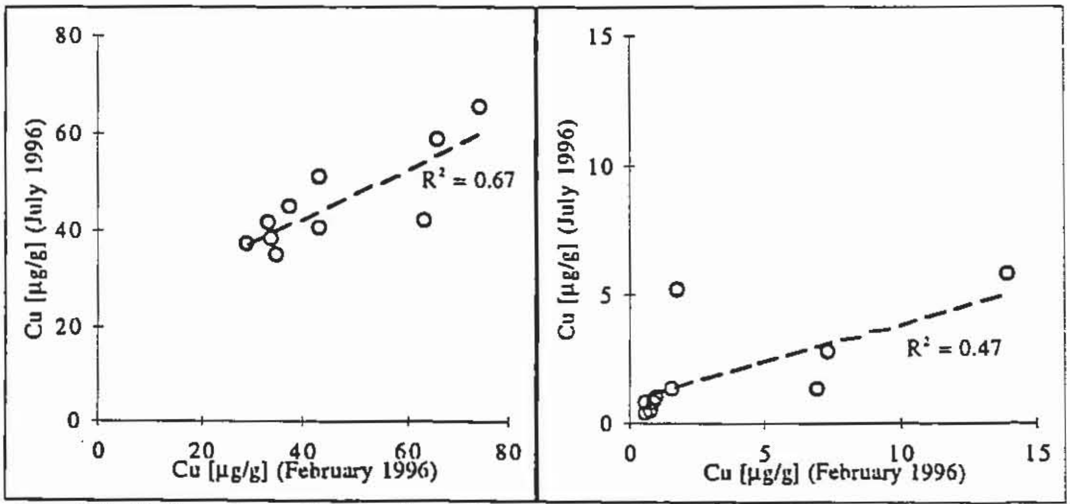

Fig.6a and 6b: Cu in sediment fine fraction (<63µm fraction, left) and gravel-free total sediment (right) in surficial sediments at 10 repeat sample locations in February and July 1996.

Small scale spatial variability and the sampling precision of surficial sediment trace element concentrations was assessed at four triplicate sample locations, with grab samples collected within 50 metres of each other. Water depths at the triplicate sample locations vary between 60 m and 79 m, and they are located between one and two nm southeast of the current spoil ground (Fig.1). Precision of trace metal fine fraction concentrations, as expressed by relative standard deviation (RSD), is less than 10% for all elements, and commonly less than 5%, which is similar to the analytical precision of the technique used. Total sediment concentrations, on the other hand, display a significantly lower precision, with RSD's commonly less than 10%, but as high as 40% for one location (Fig.7a and 7b).

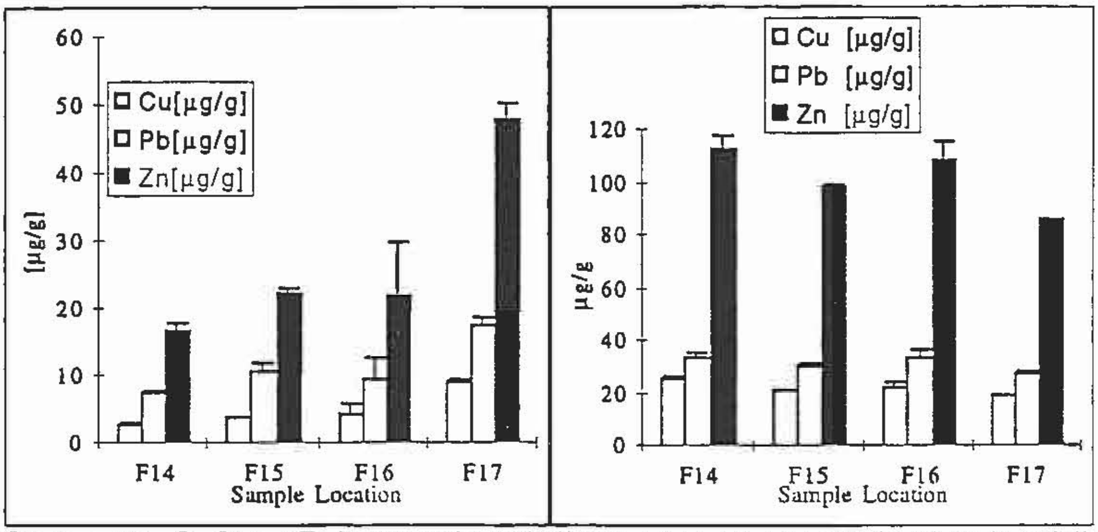

Fig. 7a and 7b: Cu, Pb and Zn in total sediment (left) and sediment fine fraction (right) for four triplicate sample locations (Error bars: +1StdDev).

CONCLUSIONS

The effects of long-term dumping on surficial sediment trace element concentrations can be clearly demonstrated, especially in the fine fraction, with elevated levels found between the Harbour mouth and the vicinity of the previous and current spoil grounds. A dispersal of the sediment fine fraction appears to occur in a shore-parallel, rather than a shore-normal direction. Efficient sediment winnowing, reworking and dispersion prevents a substantial contaminant accumulation and provides a temporally controlled process that is governed by the relationship between concentrations of dumped material and the dispersion efficiency. At water depths greater than 50 m there is no apparent effect of dumping on the sediment trace element geochemistry.

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THE CURRENT STRESS STATE IN THE SYDNEY BASIN

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BACKGROUND

The most recent information available from direct stress measurements in the rocks of the Sydney Basin has been summarised against Scheibner's 1993 structural framework of the Sydney Basin (Scheibner, 1993) in a map published recently by the New South Wales Department of Mineral Resources.

The measurements incorporated into the compilation were made using either the overcoring technique from underground excavations, or the hydraulic fracturing technique, mainly from surface holes (Enever and Walton, 1995). The data base was filtered to remove information considered not to represent the "virgin" stress condition. The information does, however, reflect the underlying impact of the geological environment.

At each measurement location, the results from a number of point measurements were combined to give average magnitudes for the horizontal secondary principal stress components and an average orientation of the major horizontal secondary principal stress. The measurements were made in a range of rock types, but with a bias toward more massive sandstones. No attempt was made in the presentation to separate lithologies and/or associated rock stiffness as a separate parameter.

This paper discusses the origin of the current stress field in the Sydney Basin with reference to both local and regional geological structure, based on the above mentioned data compilation.

THE ORIGIN OF THE CURRENT STRESS STATE

General

Deconvolution of the present state of in-situ rock stress existing in a region to separate the various elements contributing to the current net situation revolves around understanding the impact of the geological environment at various scales. Factors such as rock stiffness and surface topography can have a significant influence in particular instances, but the generally most pervasive and significant factors are likely to be the geological evolutionary process (burial, uplift and erosion in sedimentary basins) and post depositional structural events.

When considering the stress field in this context, it is possible to start from two different perspectives:

- that the overriding control on the stress field rests with regional influences such as the burial/uplift history and/or crustal tectonics, and that the impact of local features on the current stress state is of secondary importance, causing localised perturbations to the regional picture or;

- that the net current stress state arises from the modified stress fields associated with local features, overriding the regional pattern in the areas influenced by such features and merging to form a montage of modified stress fields.

Any analysis of the relationship between stress and the geological environment needs to attempt to resolve the balance between these two perspectives for any area under consideration.

The Regional Stress Field

Scrutiny of the stress map suggests, qualitatively, a NE to E trending horizontal stress field throughout much of the Sydney Basin, with notable exceptions to this orientation in some areas. This orientation is generally consistent with the trend of the most common and persistent transform faults postulated for the basin, and with the orientation of the horizontal stress field measured at various sites within the Tasman Geosyncline to the west of the Sydney Basin (Brown and Windsor, 1987). This suggests the prospect of this being the "regional" stress field. Further evidence for this lies in the results of earthquake focal plane solutions obtained from some of the major earthquake events in the basin. The relatively consistent NE-E orientation for the major horizontal stress indicated by most of these solutions implies a pervasive stress field orientation at depth, even when the direct stress measurements indicate a somewhat different orientation at shallower depths in some areas.

To investigate the impact of crustal tectonics on the current regional stress state, an idealised numerical model of a hypothetical region generally representative of the basin was employed. As a starting point, a "gravity load" was generated in the model to simulate the burial process. The "western boundary" of the model block was rigidly clamped to simulate the influence of the Lachlan Fold Belt. Active loading was then applied in a N-S, followed by an E-W orientation to reflect the commonly understood tectonic history of the basin, (Lohe et al., 1992) allowing sliding along internal boundaries incorporated in the model to simulate the major strike-slip features of the basin. The results are summarised in Figure 1, which can be used to examine some of the general attributes of the horizontal stress field suggested by this stylistic simulation. In a qualitative sense, Figure 1 suggests a number of features reminiscent of the salient aspects of the measured data:

- a general swing in the stress field orientation from approximately ENE toward NNE through the region corresponding approximately to the Southern Collieries District;

- a pronounced more northerly orientation along the eastern boundary, reminiscent of the alignment of the measured stress field approximately parallel to the coast in proximity to the coast;

- a relatively more balanced stress field with consequent somewhat more inconsistent stress field orientation along the western boundary;

- evidence of realignment of the stress field in proximity to the Hunter Thrust system.

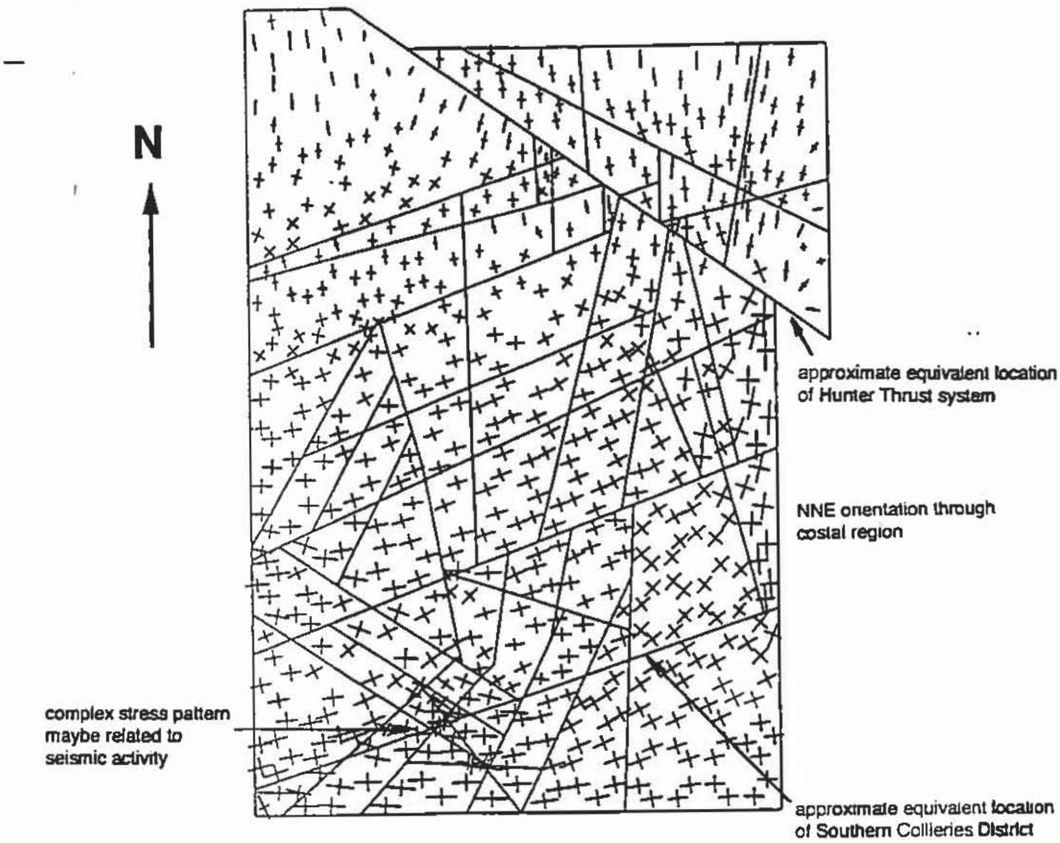

Figure 1: Results of numerical modelling study of idealised Sydney Basin, showing distribution of stresses arising from simulated tectonic activity

Apart form the detailed stress field information, Figure 1 also suggests the prospect of complex block movements in the south-west corner consistent with the concentration of seismic activity in this region.

Although not specifically explicit to the detailed structural situation suggested by Scheibner, the results summarised in Figure 1 suggest the prospect of being able to explain the current stress field in broad scale as being a derivative of the impact of crustal shortening as it is presently understood to affect the Sydney Basin.

The Local Stress Field

Various studies of the impact of specific geological structures on the local stress field in the vicinity of such structures, considered in isolation from the regional stress environment, have pointed to the substantial influence of such structures. As an example, Figure 2 summaries the results of such a study (Enever, et al., 1994) made of a synclinal structure formed by downward flexure of a layered sequence associated with formation of a graben or half graben in the basement. Figure 2 suggests the development of zones of substantially modified stress in proximity to the evolving structure. The existence of such zones of modified stress has been confirmed by direct stress measurements. Figure 3 summaries the results of measurements made at a site typified by the idealised structure shown in Figure 2. The generally low stress measured at Location 2

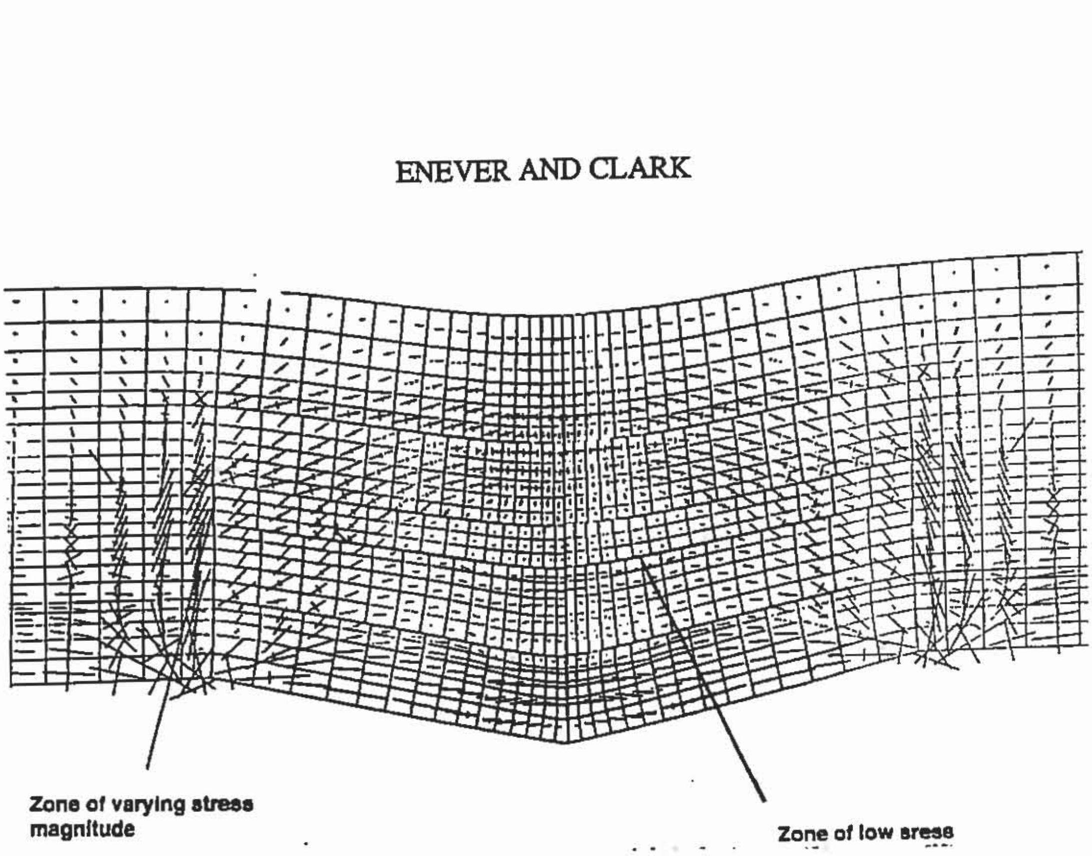

Figure 2: Results of numerical modelling study of the formation of a synclinal structure, showing impact on the stress field

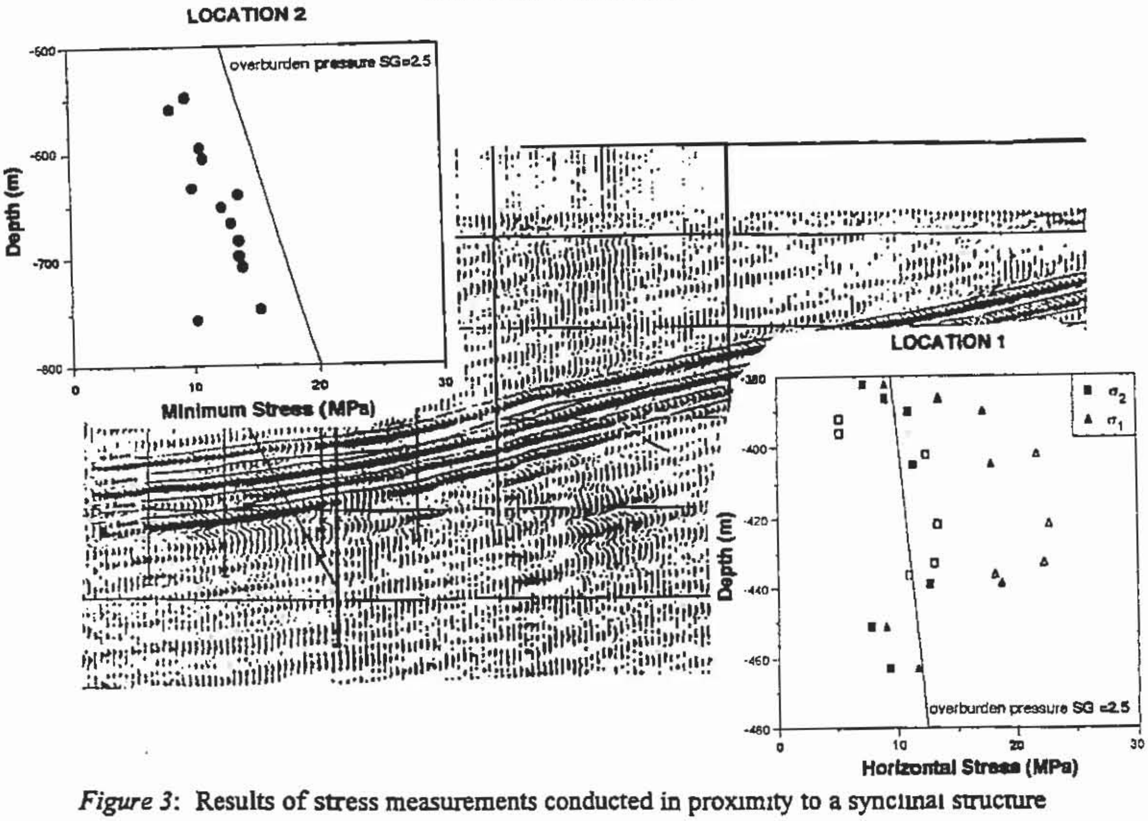

Figure 3: Results of stress measurements conducted in proximity to a synclinal structure

and the rapidly varying horizontal stress field magnitude measured at Location 1 are as would be expected from the model predictions. Similar outcomes can be expected for other styles of structures. In this case, the local structure has a major impact on the pre-existing stress situation. What is not clear, however, is to what extent local perturbations to the stress regime induced by such structures will impact the regional pattern in general. It would appear that the impact of structures on the stress field may have to be considered on a case by case basis.

STRESS IN THE SYDNEY BASIN

The horizontal stress field profile with depth measured in the Kulnura Ridge (Figure 4) reflects a very consistent horizontal stress field orientation, aligned with the ENE pattern discussed above. The trend of stress magnitude with depth, however, suggests a significant local stress modification, symptomatic of the influence of flexure of the strata and presumably associated with formation of the Kulnura Ridge. The proposed stress field modification appears most pronounced as a stress relief near the top of the Newcastle Coal Measures, diminishing with depth through the Newcastle Coal Measures and into the Tomago Coal Measures. The horizontal stress field orientation measured higher up in the stratigraphic sequence on the ridge (as shown on the map) was found to be consistent with expectations based on the alignment of the structure and the implied influence of stress relaxation associated with flexure. By contrast, the stress field measured at depth (Figure 4) appears to reflect the residual influence of the regional stress pattern, even though stress relief associated with the local structure has apparently occurred.

The stress field profile measured at depth in the Central Sydney Area (Figure 5) suggests a significant change in horizontal stress field orientation and magnitude with depth, with a relatively high stress field magnitude between about 400 and 800 metres, oriented in a more NE to ENE direction than the relatively lower magnitude horizontal stress field above and below this zone. The NE to ENE orientation is in approximate alignment with the postulated regional trend. The NNE trend for the horizontal stress field above and below this zone is in accord with shallower measurements made in the Sydney area. The implication is of the imprint of the regional horizontal stress field throughout parts of the sequence in the Sydney area, with a somewhat lower magnitude horizontal stress field of a different orientation elsewhere in the sequence. The above observation suggests that alterations to the regional stress field resulting from the impact of geological structures can occur selectively throughout a sequence, presumably with the zones of modified stress separated by dislocation along low angle planes within the sequence. The exact mechanism is unclear in this case because of the uncertainty with respect to the detailed structures influencing the location.

The above examples from somewhat different geological environments suggest that the regional stress component remains substantially imprinted on the current stress state, despite the influence of local structures on the stress field. This in turn suggests that the current stress state can be arrived at by starting with the regional stress condition and subsequently superimposing the effect of local structures.

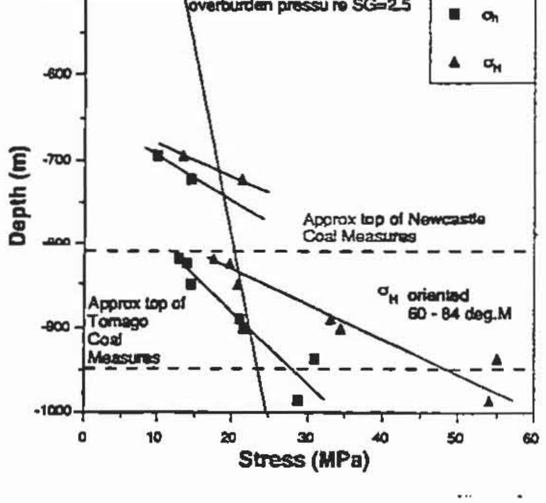

Figure 4: Profile of horizontal stress field with depth measured in a hole on the Kulnura Ridg

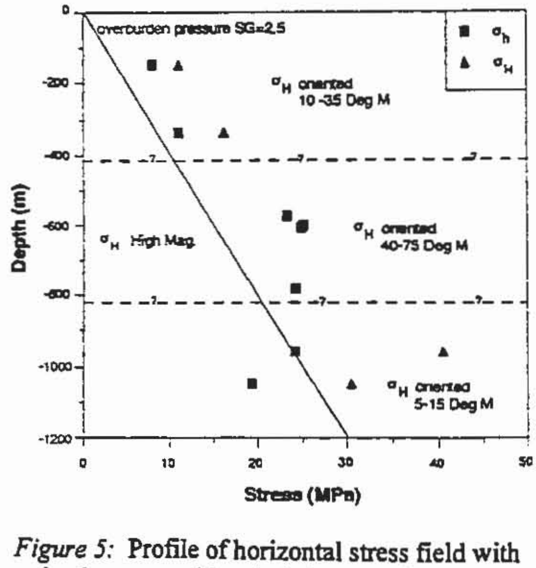

Figure 5: Profile of horizontal stress field with depth measured in a hole in central Sydney

THE GLOBAL GEOLOGICAL CONTEXT OF THE REGIONAL STRESS FIELD IN THE SYDNEY BASIN

Figure 6 summarises the stress field orientational data represented on the stress map. Figure 6 suggests three predominant clusters of the data:

- around 10 to 20 degrees;
- around 50 to 60 degrees; and
- around 70 to 90 degrees

While it may be strictly rigorous to consider these orientations separately, for the remainder of this discussion the orientations have been grouped as 0-45 degrees (N-NE), 45-90 degrees (NE-E) and 90-135 degrees (E-SE). This has been done partly to retain reasonable sample size in each category, and partly on the basis of the qualitative appreciation of the patterns evident from the stress map as discussed above.

Figure 7 summarises the average major horizontal secondary principal stress magnitude and depth of measurement data taken from the map for the NE-E trending cases. Figure 7 appears to suggest a trend for stress magnitude to increase systematically with depth for most of the data points, within a reasonable constrained band. When the E-SE data is added (Figure 8) this behaviour is reinforced. The same can not be said, however, for the N-NE data in Figure 9. The latter indicates a wide scatter in stress magnitude throughout the range of depths for which measurements were made. This, in turn, suggests that while the predominantly easterly oriented data (E-NE and E-SE) might generally reflect the impact of a primary stress generating mechanism, the more northerly oriented data (N-NE) may not. One possibility is that the latter data may reflect the response of the rock mass to readjustments (stress increases and decreases) resulting from the interaction of the primary stress generating mechanism and major structural discontinuities as discussed above.

Detailed examination of the data in Figure 8 did not reveal any obvious pattern with respect to the age of the rocks involved, the geographic location, nor the absolute elevation of the measurements. This implies that the horizontal stress field in this orientation is the result of a geographically pervasive mechanism, overriding the impact of burial/uplift/erosion history, and post dating the deposition of the complete sequence as revealed today. This general scenario would appear to be consistent with current wisdom regarding the tectonic history of the Sydney Basin (Lohe, et al., 1992) which suggest the predominant impact of post Jurassic or post Early Tertiary compressional tectonism.

In Figure 10, the raw data of Figure 8 has been adjusted by subtracting an amount from the stress magnitude to account for the component of the total stress for each point attributable to gravity loading;

$$\Delta\sigma_H = \frac{\nu}{1-\nu}\bar{\sigma}_v;$$

- where $\Delta\sigma_H$ is the amount deducted from the average horizontal stress field magnitude;
- ν is the Poisson's Ratio of the rock mass; and
- $\bar{\sigma}_v$ is the vertical stress derived from overburden loading (for an assumed average S.G. of 2.5) at the average depth of measurement.

To construct Figure 10 a value of $\nu = 0.5$ was used, the theoretical maximum value that Poisson's ratio can have. The picture portrayed in Figure 10

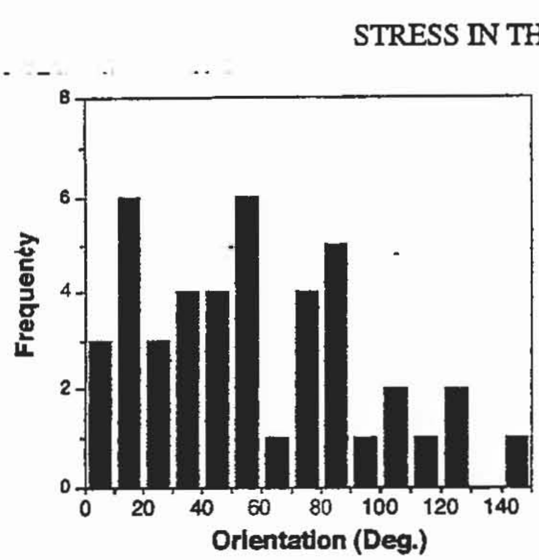

Figure 6: Summary of horizontal stress field orientation as measured throughout the Sydney Basin

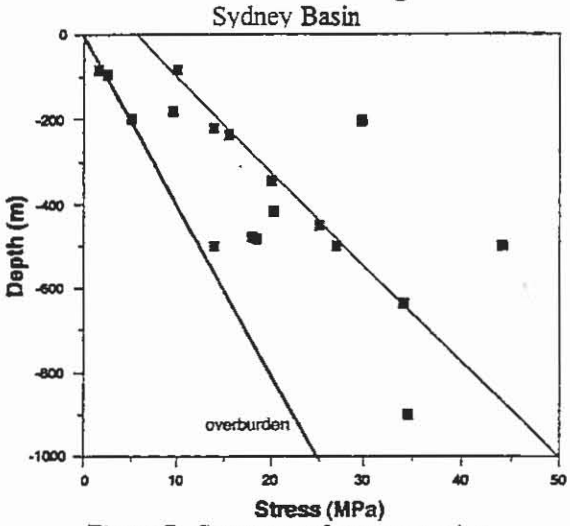

Figure 7: Summary of average major horizontal secondary principal stress component magnitude with depth for E-NE oriented data

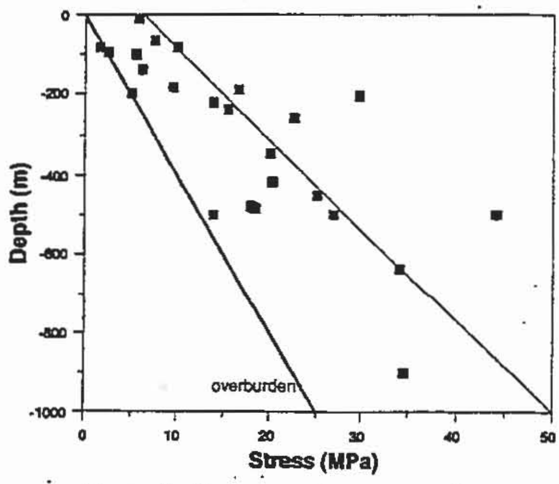

Figure 8: Summary of average major horizontal secondary principal stress component magnitude with depth for E-NE and E-SE oriented data

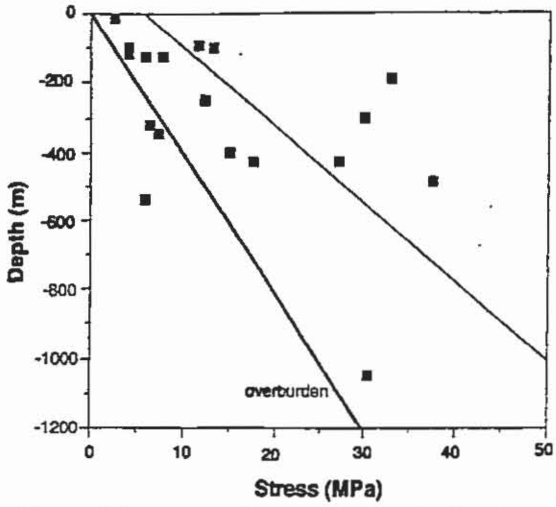

Figure 9: Summary of average major horizontal secondary principal stress component magnitude with depth for N-NE oriented data

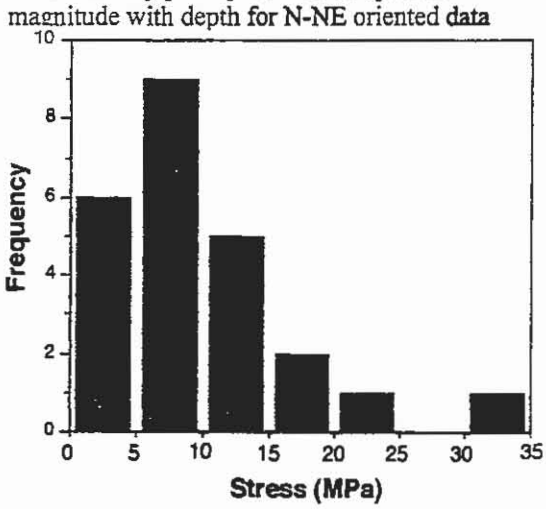

Figure 10: Distribution of residual tectonic stress component magnitude after removal of stress attributable to gravity ($\nu = 0.5$)

therefore represents the maximum allowance theoretically possible to make for a gravity loading component, based on present depth of burial (i.e. without evoking paleo burial). This condition is equivalent to the concept of lithostatic stress proposed by McGarr (1988).

Figure 10 represents one picture that can be drawn of the residual tectonic horizontal stress field magnitude in the proposed regional direction after removal of the gravity loading component. Figure 10 suggests a predominant stress magnitude of 5-10 MPa. The conditions used to remove the gravity component in Figure 10 may, however, be considered somewhat artificial, given the normal history of burial, lithofication, uplift and erosion, the latter two stages after lithofication when Poisson's Ratio can be assumed to be considerably less than 0.5. Figure 10 should be viewed as a qualitative guide as to the magnitude of tectonic stress.

The detailed mechanism producing such a tectonic stress is open to speculation. A recent study (Zhang et al., 1995) has looked at the possibility of "gravitational creep" directed approximately normal to the continental boundary, related to the geometry and density configuration of the eastern Australian lithosphere, as one mechanism. More recent work by the same authors (personal communication) has looked at a range of plate boundary and intra plate origins for tectonic stresses in the Australian continent. These studies indicate relatively low magnitudes for the tectonic stress generating mechanisms, in line with Figure 10. Another recent study of the north sea (Gölke, 1996) has looked at typical stress levels generated by a variety of tectonic processes, with "ridge push" being the most important. In the latter case, Gölke's predictions suggest a range of stress magnitude theoretically attributable to "ridge push" broadly consistent with the range suggested above.

CONCLUSION

- The current horizontal stress field in the Sydney Basin appears to reflect a regional NE-E orientated tectonic component, modified at both a broad and local scale by geological structures of various kinds.
- The magnitude of this tectonic component appears consistent with present models for the origin of tectonic stresses.

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TECHNICAL FACTORS DETERMINING THE COMPARATIVE COKING COAL PRICES IN THE JAPANESE MARKET

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1. INTRODUCTION

The expected value of a coking coal is determined by a number of factors. These include technological properties, supply and demand, and the commercial relationships between buyer and seller.

In addition to these, there are global effects on price determination such as a world-wide recession or growth, political changes, economic integrations. Local economic conditions are also important. A recession in either the buyer's or seller's countries, investment opportunities, strikes, natural disasters (floods, cyclones, earthquakes), civil wars, ability to supply consistent product and quantity can also affect the price of the product. Local legislation either in buyers' or sellers' country will equally influence the price determination. For example, changes in government legislation (such as native land title claims), environmental impact studies, tax incentives, levies, custom duties, tariffs, transport regulations can affect the cost of production and consequently the price of the product. However, this paper is concerned only with comparative coal pricing from year to year. It is presumed that technological properties dominate the price determining factors. Aberrations between predicted and actual prices may be due to a number of factors, some inherent in the nature of statistical analysis or differences in data sets used by the JSM and the data set used in this study as well as commercial relationships between buyer and seller.

Although the technological properties appear to be the preferred method for classifying the worth of a coal, only some technological properties may be related to resultant coke quality. Others, which include many laboratory carbonisation tests, may have only tenuous relevance to coke production but still are used.

The influence on price of supply and demand may be demonstrated with distinctive coals which, by their addition, enable the total character of a feed blend to be changed. These coals may attract a price premium.

The commercial relationships between buyer and seller is the third major factor influencing price. Companies seeking market share may attract custom by accepting lower prices. Also companies controlled by a downstream user may have their prices similarly influenced. Long term strategic reasons in the buyer's country may also force diversification in the market and more expensive coals are purchased for this reason.

The JSM coal price outcomes have for many years provided a fertile ground for hedonic price analysis because of large number and wide variety of the coals traded. The results of such analyses have included an array of technological factors that, for the most part, also control coke quality.

In the 1996 negotiations the JSM instituted a "Fair Treatment System" by nominating that the key factors would be the Coke Strength after Reaction index [CSR] of the NSC Reactivity Test and the Log Gieseler Fluidity. In effect, the underlying basis for the pricing did not change greatly as CSR and Gieseler Fluidity have been significant predictors of price for many years either coincidentally or by intent.

In this study, multiple linear regression analyses have been used to provide a formula that most closely predicts published coal prices. The regression models were developed using the 1996 US$ FOBT contract prices and coal specifications for Australian coking coals in the 1996 ACR Report.

2. TECHNICAL CHARACTERISTICS OF COAL DETERMINING THE COAL PRICES

Variations of technical characteristics are quite common in coal seams. This is usually a reflection of the original depositional conditions. It is quite common that original mire shape and geometry had a significant influence on the seam's technical characteristics. The other influencing factors are original plant composition and chemistry, the presence of distributary channels and crevasse splays, magmatic intrusions, post depositional effects such as diagenesis and leaching, and finally primary rank factors such as temperatures and depth of burial.

Technical features of coal are important to the end users and commonly these features are; volatile matter (%, d.a.f.), ash (%) and ash chemistry, sulfur (%) and phosphorus, reflectance values ($R_{v,max}$%), vitrinite and inertinite (%), crucible swelling index, Gieseler Fluidity, total dilatation (%), coke strength indices, coke strength after reaction (CSR), coking pressure.

In the following sections, each of these technological properties are described briefly.

2.1 Volatile Matter

Volatile matter is an important component in the technical usage of coal and it is one of the commonly used rank parameters.

Many coking coal users are quite interested in coals' volatile contents since the quantity and composition of the by-products alters with changes in the volatile matter content. By-products from volatile matter are still an important issue for these users and in many cases it is a strong factor in deciding price.

The apparent approximate JSM average volatile matter percentage of a coking coal blend is 30% d.a.f., although optimum coke properties are actually attained around 20-25% d.a.f.. The reason for this difference is partly due to minimisation of the risk of coke oven pressure. However, significant coke oven pressure is only found in some Australian coals with VM% less than 21% d.a.f..

2.2 Ash percentage and ash chemistry

The mineral content of coal seams originate from the initial depositional conditions. Initially, the original peat should be away from the clastic influence in order to form a low ash content coal seam. For this reason the shape of the original peat geometry is important. When a raised mire is present in a depositional area, the ash content will be very low since the clastics transported by rivers and distributary channels will not be able to mix with the plant life. The other possible source for the ash content could be the inorganic materials that were part of the plant structures. However, the amount of this is relatively small.

The predominant minerals in coal are usually kaolinite, detrital clay, pyrite and calcite. These give rise to oxides of silicon, aluminium, iron and calcium in the ash. Lesser, but appreciable quantities of compounds of magnesium, sodium, potassium, manganese, phosphorus and sulfur are likewise found in coal ash generally.

In the carbonisation process a substantial part of the mineral matter in the coal is retained in the coke product. The presence of high K in the ash can affect the reactions in blast furnaces and may cause degradation of the coke product. The blast furnace operators desire the ash content as low as possible since this will reduce the fuel rate of the blast furnace. Also in stamp charge operations, the ash content has other effects in addition to its influence on fissure formation in the coke

2.3 Total Sulfur

Sulfur is detrimental element in steel products. Modern blast furnaces are normally run on burdens that contain large amounts of agglomerates (sinter or pellets). In this situation, major parts (two thirds or more) of sulfur comes from coke. Therefore higher sulfur contents of coke require slightly higher slag basicities and correspondingly hot operations. This causes a slight increase in coke consumption in the blast furnace. About 5 kg of coke per net tonne of hot metal is required for each 0.1% change in coke sulfur. Where silica must be added to increase slag volume, about 35 kg of additional coke is needed for each 0.1% change in coke sulfur.

2.4 Phosphorus

Steel-plants that use high phosphorus iron ore avoid coals with significant phosphorus since it entirely passes into the iron and difficult to remove from the product.

2.5 Petrographic Characteristics

2.5.1 Maceral Content

Macerals are the microscopically identifiable organic entities that make up a coal. They are closely related to the original plants. As a result, the maceral content of the coal seams commonly show significant spatial variation in the field.

The maceral **vitrinite** commonly is accepted as an important component in the carbonisation process as it generally has the highest volume and is the plasticising component which not only swells and forms porosity but also surrounds the other less plastic macerals. It is thought that the proportion of vitrinite is desired to be within certain levels in the coking process, although these levels are extremely broad and hard to define (Coin 1995).

The maceral **inertinite** is often assumed to be the non-caking component of the coal. Coin (1987) has shown that the fusibility of inertinite can be extremely variable from almost total to almost zero. Some Australian coals have a significant amount of inertinite content yet produce some of the strongest cokes in the world.

It is unfortunate that maceral nomenclature has misled the coke making technical personnel with regard to the reactivity (fusibility) in the coking process of the inertinite maceral. However, a some research projects (e.g. Coin, 1987) have concluded that inertinite particles actively participate in coking process.

2.5.2 Coal Rank

One of the best parameters to rank a coal is its reflectance value. The reflectance of the maceral vitrinite is measured under the microscope and the average maximum reflectance value is reported. The reflectance is a measure of the coal maturation process and is dependent on the age of coal, depth of burial and coalification temperature. However, some local variations can be observed if a magmatic intrusion is present in the field. This localised temperature rise causes an increase in reflectance values in coals even up to anthracite stage. Initial plant chemistry and plant variation in the mires may also cause localised reflectance variation in coals.

It is common practice to blend the coking coals within the rank range of $R_{v,max}$=0.80% to 1.70%. The technical optimum coal rank lies between $R_{v,max}$=1.20% to 1.35%.

The petrographic analyses and the vitrinite reflectance commonly have been used in the Schapiro & Gray [1961, 1964] prediction scheme. In this elegant and detailed scheme, reactives were defined as the total vitrinite group macerals, liptinite group macerals and 1/3 of semi-fusinite. However, according to this prediction method, many of the best coking coals are defined as being unsuitable on the grounds of inappropriate reactive to inert ratio. This is just one of the criticisms of the technique. The inventors of the scheme used a very limited data set in the first instance and the data was highly correlated for rank and type. They used fractionation of the coals to explore the role of macerals without realising that any changes they saw were more highly correlated to percentage mineral matter than the macerals.

For three decades most of the coal industry has sought to reconcile the fact that most coals did not fit the scheme very well by trying to redefine the coals rather than realising that the scheme was seriously flawed. Nevertheless, the Schapiro & Gray method is still used in many markets with its intermediate indices of % Reactives, % Inerts, Composition Balance Index and Strength Index.

2.6 Laboratory Carbonisation Properties

2.6.1 Crucible Swelling Number

Crucible Swelling Number test is one of the simplest laboratory test intended to determine the coal's ability to form coke. However, the test is severely criticised as there is no direct link between the real performance of the coals in coking process and the test numbers.

Coals with a CSN less than 3½ are considered undesirable in coke-making whilst coals with CSN of 8-9 are considered the most desirable.

2.6.2 Gieseler Fluidity

Gieseler Fluidity is valued by the Japanese Steel Mills [JSM], even to the point of being a major influence on coking coal price. There are few coals with high fluidity and they often get premium prices because they can be blended with lower fluidity coals. However, there is no substantive evidence that fluidity has any role to play in determining coke quality. Evidence from Australia and Canada shows that maximum CSR for example is derived from coals with little to no significant original fluidity and not from coals or blends of any particular range such as defined by the JSM.

Decaying Gieseler Fluidity is a measure of coal oxidation in stockpiles. Significant oxidation may result in decreased coke quality, but there is no simple correlation between Fluidity decay and coke quality outcomes.

2.6.3 Dilatation Values

Most coals initially shrink during carbonisation, then swell again as the volatile matter escapes and vesicles form. These volume changes are important in determining the amount of coal that can be safely charged into the coke oven and are critical in blending of different coals for commercial coking operations. The volume changes that occur in carbonisation may be determined by various dilatometer tests.

2.6.4 Drum Indices and Coke Strength after Reaction (CSR) Values

The quality of a coke can be assessed by several strength tests. The most appropriate test of coke quality is its use in a blast furnace where the coke is tested under real conditions of load, temperature, and gaseous environment. However, as a means of efficient evaluation of a range of cokes it is impractical. The various drum tests such as the ASTM, MICUM, IRSID and the JIS drum tests provide information on the strength and abrasion resistance of the coke at 25°C.

The NSC Reactivity Test (CRI/CSR) provides more valuable information on the coke quality as much of the test is conducted at 1100°C. The coke CSR has been shown to have direct bearing on the blast furnace coke consumption. The general form of the best fit relationships is established from various sources is,

$$\text{Corrected Blast Furnace Coke Rate} = \text{Constant} + e^{(k - a * CSR)}$$

The addition of any of the prime coking coals into an industrial blend provides a major potential reduction in coke rate. The reduction in coke rate has a direct effect on the economics of steel production, not only from the reduced quantity of coal that will need to be procured but also from the reduction of coking capacity required and the consequent improvement to coking conditions that can be obtained. No attempt has been made in this report to quantify such changes as there are too many factors that would need to be considered.

2.6.5 Coke Oven Wall Pressure

During the carbonisation process, the plastic layers proceed from the oven walls towards the centre of the oven. As the volume of the uncoked portion of the oven charge decreases to zero, the pressure rises until the plastic layers actually contact. At this point significant pressure may be directed at the walls, in some cases severe enough to cause permanent damage to the oven. [Values greater than 6.9 kN/m^2 (1 psi) are considered dangerous for the oven walls in many operations, especially those that are old or damaged]. Therefore it is important for the buyers to know the details of the coke pressure data.

Generally, high volatile matter coals do not produce dangerous levels of pressure and most Australian coals generally do not develop any significant pressure during coking. Even the coals that produce some pressure on the coke oven walls do not seem to damage oven walls.

3. Estimation of price from regression analysis

In previous years, regression analyses indicated that the following factors were thought to control the coal prices; volatile matter, ash, logarithmic Gieseler fluidity, CSN and phosphorus. Sulfur did not play any significant role in price determination. This is due to the historically low sulfur content of the coal set that was used to derive the regression equation. Also if the coal has undesirable level of sulfur such as greater than 0.8%, it is subject to penalty rates.

In 1996, JSM decided to move to a different treatment system in pricing. This system uses the major factors of CSR, Log Gieseler Fluidity and Ash. Following regression equation was achieved by using these factors:

USS = a + b*CSR + c*Log Fluidity - d*Ash	$r^2 = 0.91$ n = 17 SEEy = 1.25

Figure 1 displays the actual and predicted coal prices for Australian coals.

It may be noticed that there are only 17 coals available with CSR data. It is a pity that other coals with no CSR data could not be included in the regression.

There was no accounting for penalties/bonus that may regularly apply or be non-correlatable and thereby adjust the usual transaction price.

4. CONCLUSION

The expected value of a coking coal is determined by a number of factors. These include technological properties, supply and demand, and the commercial relationships between buyer and seller.

Technological properties appear to be the preferred method for classifying the worth of a coal. However, only some technological properties may be related to resultant coke quality. Others, which include many laboratory carbonisation tests, may have only tenuous relevance to coke production but still are used.

The JSM coal price outcomes have for many years provided a fertile ground for hedonic price analysis. The results of such analyses have included an array of technological factors which for the most part also control coke quality.

In this study, multiple linear regression analyses have been used to provide a formula that most closely predicts published coal prices with an r^2=91. The regression models were developed using the 1996 US$ FOBT contract prices and coal specifications for Australian coking coals in the 1996 ACR Report.

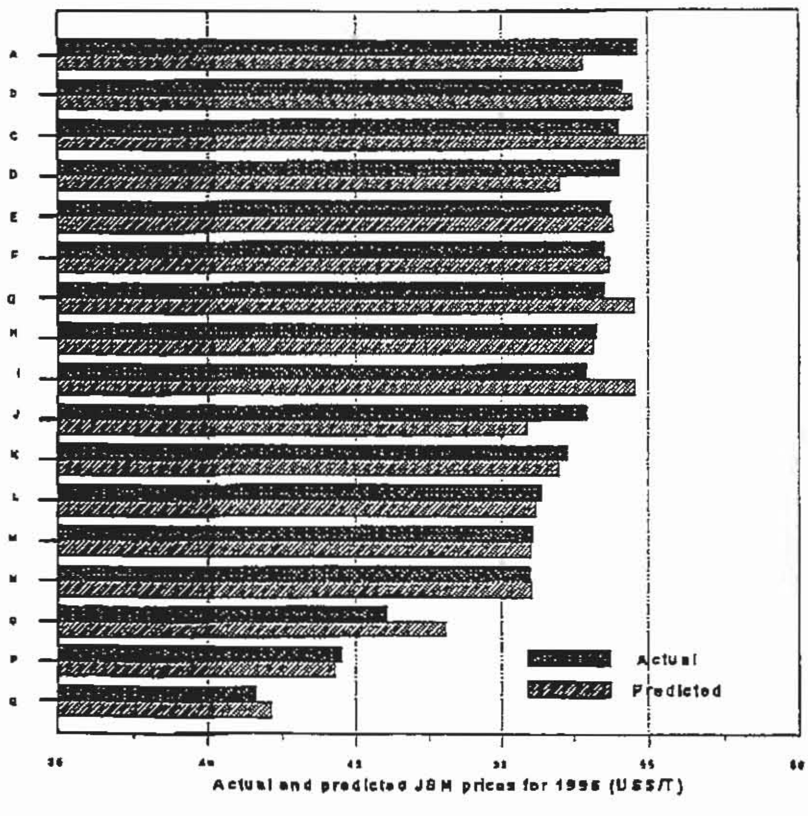

Figure 1 Actual and predicted coking coal prices in the Japanese market ($US, FOBT)

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INSIGHTS INTO COAL UTILISATION THROUGH CHAR RESEARCH

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INTRODUCTION

As a result of economic and environmental pressures, technological advancement in the coal utilisation areas of energy generation and steelmaking is somewhat ahead of fundamental understanding of coal processes. Process conditions in these newer technologies differ from conventional entrained flow combustion in some critical aspects, such as pressure, atmosphere, feed rate, peak temperature and heating rate (Table 1).

Efficiency gains of over 10% may be made by moving from conventional Rankine Cycle p.f. combustion power plants to gas turbines, so coal gasification, or IGCC, is attractive technologically for the future of power generation. Inclusion of a gasification cycle also promises to lower CO_2 emissions per unit of power generated. The gasification of coal involves three stages: pyrolysis of coal to produce char and volatile species, reaction of volatile species and partial combustion of resultant char with oxygen, and gasification of char with CO_2 and steam (Harris and Patterson, 1994). Syngas produced (mixture of CO and H_2) is purified and sent to a gas turbine where it is burnt with compressed air to provide a stream of hot and high pressure gas which turns the turbine to generate electricity. Efficiencies appear to improve with higher gas turbine inlet temperature (1420-1450 °C), and using a pressurised rather than atmospheric gasifier (Lowe, 1997). Since entrained flow combustors are commonly operated at just under atmospheric conditions and at somewhat lower temperatures, important aspects of coal behaviour under high intensity operating conditions need to be investigated.

In terms of steelmaking, the lower cost of thermal coal over prime coking coal gives incentive for the increased use of pulverised injection of coal to the blast furnace, or PCI. PCI is also injected at pressure, about 2-4 atm (Table 1).There is little information in the literature concerning coal behaviour under pressurised conditions, although Green and Thomas (1985) found that pressurised dilatometry (up to 6 Mpa) produced an increase in the plastic range of coals between sub-bituminous B and medium volatile bituminous ranks. Dilatation showed a pressure dependance which appeared to be a function of coal rank and structure (ibid.). Lee et al. (1991) found that coals pyrolysed between 1 and 38 atm swelled most extensively at 8 atm, with large blowholes developed on the particle surface following volatile transport by bubbles. Applied pressure above 8 atm resulted in swelling resistance, with fewer and smaller holes in the char surface. Thus, standard (atmospheric) measures of coal plasticity are not applicable to high intensity gasification processes, or to PCI.

Although heating rates are similar, peak temperature is often higher in gasification than combustion, due to the use of pure oxygen to entrain the p.f., rather than air. Therefore coal devolatilisation, a function of peak temperature, can reach 80% of the total dry ash-free coal (Hedman et al., 1982). Standard proximate measures of volatile matter content are inadequate to characterise coals for entrained flow combustion and gasification purposes. The higher peak temperature experienced also calls for detailed knowledge of ash fusion temperatures, since many gasifiers will be operated on a slagging basis. Despite successful implementation of the new technologies, there is relatively little knowledge about their fuel-related aspects, so that prediction of the relative performance of new coals in the same processes is not readily possible. One way to address this gap in our knowledge is to investigate the behaviour of coal grains during each process.

EXPERIMENTAL

A number of coals were treated under laboratory conditions, simulating p.f. combustion, gasification and PCI. Combustion was simulated in an Astro1000A drop-tube furnace with a hot zone of 33 cm and residence time of 30 ms. Gasification experiments were simulated in a pressurised drop-tube furnace at the Cooperative Research Centre for New Technologies for Power Generation from Low Rank Coal in Victoria. PCI chars were generated in a test rig developed by BHP Newcastle Research Laboratories.

Coal	1 Drayton	2 Ulan	3 Hunter Valley	4 Moura	5 Newlands	6 Blair Athol
Moisture % ar	2.4	2.5	3.0	2.7	2.3	4.3
Ash % db	14.1	12.3	12.0	10.6	14.5	8.8
V.M. % daf	39.5	36.0	34.0	33.7	31.4	30.8
Burnout C 1100°C	72.9					
Burnout G 1100°C/ 15atm	29.8	18.2	10.1	30.5	1.8	20.3
Burnout G 1100°C/ 8atm	na	1 atm / 25% stoichiometry		50.1		
Burnout G 1100°C/ 5atm	28.6	1 atm / 50% stoichiometry		57.5		
Burnout G 1100°C/ 1atm	13.8	1 atm /125% stoichiometry		67.3		

C = combustion; G = gasification

Table 2 Proximate analysis and burnout % for a range of coal ranks and types

	COMBUSTION	**GASIFICATION**	**P.C.I.**
Type	entrained flow p.f. furnace	entrained flow gasifier	blast furnace
Major Products	CO_2 H_2O	CO H_2	CO
Process	oxidation	oxidation → reduction	oxidation → reduction
Atmosphere	> 20% excess air	steam, oxygen, air	injection with air
Pressure (atm.)	slightly below atmospheric	1-30	injected at 2-4
Operating Temperature (°C)	1600-1700	1150-2500	2000
Heating Rate (°C/s)	10^4 - 10^5	10^5	10^5
Residence Time (s)	<1	0.4 - 12	<1
Feed Rate	up to 120,000 kg/hr	35-92,000 kg\hr	up to 210 kg/t_{HM}
Particle Size	>75% <75μm <2% >300μm	10 - 150μm	75% <75μm - pf. < 3mm - gf.
Advantages	• high efficiency • high capacity • large scale possibilities	• use all coal types • simple design • recirculation • slagging desirable	• reduces coke consumption • stabilize BF operation • uses domestic product
Disadvantages	• high emissions • fly ash disposal • pulverising expense	• high capital cost	• use of low rank coal means increased impurities • pulverising expense • require a stronger coke

Table 1 : Summary of operational conditions and variations between the three modes: p.f. combustion, gasification and P.C.I.

Comparison was made of chars from Coal 1 in combustion and gasification modes at 1100°C, and at a range of gasification pressures from 1 to 15 atm. Coals 1-6 (all high volatile bituminous) were gasified at 15 atm and 1100° C. Coal 4 was gasified at a range of oxygen stoichiometries, being 25%, 50% and 125% of the oxygen required for gasification to CO. Chars from 5 coals from high volatile bituminous to anthracite were examined after treatment in the PCI test rig at 1100 °C. Chars were collected at the furnace exits in all cases. Samples were prepared for reflected light microscopy (RLM) and for scanning electron microscopy (SEM). Results of standard proximate analyses of the coals, burnout figures for Coal 1 gasified at 1 atm to 15 atm, Coals 1-6 at 15 atm and Coal 2 at various O_2 stoichiometries calculated using the ash tracer method appear in Table 2. Char morphological analyses have been carried out using Bioquant image analysis.

RESULTS

Although the gasified samples have been obtained only recently, and results are preliminary, a number of important observations can be made. Firstly, combustion, gasification and PCI appear to produce different surface characteristics in char, depending on the atmosphere and pressure conditions. Combustion at 1 atm and 1100°C produces spheroidal char with a smooth, fused surface, numerous pores, an open honeycomb structure (Plate 1) and ash which separates quite efficiently from carbonaceous residue. By comparison, PCI char from the same coal (Coal 4) appears to have undergone less fusion and swelling, has softening features and poorly formed pores, and has small (<<10μm) ash spheres still attached to the char (Plate 2). Char gasified at 15 atm has good sphericity, confirming the tendency to enhanced thermoplasticity with pressure, but is peppered with fine, non-spherical debris (Plate 3), which may be a mixture of recrystallised ash and fragments of char blown out of thin-skinned "windows" which form between thicker ribs on the char surface (Plates 4 and 5). Plate 5 shows a close view of partly exploded "windows" from a char for which the external pressure was insufficient to contain the internal pressure created by the enhanced dilatometry. A segment of "window" and many minute aggregates (<1μm) of ash fume, some of which appear spherical at this magnification, are visible in the foreground of Plate 5.

Both image analysis and SEM reveal that laboratory simulation of gasification results in significant agglomeration of chars. The percentage of chars which comprised part of an agglomerate rose from 0% in combustion and gasification at 1 atm, to 22.5% at 8 atm (Plates 6 and 7), and closer to 50% at 15 atm (Plate 8 and 9). The agglomerate sizes also increased with pressure (Plates 7 and 9). This agglomeration may be attributable to the enhanced plasticity the coals experience at higher pressure (Green and Thomas, 1985), which would be expected to increase both the "stickiness" and the diameter of the swollen cenospheres they produce. Because chars gasified at pressure are also fed to the furnace under pressure, it is contentious whether this agglomeration is an artefact of the coal feed, and future experiments will be designed to address this issue.

However, when the char components within the agglomerates were examined, it was found that even discounting agglomeration, chars from the same feed coal increased in diameter, porosity and sphericity with increasing pressure (Table 3), indicating enhanced dilatometry. It appears that coals with no apparent caking characteristics at atmospheric pressure may acquire them at higher pressure, and that any caking characteristics present at 1 atm will be enhanced at higher pressure. Lee et al. (1991) contend that swelling and bubble transport of volatiles to the char surface is restricted at pressures above 8 atm.

The suite of PCI chars examined covered a rank range of 0.80-3.2% mean maximum vitrinite reflectance, i.e. from high volatile bituminous to anthracite. Nebo anthracite produces over 91% of solid chars, with the appearance of unaltered coal grains. Although unreactive, anthracite grinds very finely, so the porosity (24%), mean diameter (25μm) and sphericity (0.65) of Nebo char are all considerably lower than for the other samples. In most other samples, crassinetwork char makes the greatest mass contribution to unreacted carbon, because of its generally large grainsize, and limited devolatilisation. These chars originate from medium reflectance inertinite, often in mixed heterogeneous grains which have a high grinding toughness (Hower et al., 1987; Bailey, 1995). The highest mean porosity (67%) was obtained for Norwich Park PCI char, of prime coking rank, while the high volatile bituminous chars, Blackwater and Moura, have mean porosities of 54%. In PCI conditions, swelling behaviour at 2-4 atm pressure is expected to be enhanced, so that agglomeration may become apparent.

CONCLUSIONS

The different char surface textures in the three utilisation modes have several implications. Firstly, the amount of sub-micron debris of both carbonaceous and inorganic material appears to be greater in pressurised gasification. Applied pressure appears to enhance the plasticity of coal at least up to 8 atm, causing char to swell more, and shattering smaller chars. Inorganic matter shows signs of having devolatilised or sublimed, recrystallising as sub-micron sphere aggregates. Removing this fume from flue gases would require collection devices of a high capture efficiency, such as bag filters. The effect of the coating of debris on available surface area for reaction and the reason for the attachment of fume to the char aggregate surface require consideration. Detachment of fused ash from char appears to be efficient in combustion in excess air, but not in gasification or PCI, so may be linked to the oxidising/reducing nature of the atmosphere.

At pressures higher than 8-10 atm, applied pressure increases the resistance to volatiles transport from the interior to the exterior of the particles. This results in retarded release of volatiles, reduced tar yield and enhanced secondary reactions of the volatiles both inside and outside the char. The development at these pressures of ribbed chars with thin-skinned "windows", also noted by Lee et al. (1991) and Newall and Sinatt (1924), will have significant effects upon surface chemistry, reactivity and unburnt carbon levels.

Char morphological analysis indicates that rank and petrography play important roles in char development, and hence in predicting unreacted carbon in PCI and gasification. Prime coking coals may be particularly unsuitable for PCI due to their enhanced swelling characteristics. Anthracites may be efficient PCI coals because of their fine grinding, which may mean the particles burn in regime I combustion, while providing high carbon fuel.

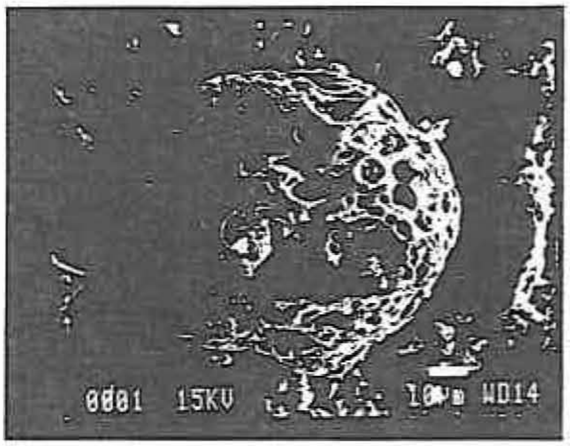
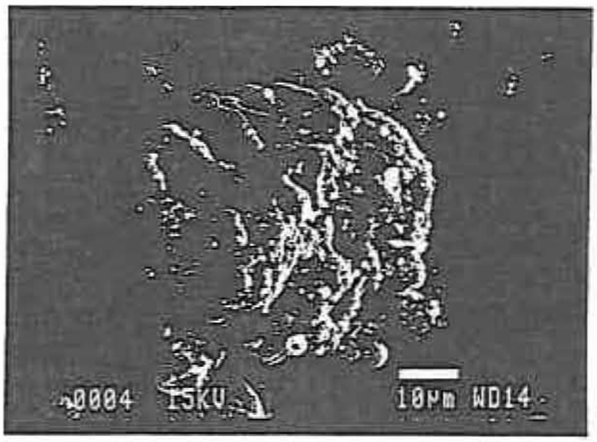


Plate 1



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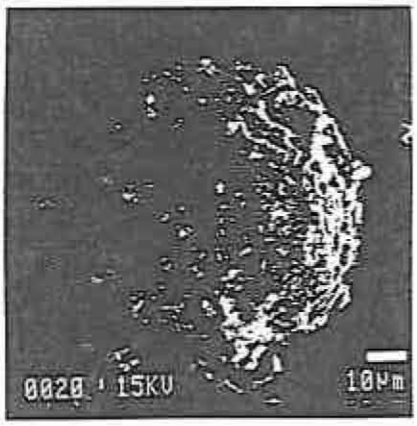

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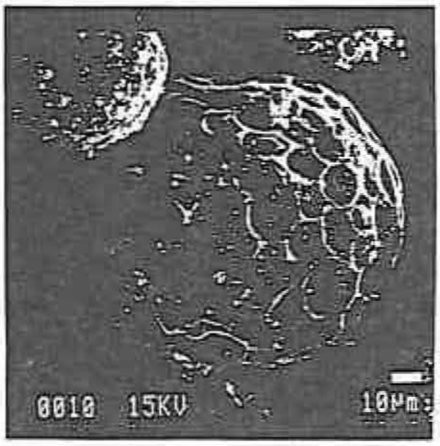

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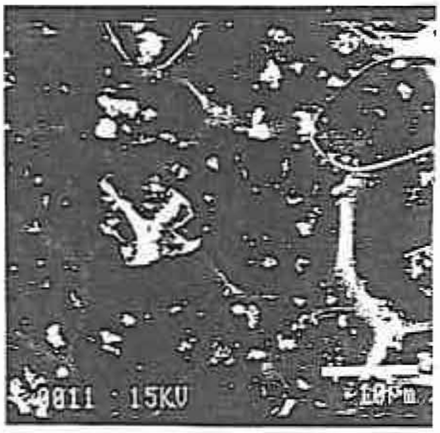

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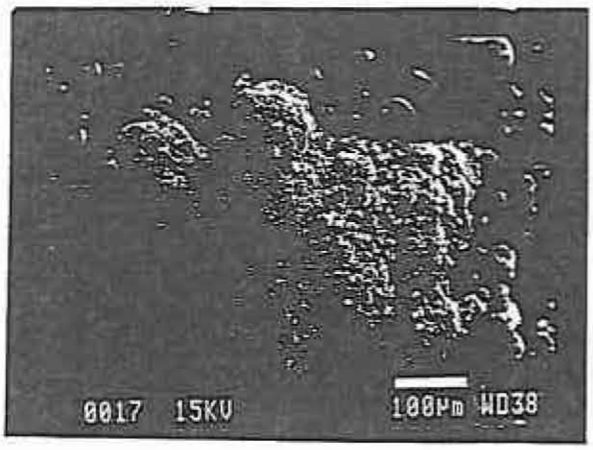

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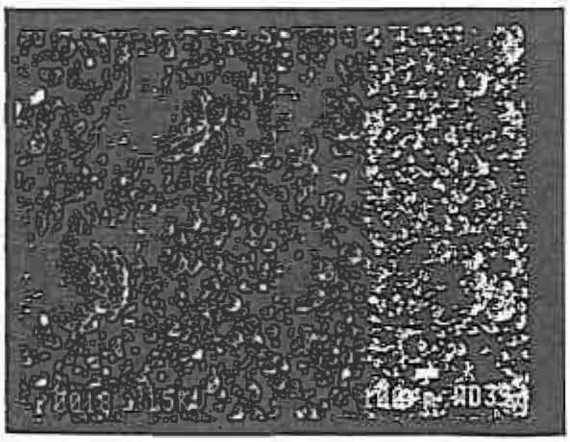

Plate 7

Pressure	Burnout	Diameter (μm)	Porosity %	Sphericity	Agglomeration %
1 atm	13.8	29.0	53.6	0.59	0
5 atm	28.6	39.3	69.9	0.60	13.2
8 atm	n.a.	56.8	82.9	0.63	22.5
15 atm	29.8	110.0	89.0	0.60	40.3

Table 3 Burnout % and char parameters for gasification of Drayton coal at 1100°C

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Plate captions

Plate 1 Moura combustion char produced at 1100°C at 1 atm, showing smooth, fused surface, spheroidal shape, open honeycomb structure and numerous well-formed open pores.

Plate 2 Moura PCI char produced at 1100°C and 1 atm, showing lower sphericity, softening features and fewer, less well-formed pores. Spheres of fused ash (1-3μm) cling to the surface.

Plate 3 Moura gasification char produced at 1100°C and 15 atm, showing spheroidal shape, and surface peppered with fine ash and char debris.

Plate 4 Moura gasification char (1100°C/15atm) with high sphericity showing characteristic structure of thicker ribs and intervening thin-skinned "windows" formed by fusion and swelling.

Plate 5 Close view of Plate 4, showing partly blown-out char "windows", with fragment of window debris and minute aggregates (<<1μm) of spherical ash fume in foreground.

Plate 6 Drayton char gasified at 1100°C and 8 atm; 500 μm agglomerate of spheres,peppered with debris.

Plate 7 Drayton char gasified at 1100°C and 8 atm, showing 22% agglomerate frequency.

Plate 8 Drayton char gasified at 1100°C and 15 atm, showing 500 μm agglomerate of spheres with "window" structure (see Plates 4,5).

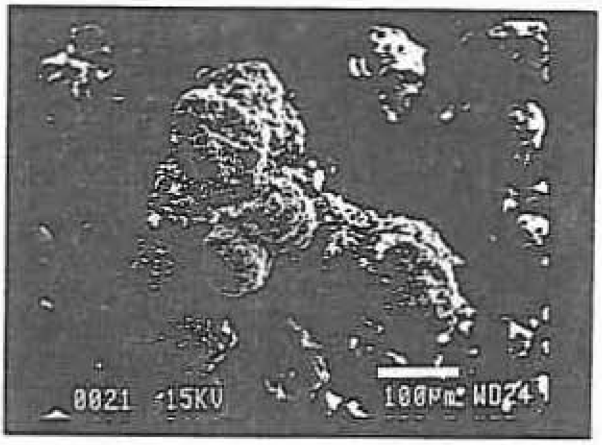
Plate 9 Drayton char gasified at 1100°C and 15 atm, showing 40-50% large agglomerates.

Plate 10 Moura char gasified at 25% oxygen stoichiometry showing pore development restricted to particular petrographic band containing higher volatile coal.

Plate 11 Moura char gasified at 50% O_2 stoichiometry showing numerous pores of about 5-20 μm.

Plate 12 Moura char gasified at 125% oxygen stoichiometry showing good development of sub-10 μm pores in fused vitrinite (right) and numerous coarser and finer pores in essentially unfused, inertinite-rich char (left), with attached ash cenospheres.

Plate 13 Moura char gasified at 125% oxygen stoichiometry showing ridged structure of unreacted fusinite cell lumens, with attached ash cenospheres.



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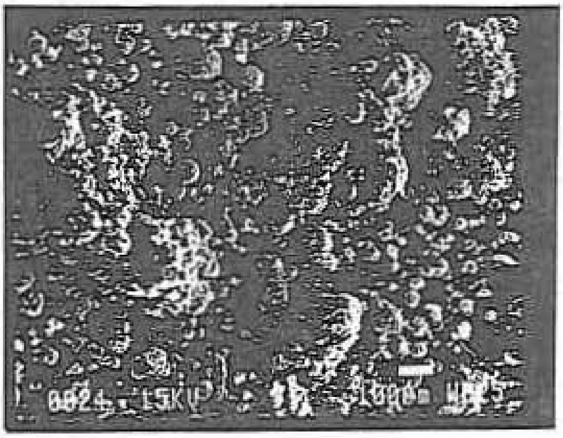

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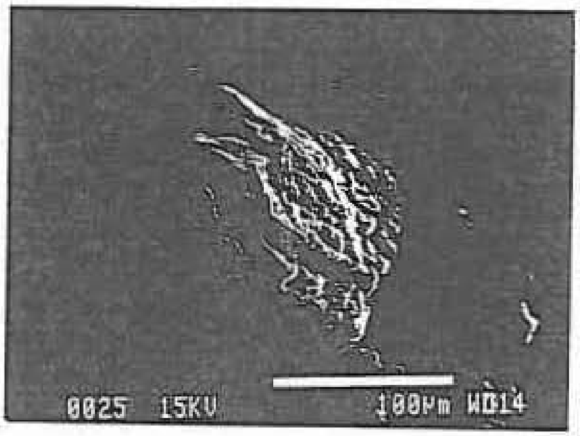
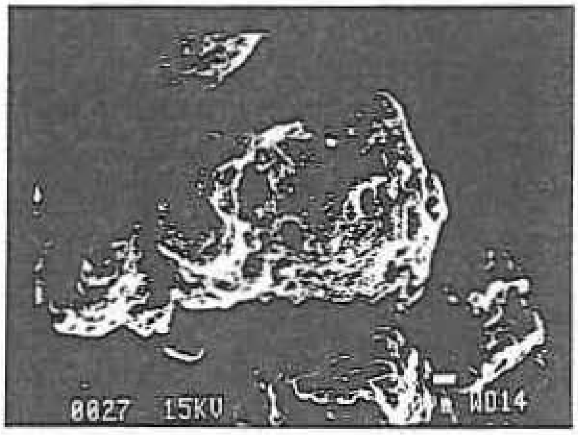


Plate 10



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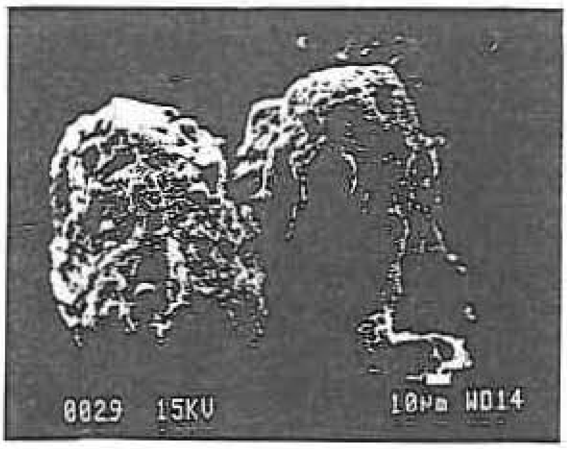

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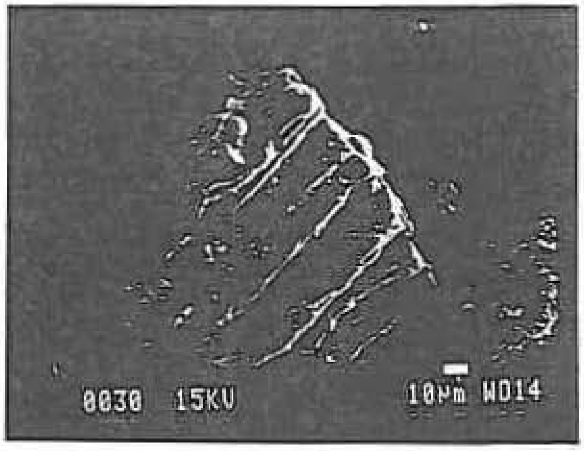

Plate 13

USE OF THE ELECTRON MICROPROBE IN CHEMICAL ANALYSIS OF COAL MACERALS, WITH SPECIAL REFERENCE TO THE DIRECT DETERMINATION OF ORGANIC SULPHUR

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ABSTRACT

A method has been investigated for measuring organic sulphur directly by use of the electron microprobe. This method is based on the recent application of electron microprobe techniques to light elements in coal by Bustin et al. (1993). It avoids the uncertainty of calculating organic sulphur by difference, and also allows direct determination of organic sulphur (and other elements such as carbon) on small particles such as individual macerals.

Electron microprobe analysis was carried out on several high-volatile bituminous coals of Permian age from the Gunnedah Basin, New South Wales. The specimens were prepared as either polished blocks or as grain mounts in the same way as for petrographic examination, and the polished surfaces coated with carbon for examination under the electron microprobe. Along with sulphur, the elements C, O, N, Al, Si, and Fe were monitored. If the intensities of Al, Si or Fe were significantly higher than background, however, the data were discarded as representing mineralised rather than pure maceral components.

Sulphur was found to have a relatively uniform distribution within each individual maceral component. For a given coal the organic sulphur content of vitrinite was also found to be consistently greater than that of the inertinite macerals. These relationships are identical to those reported in the literature for US and other Northern Hemisphere coals; however, in Sydney-Gunnedah Basin coals the contribution of inertinite is usually more significant in determining the total organic sulphur content. Organic sulphur can therefore be related, for a given sequence, to the relative proportions of macerals in the individual coal samples. Inertinite-rich coals, common in Sydney-Gunnedah Basin sequences, tend to have lower organic sulphur contents than vitrinite-rich coals in the same coalfield or geologic succession, due to the lower sulphur content and greater abundance of the inertinite macerals.

INTRODUCTION

The determination of organic sulphur (S_o) in coal is based on an indirect chemical procedure that involves subtraction of the sulphur occurring in pyritic and sulphate forms from the total sulphur content. Any errors in determination of the total, pyritic or sulphate sulphur therefore have a cumulative influence on the derivation of an accurate value for the organic sulphur content. Apart from the experimental errors associated with each determination, the results may also be influenced by factors inherent in the coal itself. As an example, determination of pyritic sulphur is based on determination of the iron (Fe) occurring in sulphide form. Sulphur occurring in sulphide minerals other than pyrite, such as galena (PbS), spalertite (ZnS) or millerite (NiS), which have also been reported in coal samples, would be grouped together by conventional techniques with the organic sulphur content.

Direct determination of the organic sulphur concentration in coal by conventional chemical means is difficult because the element is present in many different organic functional groups and is dispersed throughout the organic matrix. Analytical methods of measuring organic sulphur directly by use of techniques such as the electron microprobe, however, avoid the uncertainty associated with calculating the organic sulphur content by difference. They also allow determinations to be made on individual macerals within the coal, allowing better resolution of organic sulphur distribution than the bulk chemical techniques.

The electron microprobe has been applied to the direct determination of organic sulphur in coal in different ways over many years (Sutherland, 1975; Harris et al., 1977; Solomon and Manzione, 1977; Raymond and Gooley 1978; Maijgren et al.,1983; Straszheim et al., 1983). Recent advances in electron microprobe technology have also enabled development of techniques for direct analysis of light elements (C,O,N), along with the organic sulphur, in the different maceral components (Bustin et al., 1993, 1996; Mastalerz and Bustin 1993a,b).

Harris et al. (1977) were among the first to record a variation in organic sulphur content between maceral groups. They noticed a consistency of the relations between organic sulphur concentrations and macerals for a given coal: S (exinite) > S (vitrinite) > S (inertinite). These relations were identical to those reported for the hydrogen distribution between macerals in a given coal. Raymond (1982) found a similar relationship between the organic sulphur contents of the various maceral components: sporinite, resinite > micrinite, vitrinite > pseudovitrinite > semifusinite > macrinite > fusinite. This was shown to be true for 29 coals representing 27 seams from 13 states in the US, including coals containing as little as 38.9% vitrinite.

Most of the results obtained by use of the electron microprobe reported in the literature prior to 1983 were carried out on vitrinite rich US coals (e.g. Sutherland, 1975), with total sulphur which is well above 1.5 % and mostly due to pyrite. Maijgren et al. (1983), however, showed that the method could also be used on coals from a wider range of countries, and included study of a Hunter Valley coal with 64% vitrinite. The electron probe technique, however, has not been shown to be applicable to inertinite rich coals, such as those common in the Sydney-Gunnedah Basin, where total sulphur is generally less than 0.7 % and the sulphur is mostly in organic form.

The purpose of this paper is to report the results of the electron microprobe analyses carried out on high-volatile bituminous coals of the Gunnedah Basin. This study, based on new measurement techniques described by Bustin et al. (1993, 1996), has led to a better understanding of the distribution of both organic sulphur and light elements (C, O, N) generally among the macerals in Australian coals.

EXPERIMENTAL

Samples of five high-volatile bituminous coals collected from cored boreholes in the Gunnedah Basin were analysed for the present study. Specimens were prepared as polished sections, either as blocks of solid coal or as grain mounts such as might be prepared for conventional petrographic examination in accordance with Australian Standards. The polished surfaces in both cases were coated with carbon for examination under the electron microprobe. They were re-polished after this examination, where appropriate, for examination under oil immersion by conventional optical microscope techniques.

A Cameca SX 50 model electron microprobe analyser was used in this study. A full description of the analytical routine for analysing major and minor elements in coal with such an electron microprobe is given by Bustin et al. (1993, 1996).

Multiple analyses were carried out on individual maceral bands and particles in the coal, together with repeated analyses of identical macerals at other locations in the individual specimens. The elements C, O, N, Al, Si, and Fe were monitored along with sulphur; if the proportions of the non-organic elements (Al, Si, Fe) were higher than background levels, the information from that particular analysis (data point) was discarded as being unduly influenced by mineral matter.

RESULTS AND DISCUSSION

The characteristics_of the coals chosen for the experiments are given in Table 1. For these samples the proportion of pyrite as observed by optical microscopy is negligible.

The results of each individual sample analysis included a number of organic sulphur measurements for the major macerals present in the sample (telocollinite, desmocollinite, pseudovitrinite, semifusinite and fusinite). The estimates of organic sulphur were checked in general terms by combining the organic sulphur as determined by the electron probe for each maceral with the maceral composition for each sample as determined by point counting. The results were then compared to (total) sulphur values obtained from other sources for the respective coal seams.

The results of the microprobe analyses for sulphur in the individual macerals are shown in Table 2. Analysis of different points within a number of individual bands or particles further suggests that the organic sulphur has a relatively uniform

Table 1: Location of samples studied

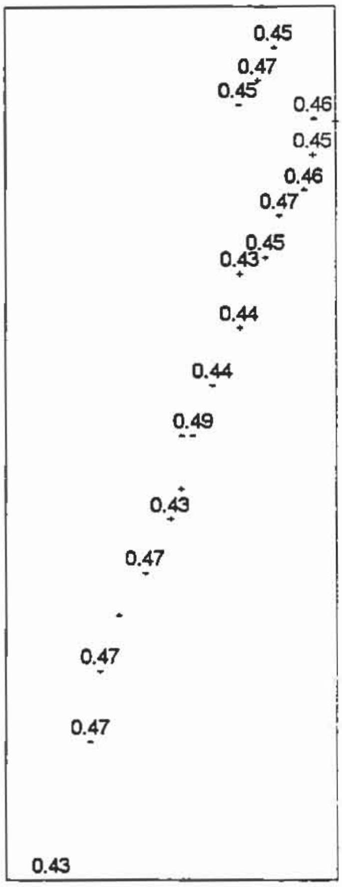
Borehole name	Depth (m)	Rv_{max} (%) of telocollinite	Age	Host sequence
Nombi DDH 1	468.3	0.80	Late Permian	Black Jack Group
Texas DDH 1	272.9	0.77	Early Permian	Maules Creek Formation
Ferrier DDH 2	514.78	0.80	Early Permian	Maules Creek Formation
Morven DDH 1	301.1	0.83	Late Permian	Black Jack Group
Mirrie DDH 1	292.5	0.72	Late Permian	Black Jack Group

Table 2. Microprobe analyses of organic sulphur in macerals of high-volatile bituminous coals from the Gunnedah Basin.

Sample location	Depth (m)	Maceral	S_o average (wt %)	S_o min (wt %)	S_o max (wt %)	Number of values N	Standard deviation SD
		PSV	0.954	0.719	1.163	49	0.079
Nombi 1	468.3	TC	0.860	0.730	1.066	31	0.073
		DSC	0.853	0.708	1.098	10	0.117
		SF	0.453	0.279	0.661	35	0.090
Texas 1	272.9	PSV+TC	0.399	0.261	0.563	211	0.055
		DSC	0.377	0.301	0.48	21	0.044
		SF+F	0.222	0.084	0.326	49	0.060
		PSV	0.422	0.383	0.460	2	
Ferrier 2	514.78	TC	0.359	0.275	0.431	34	0.035
		DSC	0.384	0.332	0.443	4	0.053
		SF	0.195	0.128	0.269	5	0.055
Mirrie 1	292.5	TC	0.537	0.423	0.596	6	0.067
		SF	0.307	0.250	0.359	3	0.055

TC = telocollinite; DSC = desmocollinite; PSV = pseudovitrinite; SF = semifusinite; F = fusinite

distribution within each maceral occurrence (Figure 1). Reproducibility of the method was checked by comparing the results carried out on the same samples over a span of several weeks (Table 3). The results typically vary by less than ±10% (relative). Greater accuracy can be achieved where necessary by using a larger number of data



Organic sulphur for this telocollinite particle:

Average = 0.453%
Minimum = 0.430%
Maximum = 0.490%

Number of readings = 18
Standard deviation = 0.018

Organic sulphur for all telocollinite particles in this sample:

Average = 0.460%
Minimum = 0.385%
Maximum = 0.597%

Number of readings = 125
Standard deviation = 0.043

Dimensions:

Length = 4.64 mm
Width = 1.75 mm

Figure 1: Organic sulphur content as determined by electron microprobe for different points within a single telocollinite layer (Morven DDH 1, 301.1 m).

points per sample. The organic sulphur concentration for the different macerals for a given coal consistently falls in the following order: S_o vitrinite > S_o inertinite. This is identical to relationships reported in the literature (Harris et al, 1977, Raymond and Gooley, 1978). However, in case of the Gunnedah Basin coals, the contribution of inertinite to the total organic sulphur is much lower (about 50 % less) than that of the vitrinite in the same coal sample. This implies that, in inertinite rich coals (i.e. coals with a low vitrinite content), the organic sulphur content of the inertinite has a major influence on the total organic sulphur of the coal. The organic sulphur in a given Sydney-Gunnedah Basin coal (and in the absence of significant pyritic or sulphate sulphur also most of the total sulphur) will depend on the maceral composition of the coal and the proportions of organic sulphur in the different maceral components.

To investigate this relationship, the organic sulphur of Permian coals from several different New South Wales and Queensland successions was plotted against the vitrinite contents of the same samples, using data from Joint Coal Board and Queensland Coal Board publications. An example of the output from this evaluation is given in Figure 2.

Table 3. Microprobe analyses of organic sulphur in macerals repeated at different times on the same coal samples.

Sample location	Date	Maceral	S_o average wt %	S_o min wt %	S_o max wt %	Number of values N	Standard deviation SD
Nombi DDH1 Depth 468.3 m	951112	PSV	0.965	0.829	1.099	21	0.070
	960626	PSV	0.960	0.851	1.163	6	0.111
	960821	PSV	0.930	0.901	0.951	3	0.026
	960826	PSV	0.943	0.719	1.054	19	0.085
	960626	TC	0.884	0.73	1.037	8	0.089
	960808	TC	0.847	0.773	0.937	17	0.043
	960826	TC		0.732	1.066	5	0.127
	960808	DSC	0.827	0.724	0.952	5	0.089
	960826	DSC	0.878	0.708	1.098	5	0.145
	951112	SF	0.430	0.179	0.661	13	0.113
	960626	SF	0.467	0.366	0.533	6	0.056
	960808	SF	0.486	0.352	0.615	11	0.080
	960821	SF	0.463	0.397	0.499	3	0.057
Texas DDH 1 Depth 272.9 m	960808	PSV	0.380	0.27	0.474	77	0.042
	960821	PSV	0.407	0.3	0.563	90	0.059
	960826	PSV	0.426	0.278	0.53	27	0.057
	960808	DSC	0.357	0.301	0.384	6	0.031
	960826	DSC	0.384	0.300	0.479	11	0.044
	960808	SF	0.226	0.084	0.313	22	0.07
	960821	SF	0.253	0.161	0.326	5	0.06
	960826	SF	0.212	0.12	0.296	22	0.047

A positive correlation between the organic sulphur and vitrinite percentages was found for each individual sequence or coalfield area studied in this way. Comparison of several such plots, however, suggests that the vitrinites and inertinites of one coal-measures succession or coalfield area do not necessarily have the same organic sulphur contents or the same contrast in organic sulphur as the vitrinites and inertinites from other successions or areas within the basin. The reason why vitrinite and interinite from one coalfield or coal-bearing succession (e.g. the Illawarra Coal Measures in the Southern Coalfield) is different to that of another (e.g. the same sequence in the Western Coalfield) is not clear at this stage, although environmental factors such as marine influence are probably involved. Indeed, the organic sulphur of specific macerals may in itself be of value as an environmental indicator in Sydney-Gunnedah Basin deposits.

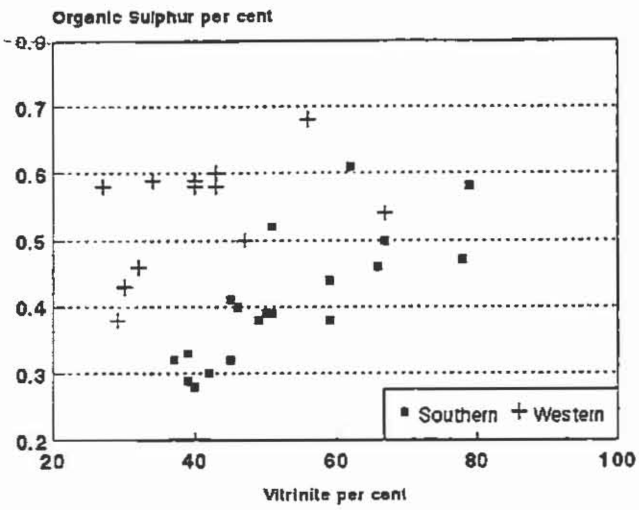


Figure 2: Relationship between organic sulphur and vitrinite content for the Illawarra Coal Measures, Southern and Western Coalfield, Sydney Basin (data from Joint Coal Board and Queensland Coal Board, 1974).

CONCLUSIONS

The combination of coal petrography with the electron microprobe analysis offers a direct method for organic sulphur determination. The method includes the possibility of obtaining organic sulphur concentrations in the individual coal macerals, and shows significant differences between the organic sulphur content of vitrinites and inertintes in the coals tested. The method is rapid, requires only small samples and is non-destructive; so that analyses may be readily repeated if necessary.

Additional work is required to determine the distribution of organic sulphur in coal macerals from different geological settings. Future studies are also planned to address other elements and other maceral forms, and to apply additional statistical treatment to the results obtained from electron microprobe analysis.

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A NEW INTERPRETATION OF THE GRETA COAL MEASURES IN THE MAITLAND-CESSNOCK-GRETA COALFIELD & CRANKY CORNER BASIN

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BACKGROUND

The Greta Coal Measures is one of a series of early Permian coal bearing depositional episodes in the Sydney-Gunnedah Basin. The other carbonaceous units are the Clyde Coal Measures, the Leard Formation and the Maules Creek Formation. The Ashford Coal Measures occur in the early Permian Ashford Basin. In outcrop and subcrop the Greta Coal Measures form a shallow, linear basin on the boundary of the northern Sydney Basin. A small inlier, the Cranky Corner Basin, is found on folded and thrusted Carboniferous sediments to the north of the Lochinvar Anticline. The Greta Coal Measures depositional episode has been placed in the late Artinskian (Scheibnerova, 1980).

The Maitland-Cessnock-Greta Coalfield (Jones, 1939) was first mapped by T.W. Edgeworth David between 1886 and 1891. The coal seams were first mined at Greta and West Maitland in the 1880's. Most extensive coal extraction has taken place in the subcrop area south of Cessnock. Currently only two coal mines are in operation at Ellalong and Pelton by the Newcastle Wallsend Coal Company.

STRATIGRAPHY AND SEDIMENTOLOGY

The Greta Coal Measures are a thin terrestrial wedge between the lower marine Dalwood Group and the upper marine Maitland Group. The maximum thickness of the Greta Coal Measures is 334 m in the Cranky Corner Basin. In the Maitland-Cessnock-Greta Coalfield maximum thickness is 70 m north of Greta. Currently accepted stratigraphic terminology was developed using sedimentation patterns occurring in the southern portion of the Maitland-Cessnock-Greta Coalfield. The presented stratigraphic terminology is based on the Standing Committee on Coalfield Geology of NSW (1971) and proposals by Edgeworth David (1907) and Britten (1975) to include stratigraphically significant units (figure 1).

The Farley Formation is a fossiliferous, silty sandstone which grades into the overlying Neath Sandstone. This is a massive, cross-bedded sandstone with minor conglomerate and shale phases. The Kurri Kurri Conglomerate is predominantly a pebble orthoconglomerate with intercalated sandstone bar top lenses in a braided stream facies. The Greta and Homeville Coal Members are split in parts by sandstone and shales in meander stream facies of the Kearsley and Abernethy Lens respectively. The Paxton Formation varies from fine conglomerate, sandstone and shale distally to pebble conglomerate proximally in the study area. Brackish water sediments occur in the Bellbird Lens in the southwest of the Maitland-Cessnock-Greta Coalfield. The Cessnock Sandstone is a massive, fine to medium grained sandstone with very minor conglomerate bands. It can be heavily bioturbated and contains marine fossils. This unit forms an estuarine facies near Maitland.

GROUP	SUB-GROUP OR FORMATION	MEMBER	MAXIMUM THICKNESS
Maitland Group	Mulbring Siltstone	Chaenomya Beds	41m
Maitland Group	Mulbring Siltstone		330m
Maitland Group	Muree Sandstone		300m
Maitland Group	Muree Sandstone	Bolwarra Conglomerate	
Maitland Group	Branxton Formation		1300m
Maitland Group	Branxton Formation	Fenestella Shale	32m
Maitland Group	Branxton Formation	Cessnock Sandstone	16m
Greta Coal Measures	Paxton Formation		42 m
Greta Coal Measures	Paxton Formation	Pelton Coal	1.5m
Greta Coal Measures	Paxton Formation	Bellbird Lens	6m
Greta Coal Measures	Kitchener Formation		12m
Greta Coal Measures	Kitchener Formation	Upper Greta Coal	2.5m
Greta Coal Measures	Kitchener Formation	Kearsley Lens	5.2 m
Greta Coal Measures	Kitchener Formation	Lower Greta Coal	6m
Greta Coal Measures	Kurri Kurri Conglomerate		43 m
Greta Coal Measures	Kurri Kurri Conglomerate	Upper Homeville Coal	4.5m
Greta Coal Measures	Kurri Kurri Conglomerate	Abernethy Lens	10m
Greta Coal Measures	Kurri Kurri Conglomerate	Lower Homeville Coal	3 m
Greta Coal Measures	Neath Sandstone		18 m
Dalwood Group	Farley Formation		300m
Dalwood Group	Farley Formation	Ravensfield Sandstone	6m
Dalwood Group	Rutherford Formation		384m
Dalwood Group	Allandale Formation		300m
Dalwood Group	Lochinvar Formation		850m

Figure 1. Modified Stratigraphy of the Greta Coal Measures and Bounding Groups

STRUCTURE

The Greta Coal Measures outcrop in a U-shape around the flanks of the Lochinvar Anticline. The bedding dips range from 8° in the Cessnock area, 22° in the Greta area to 50° near Maitland. The Coal Measures in the north of the study area terminate at the south directed Hunter Thrust and are cut there by the Hunter River Cross Fault. The north directed Greta Thrust Fault cuts the Coal Measures south of the town of Greta. The Elderslee Fault and Rothbury Thrust Fault occur on the western edge of the study area. The Buchanan Monocline occurs on the eastern edge of the study area. All these structures are post-depositional features (figure 2).

A regional isopach construction of the Greta Coal Measures show it to be a braidplain fan sourced from the northeast. The fan is thickest between Muswellbrook and Singleton (figure 3). Sediments in the Cranky Corner Basin are much thicker (>300m) than those to the south of the Hunter Thrust. This suggests that the sediments in the Cranky Corner Basin were deposited in a more proximal location than its present position. The depositional paleoslope of the Greta Coal Measures is very low with an inferred slope of 0.2° within the study area. A graben feature is found in the subsurface trending southeast from Cessnock. This feature has caused localised valley fill sedimentation to thicken the Coal Measures in this area.

CORRELATION METHOD

The Greta Coal Measures in the Maitland-Cessnock-Greta Coalfield were correlated with 27 borehole logs and 7 measured sections (figure 2). Very few boreholes intersected the whole of the Greta Coal Measure sequence. These correlations were then tied in with a separate study of 2 boreholes in the Cranky Corner Basin. Geophysical logs exist for a few modern boreholes southwest of Cessnock and for 2 boreholes in the Cranky Corner Basin. Sequence stratigraphic principles were applied to distinct facies patterns. The significant marine signature near the top of the Greta Coal Member and the Tangorin Coal Member was used as a time correlation marker.

COAL QUALITY

The Greta Coal Measures contain high volatile, bituminous coals. The worked coal seams have low ash, high sulphur and good coking properties. Sulphur content can be laterally and vertically variable over a seam block ranging from 0.6% to 2%. Most coal seams appear to be laterally discontinuous and contain multiple splits proximally.

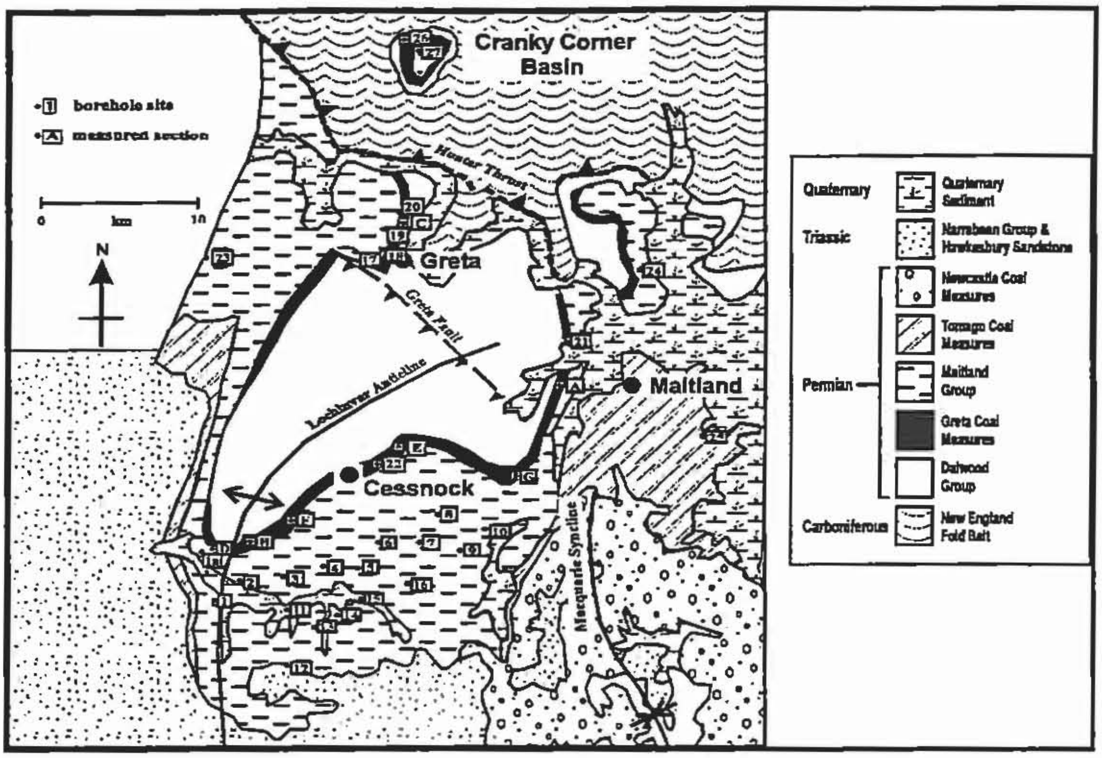

Figure 2. Geology of the Maitland-Cessnock-Greta Coalfield and Cranky Corner Basin. Modified from Hawley et.al., 1995.

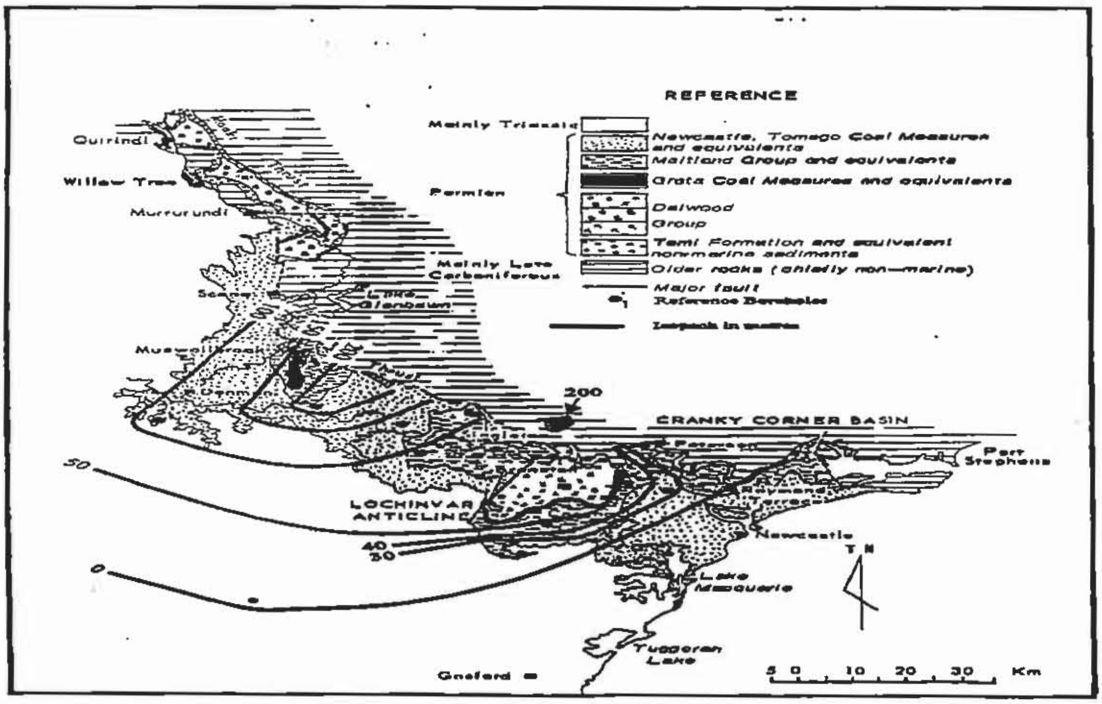

Figure 3. Isopachs of the Greta Coal Measures in the Hunter Valley, NSW. Modified from McClung, 1980.

SEQUENCE STRATIGRAPHIC INTERPRETATION

In the Cranky Corner Basin two sequences have been interpreted to have formed in the Greta Coal Measures (figure 4). An erosional unconformity separates the marine high stand systems tract of the Billy Brook Formation from Sequence 1. A late lowstand system tract was formed as coarse braidplain sediments filled the space made available by rising relative sea level. An increase in the rate of relative sea level rise produced a reduction in grade of the fluvial streams in a transgressive systems tract. Meander floodplain sediments were deposited with overbank peat formation. Coal seams are thin as the accommodation change became to rapid for peat growth to keep up and/or a high sediment load produced rapid channel switching. Aggradational to progradational parasequences occasionally terminating in thin carbonaceous units are interpreted to be a high stand systems tract. Sequence 1 and sequence 2 are separated by an erosional unconformity.

Distally from the source only one sequence is preserved in the Greta Coal Measures. The Neath Sandstone is conformable with the underlying marine Farley Formation which is diachronous with sequence 1 in the Cranky Corner Basin. A disconformable boundary occurs between the transgressive barrier sand of the Neath Sandstone and overlying coarse grained fluvial sediments. In sequence 2 the early lowstand systems tract was a sedimentary bypass surface in most of the Greta Coal Measures. A valley fill occurring in the early lowstand systems tract is found in a graben structure trending southeast of Cessnock. Sediment infill is distal to the source area and finer grained than later lowstand tract deposits. Peat deposition occurred in overbank deposits at the top of the valley infill. Aggradational to progradational parasequences terminating with peat development are interpreted to have been developed in a late lowstand wedge systems tract. As accommodation gradually increased braided stream deposits occur with progradation at the depositional shoreline break eg. Kurri Kurri Conglomerate. Peat formation occurred in zones of non-deposition forming discontinuous coal units eg. the Homeville Coal Member. The relatively continuous Greta/Tangorin Coal Member occurs at the top of the lowstand system tract. Fluvial deposition became lateral as the grade decreased. Peat development kept pace with the rise in relative sea level and a thick, laterally continuous coal seam formed. This seam is split by migrating meander channels over the floodplain eg. the Kearsley Lens.

A significant marine flooding surface separates the lowstand systems tract and the transgressive systems tract. Fluvial parasequences show an aggradational to retrogradational pattern and delta facies show tidal influences eg. Paxton Formation. Thin peats developed on delta plain swamps and behind barrier sands eg. the Pelton Coal Member. Maintenance of a steep graded profile allowed conglomeratic braid plain sediments to develop proximally. An increase in rate of the rise of relative sea level caused backstepping of the shoreline. The Cessnock Sandstone is interpreted as a transgressive barrier sand sheet formed in front of a retrograding fluvial system.

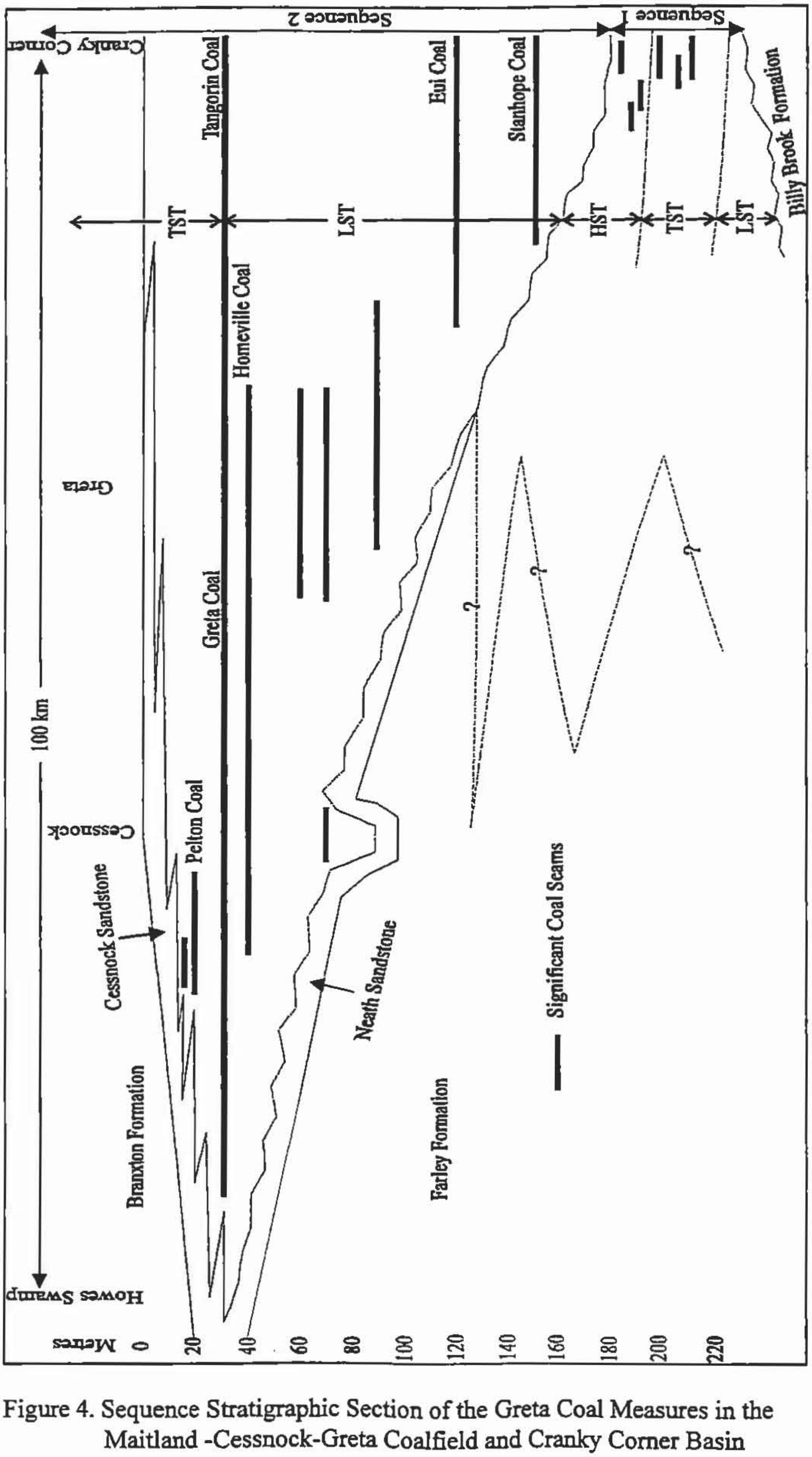

Figure 4. Sequence Stratigraphic Section of the Greta Coal Measures in the Maitland -Cessnock-Greta Coalfield and Cranky Corner Basin

TECTONIC IMPLICATIONS

The Greta Coal Measures were formed in a retro-arc foreland basin setting. Tabulation of radiometric age dates for significant events or depositional episodes in the northern Sydney Basin and New England Fold Belt (NEFB) show that movement on the Peel Manning Fault System preceded the deposition of the Greta Coal Measures (figure 5). Uplift on the Fault System produced an isostatic downwarp on the footwall side of the upthrust. Post orogenic deposition formed sequence 1 in the Greta Coal Measures/Farley Formation. As the uplift eroded the tectonic loading decreased and rebound of the downwarp occurred leading to erosion of the first sequence. Renewed uplift on the Peel Manning Fault System began sequence 2 in the Greta Coal Measures/Branxton Formation. The major transgression at the top of the Greta Coal Measures and deposition of the marine Branxton Formation is associated with a tensional event denoted by intrusion of the Barrington Tops Granodiorite.

Event	Age	Significance	Source
Deposition of Awaba Tuff	256 ± 4 Ma	Marker horizon near top of Newcastle Coal Measures	Gulson et.al, 1990
Formation of amphibolite facies in Hillgrove Suite	268-256 Ma	Uplift at culmination of major east-west compression	Landenberger et.al., 1995
Deposition of Mulbring Siltstone	264.1± 2.2 Ma	Sedimentation at end of major transgression	Roberts et.al., 1996
Intrusion of Barrington Tops Granodiorite	265± 2 Ma, 269± 2 Ma	Tensional episode in southern NEFB	Roberts & Engel, 1987
Deposition of Thornton Claystone	266.1± 0.4 Ma	Marker horizon in middle of Tomago Coal Measures	Gulson et.al., 1990
Deposition of upper Greta Coal Measures	268.9± 2 Ma	Major regression	Roberts et.al., 1996
Deposition of the base of the Branxton Formation	272.2± 3.2 Ma	Beginning of major transgression	Roberts et.al., 1996
Serpentinite injection along Peel Fault	273± 5.8 Ma, 280± 5.6 Ma	Thrusting and transcurrent movement on Peel & Manning Fault Systems	Lanphere & Hockley, 1976
Deposition of the Billy Brook Formation	287.9± 3 Ma	Termination of marine sedimentation in the Cranky Corner Basin	Stevenson, pers. comm., 1997
Intrusion of S-type granitoids in Hillgrove Suite	290± 4 Ma	Termination of subduction/accretion in southern NEFB	Watanabe et.al., 1988
Deposition of the Tamby Creek Formation	305.3± 3.2 Ma	Rifting in the northern Sydney Basin	Stevenson, pers. comm., 1997
Deposition of the Matthews Gap Dacitic Tuff	309± 3 Ma	Acid volcanism prior to rifting basalts	Gulson et.al., 1990

Figure 5. Radiometric Age Dates of Tectonic Events

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PYRITE MORPHOLOGY OF THE GRETA AND LISKEARD SEAMS

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INTRODUCTION

This study is part of a wider investigation into marine influenced coal seams. The Greta (Sydney Basin) and Liskeard (central Queensland) seams have both been affected by marine inundation, either during or shortly after peat accumulation. These seams feature characteristics typical of marine influenced coal, such as high pyritic sulphur concentration, elevated microfluorescence intensity and unusual swelling properties. Both these seams contain relatively high concentrations of sulphur which increase towards the top of the seam. The occurrence of pyrite in these seams was examined to determine differences in pyrite formation between the two seams. This may aid in identifying the exact timing of marine influence and whether there is a difference in timing between the two seams.

EXPERIMENTAL PROCEDURES

A strip sample of the Greta seam was obtained and fresh core samples of the Liskeard seam. Grain mounts were prepared and polished for incident light microscopy. Using a mechanical stage and a point counting device the surface of the coal blocks were traversed at even intervals. A Zeiss Universal microscope was implemented with a 25x oil immersion objective. Observation of the surface was via a 20 point, 8x ocular.

When a cross point of the ocular fell on a pyrite nodule it was noted whether it was a single crystal, a cluster or a framboid, placed into a size category and recorded as infilling, cleat, replacing tissue, euhedral, subhedral or anhedral. Some of the pyrite bodies in the smallest size category were problematic since their size made it difficult to determine the morphology. One hundred pyrite grains were categorised for each sample. Samples near the base of the seams, with low pyrite content were traversed at a smaller interval or reground to provide a fresh surface so that one hundred pyrite grains could be counted.

RESULTS

A number of forms of pyrite were observed. The forms became more varied as the concentration of pyrite increased, towards the top of the seam. Several types of occurrences were common:

1) isolated, single, euhedral crystals usually found in bands of telovitrinite,

2) clusters of euhedral, densely packed crystals,

3) framboidal pyrite, usually solid spheres, generally <20 microns in diameter,

4) spherical clusters of anhedral to subhedral crystals of variable size, the proximity of the individual crystals vary, loose packing creates a 'spongy' texture, while more closely packed crystals produce a more solid sphere. These spherical shapes often occur together, and may be found infilling semifusinite, telovitrinite or bands of mixed macerals. Less commonly similar arrangements of crystals occur in an ellipsoidal or rectangular shape, rather than a sphere.

5) Spheroidal bodies were observed which have an equigranular textured centre but have radiating lath shaped crystals surrounding it.

5) Irregular shaped areas of pyrite in which the texture of plant tissue has been preserved. The tissue has variable features and may represent relatively unaltered structure to partially humified plant material. Often these pyrite grains are very large, visible with the naked eye. Occasionally cell tissue may be recognised in the centre of the grain but is obliterated towards the edge.

6) Cleat and fracture fillings are comprised of solid euhedral pyrite.

A number of general trends regarding pyrite size and morphology were observed. Figure 1 illustrates the relationship between the morphology of the pyrite and whether the occurrence was a single crystal, cluster or framboid. Pyrite replacing cell tissue was only found as a cluster of crystals. Subhedral forms occurred in all three categories, single, framboid and cluster. Framboidal arrangements of crystals, by definition, occurred only as euhedral and subhedral crystals. Individual isolated crystals were predominantly euhedral.

The largest pyrite bodies observed were examples of pyrite replacing cell tissue. The proportion of pyrite representing replaced tissue increases with increasing size category. A similar trend is found for pyrite infilling cleat and fractures. The reverse trend is shown by subhedral and euhedral crystals which decrease in abundance with increasing size class, especially the euhedral crystals which are predominantly in the smallest size category. Pyrite classed as anhedral also decreases in abundance with increasing size class.

Greta And Liskeard Seam Compared

The relationship between the size of the pyrite particle and its morphology in the Liskeard and Greta seams is shown in figures 2a and 2b. The seams show clear trends as discussed above however, the Greta seam has a more uniform pattern of size distribution.

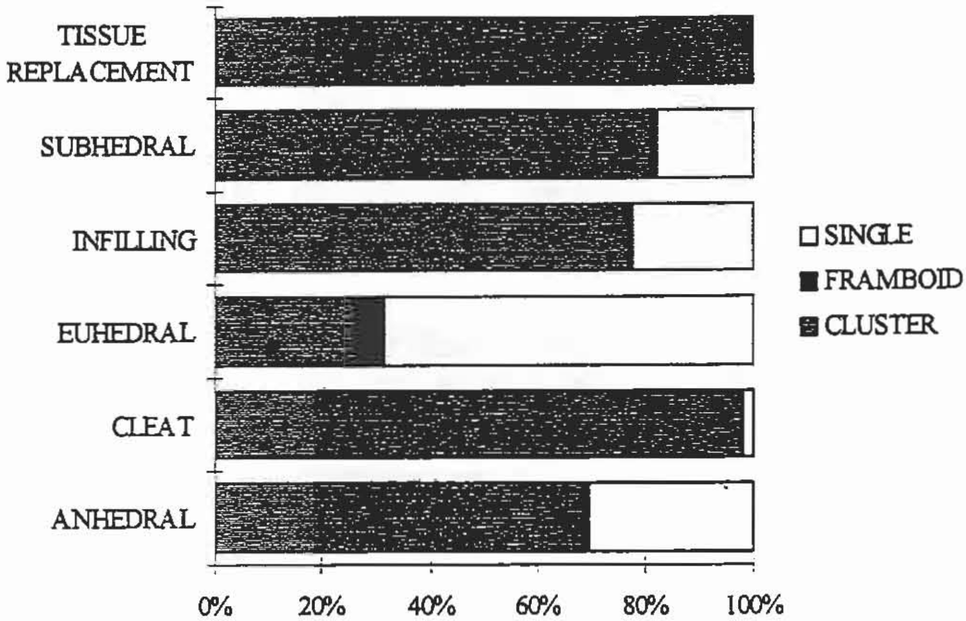
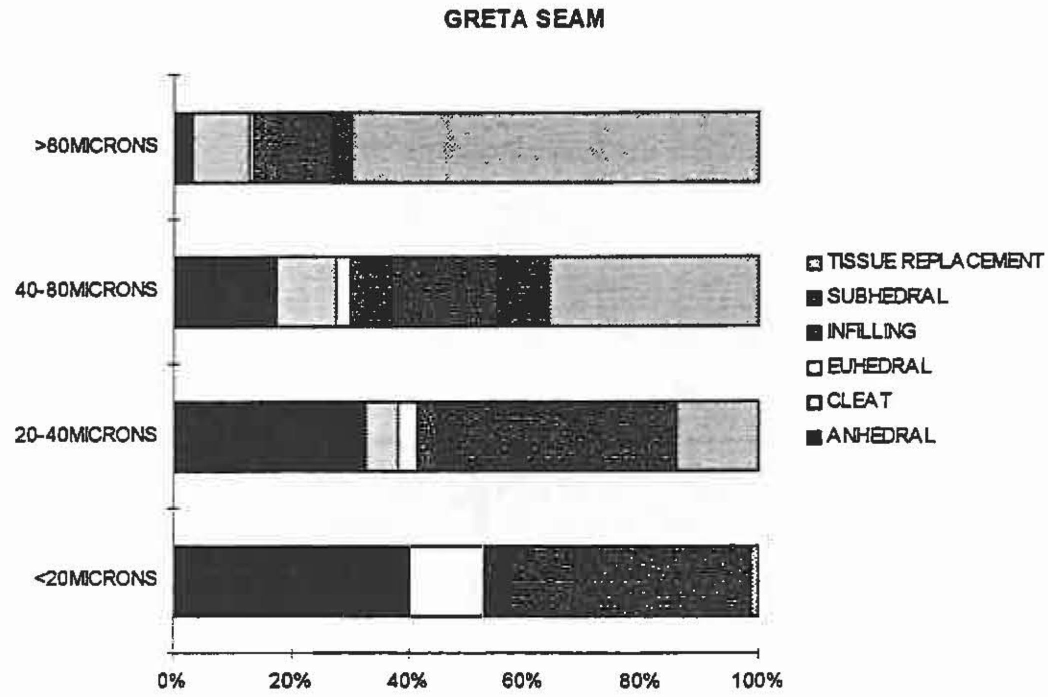


Figure 1 Morphology of pyrite occurrences according to whether they are single crystals clusters of crystals or framboids.

Figure 3a and 3b indicate the pyrite morphology of each ply in the seams. The Greta seam has an abundance of anhedral pyrite which illustrates two decreasing cycles downwards in the seam. There is a greater abundance of euhedral pyrite in the Liskeard seam. From the base of the seam two cycles are observed decreasing upwards, in the concentration of euhedral grains. The Greta seam also demonstrates a decrease in euhedral crystals upwards in the seam up to ply 7 but then remains at a constant low level.

The occurrence of cleat and fracture filled pyrite is relatively rare, but occurs in the lower portion of both seams.

The size distribution of pyrite grains for the seams is shown in figures 4a and 4b. Both seams have an increase in pyrite size upwards in the seam. The Liskeard seam has a higher proportion of smaller pyrites which decrease upwards, except for ply 5 which has an unusual size distribution. The 20 - 40 micron size grains oscillate in abundance but generally slowly increase in abundance towards the top. Pyrite grains in the next size category are more frequent and increase in quantity upwards in the seam. Pyrite bodies in the largest size class increase upwards in the seam, becoming the dominant size in the top three plies.



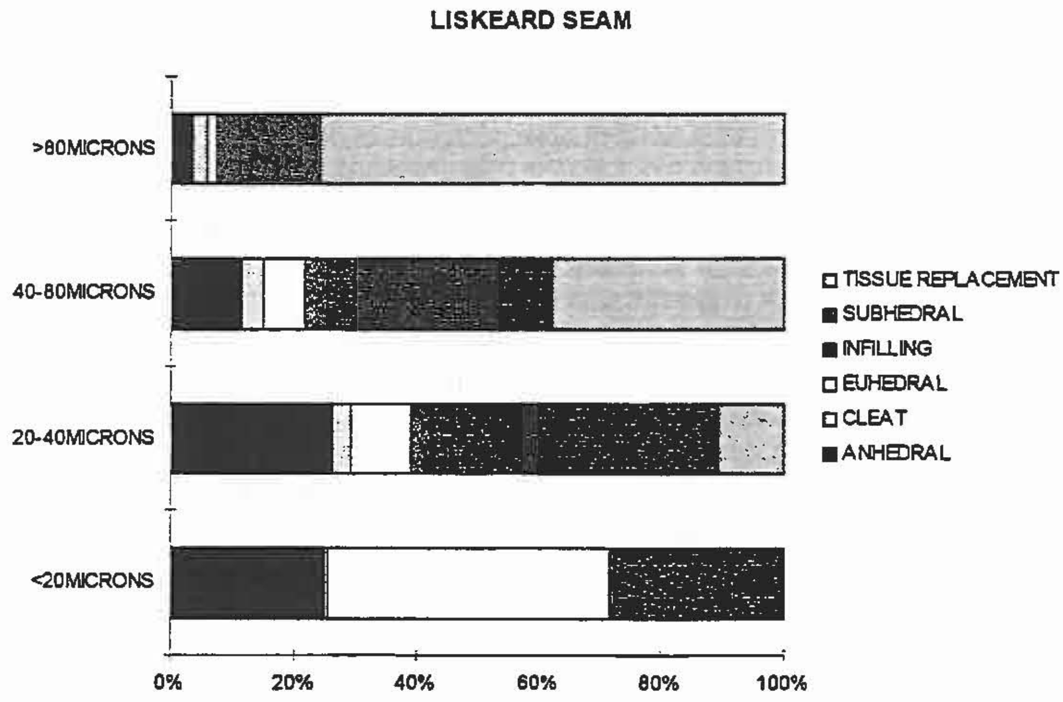
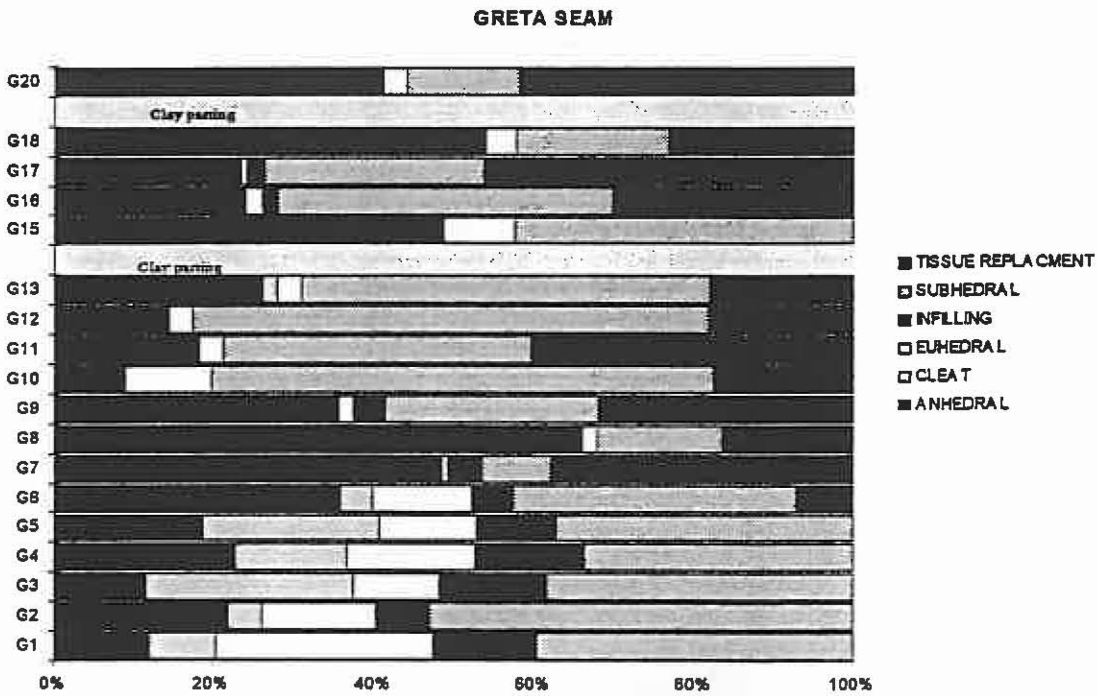


Figure 2a (Greta) and 2b (Liskeard). The relationship between the size of pyrite bodies and their morphology.

In the Greta seam the proportion of bodies less than 20 microns in diameter decreases rapidly upwards in the seam. This class is dominant throughout most of the seam. The size distribution is affected by the inorganic bands, above the lowermost clay parting the size distribution is reversed. The pyrite in the next size class increases upwards in the seam, oscillating in occurrence above the first clay band. The proportion of pyrite in the 40 - 80 micron size category increases upwards in the seam and like the smallest size class reverses its trend above the clay parting. Large pyrite bodies (>80 microns) oscillate in their frequency but overall increase in occurrence upwards in the seam, these pyrites are relatively low in occurrence.



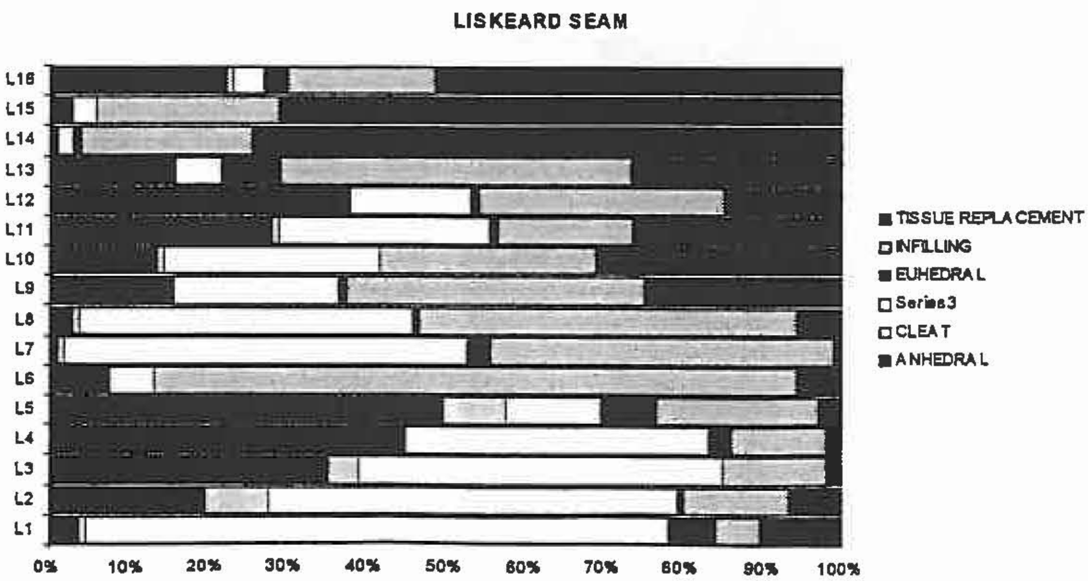
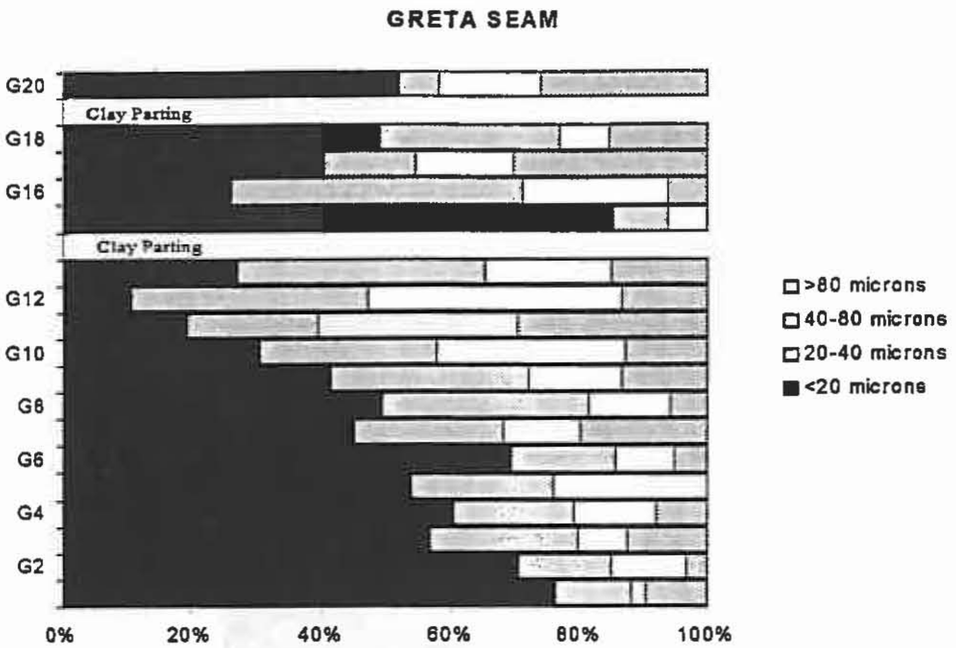


Figure 3a(Greta) and 3b(Liskeard) The pyrite morphology with respect to depth



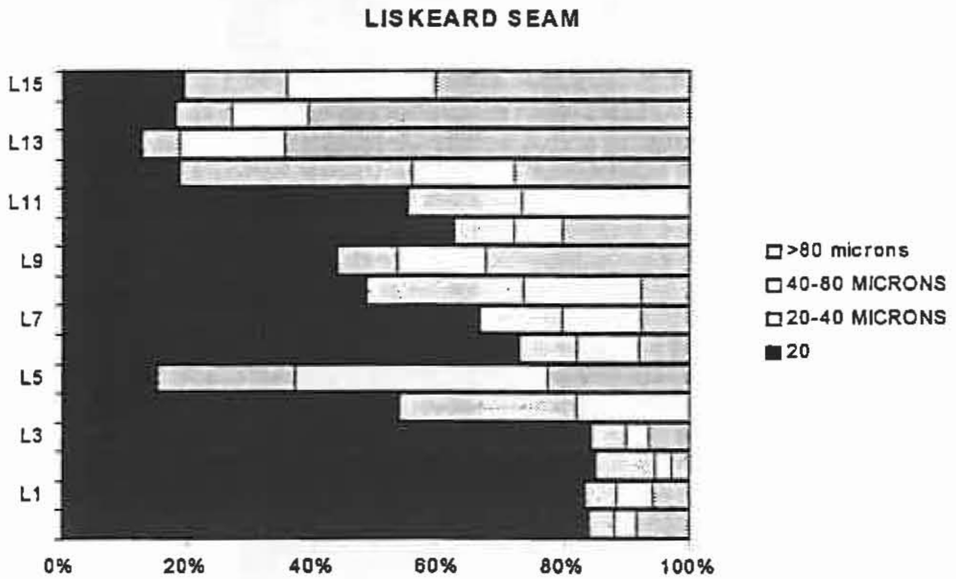


Figure 4a (Greta) and 4b (Liskeard). The change in pyrite size with depth within the seam.

The size distribution is relative to the total sulphur content. The proportion of pyrite in the <20 micron size class decreases as the total sulphur of the ply increases. The remaining size classes increase their frequency with increasing total sulphur content.

DISCUSSION

Stevenson (1991) studied the vertical and lateral variation of sulphur concentration in the Greta seam in the Ellalong-Pelton-Quorrobolong area, he delineated areas of high, medium and low sulphur content. The strip sample of the Greta seam used in this study is representative of a high sulphur area.

Since only one strip sample was taken for both seams the results obtained do not represent the entire seam only the locality where the samples were taken. However it was hoped that systematic variations observed within the two seams would support the hypothesis that the timing of marine influence was different for each seam. This is indicated by petrological and chemical analyses, the discussion of which is outside the scope of this paper.

The variety of pyrite bodies observed in these two seams is similar to that described in other studies on pyrite morphology (Kortenski and Kostova 1996, Renton and Bird 1991, Querol et al. 1989). The timing of the appearance of the forms described is difficult to determine. Cleat and some infilling pyrite is secondary, and emplaced after consolidation of the peat during diagenesis or later. Other forms of pyrite for example bodies replacing cell tissue, framboids and solid masses of euhedral grains, have macerals wrapping around them, indicating that they were formed prior to final compaction and diagenesis. The 'spongy' textured spheres of pyrite varied, some did not appear to have disturbed the macerals and were probably formed later, while others had macerals wrapping around them. Isolated euhedra in telovitrinite bands did not affect the structure of vitrinite, where it was possible to see any structure within the telovitrinite.

Querol et al. discuss the timing of formation of different pyrite morphologies. They divided both the syngenetic and epigenetic phases in two. Framboidal and rhombododecahedral euhedral crystals were found to form first, in the early syngenetic stage and cubes and octahedral euhedral pyrite forms next, still within the early stage. Then massive pyrite, described as infilling cell structure, coating framboids and replacing organic matter, formed. Using their system of timing, the framboidal and some of the euhedral crystals formed first followed by the tissue replacing pyrite and anhedral forms.

The Liskeard seam has a greater quantity of framboidal and euhedral pyrite particularly in the lower part of the seam this would suggest that this pyrite formed very early. The greater amount of anhedral pyrite in the throughout the Greta seam indicates that formation of pyrite was later. This suggests that pyrite within the Greta seam may be due to a marine inundation after peat accumulation whereas the Liskeard seam was affected during peat formation.

CONCLUSIONS

The occurrence of pyrite in the Liskeard and Greta seams is similar, which corresponds to their similar depositional history. The Liskeard seam appears to have a greater proportion of pyrite which forms at an early stage compared with the Greta seam. The Greta seam also has a very uniform pattern of pyrite occurrence vertically within the seam. These arguments add weight to the hypothesis that the Liskeard seam was affected by marine waters during peat development while the Greta seam was inundated by sea water at least after the deposition of the lower clay parting, or at the completion of peat accumulation.

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