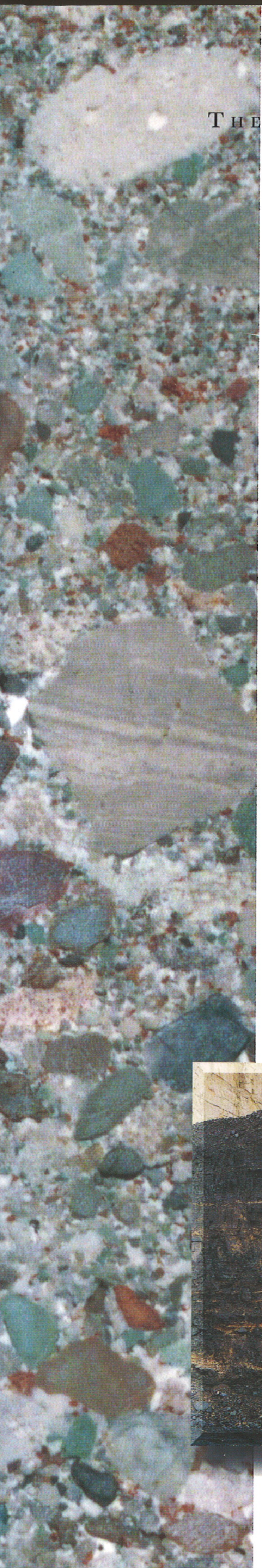
THE COALFIELD GEOLOGY COUNCIL OF NEW SOUTH WALES



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Cover photograph: *The Fassifern seam, the topmost seam within the Boolaroo Formation—Newcastle Coal Measures - exposed in the Westside open cut mine, 26 km south west of Newcastle.*

Spine: *Lithic, pebble to granule conglomerate of the Late Permian Wallala Formation—Black Jack Group in the Gunnedah Basin. (Magnification 3.5X)*

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COALFIELD GEOLOGY COUNCIL OF NSW

The Coalfield Geology Council of New South Wales is a joint Government/Industry body which was established in 1961 to provide a forum for discussion and dissemination of detailed knowledge on the various coalfields of New South Wales and geological issues of interest to the coal mining industry.

The Council facilitates the establishment and revision of codes, standards and guidelines for the practice of coalfield and mining geology. The Council is responsible for the revision of the stratigraphy for the various coalfields in the State and assisting industry with issues such as environmental geology, longwall mining geology, engineering geology, coal resources and reserves, education, coal geology and mine safety and coal seam methane.

The Council also provides a mechanism for effective industry/government consultation on all matters involving coalfield and mining geology and draws its membership not only from industry and government but also research organisations and tertiary institutions.

COALFIELD GEOLOGY COUNCIL OF NEW SOUTH WALES

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Computer-based resource/reserve estimates	B. Mullard
Guide to systematic evaluation of open cut coal reserves	J. Beckett R. Davis B. Mullard B. Preston C. Weber
Environmental considerations for coal geologists	M. Fahey G. Holt R. Nolan B. Mullard C. Ward C. Wootton
Permian stratigraphy of the Gunnedah Basin	N. Z. Tadros
Stratigraphy of the Greta Coal Measures, Muswellbrook Anticline area, Hunter Coalfield	J. Beckett H. Binnekamp J. Rogis G. Salter
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Production Team

Coordinator:	N.Z. Tadros
Editors:	J.R. Stewart R.A. Facer
Word processing/layout:	D. Lum H. Martino
Cartography:	Z. Drugakov N.Z. Tadros A.C. Hutton
Cover Design:	V. Grant

Postal Address
Coalfield Geology Council of New South Wales
c/- New South Wales Department of Mineral Resources
PO Box 536
St Leonards NSW 1590
Australia

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COMPUTER-BASED RESOURCE/RESERVE ESTIMATES

B. Mullard

INTRODUCTION

The advent of computers has revolutionised many areas of geology. Computers have become an essential element in analysing the vast amount of data generated by exploration programs. In addition, the high cost of drilling and sampling a deposit demands that as much information as possible be squeezed from the data.

In coal geology, computers have revolutionised the data acquisition and storage phases of an exploration program. They have provided the means to create an interactive model of a coal deposit from which reserves can be delineated, extraction schedules generated and coal quality variations analysed.

The topic of geological modelling and reserve estimation is a very large one and it is not possible to cover the full range of issues in a single paper. As a result this paper concentrates on what is considered to be the key determining factor for a geological model, the interpretation method.

The objective of this report is to examine briefly the process of generating a geological model by examining the properties of some of the better known interpolation techniques. It is hoped that this will give geologists a better understanding of how modelling systems work and thus lead to better geological models.

DEFINITIONS

In order to avoid confusion it is necessary to define briefly a number of terms which are used in this paper.

Geological Model

In its most general sense a geological model is a representation of the geology of a deposit. A model represents, but is not itself, reality. A model allows questions to be answered about a deposit which will enable a better understanding of the behavior of the actual (ie real) geology.

A computer based model is a symbolic model. It employs symbols to represent reality and can include both visual (graphs and diagrams) and mathematical models.

A geological model may be a set of plans, a number of trend surface equations, grids of interpolated data points or a mathematical technique for interpolating points.

Contour Plans

A contour plan is a visual representation of the various attributes which make up a geological model, eg thickness, structure, ash, etc. In this regard a contour plan should accurately reflect the underlying model. Routines which smooth or alter the contour plans without changing the underlying model should, in general, be avoided.

Surface

The term surface is used in this report to describe the plot of a variable in three dimensional space. For example the thickness of a seam across a deposit can be plotted as a single surface with the variable thickness component represented by the z axis direction values.

WHAT IS A COMPUTER-BASED RESOURCE/RESERVE ESTIMATE?

The terms 'resource' and 'reserve' can, in their most basic form, be defined as follows

- A 'resource' refers to in situ coal which may have potential for use
- A 'reserve' is that part of a 'resource' which it is planned to mine and for which such planning has been undertaken (Australian Code for Reporting Coal Resources and Reserves, June 1997 — but is under review)

The problem is that there is no direct method (apart from mining the deposit) for determining these figures. Geologists must therefore attempt to estimate resource and reserve figures by sampling the deposit. In many cases the geologist must try to extrapolate the properties of millions of tonnes of coal from a total sample weight of only a few kilograms.

The steps taken in arriving at a reserve or resource estimate can be summarised as follows:

- The deposit is sampled
- The values obtained by sampling are then used to interpolate and extrapolate to unsampled parts of the deposit
- These estimated valued are then used to arrive at an estimate of the amount of coal contained in the deposit.

In the above procedure two assumptions are made:

- The sampling is representative
- The interpolation and extrapolation method gives accurate results.

In modelling a coal deposit, most computer methods generate a regularly spaced grid of values from the original data points. The main advantage of this is that it is very easy to manipulate such data. Grids of values can be added, subtracted and multiplied together. A grid of values can also be multiplied by a constant such as a washery recovery or mining recovery factor.

A major problem with grids is that the original sample points are not retained. As a result data 'honouring' (ie validating in the same way as the original point data can be validated) is generally impossible, although very fine grids can for all practical purposes honour data.

The alternative to the establishment of a grid is to undertake direct interpolation from the original data points each time a reserve estimate or contour plan is generated. This technique allows the honouring of borehole data and is particularly useful where it is necessary to model linear features, eg outcrop, limits to oxidation, etc.

So what is a computer-based reserve/resource estimate? It should be apparent from the above discussion that computer based reserve estimates are the end result of a mathematical manipulation of the original data. The assumption that this manipulation represents reality should only be made with caution. Unless considerable care is taken, the modelling process could result in there being no connection between the estimates obtained and the real values one is trying to estimate.

DESIRABLE PROPERTIES OF A RESERVE ESTIMATION METHOD

Most reserve estimates are quoted as a single number rather than a range. In statistics this is known as a point estimator. Ideally a good point estimator should have a number of important properties which in general relate to the criterion that an estimation method should provide reasonable assurance that the reserve estimate obtained will be close to the real reserve figure. The three most important properties are:

Unbiasedness
Efficiency
Consistency

Unbiasedness

An unbiased reserve estimator is one which does not introduce a systematic error to a reserve estimate. In other words, if it were possible to independently drill a deposit a large number of times and a reserve estimate were calculated using the results from each drilling programme then the errors associated with each estimate would tend to cancel each other.

Most commonly used reserve estimation procedures are biased. This however does not make them unsuitable estimators provided that the bias is not too large. In many cases a geologist may deliberately bias a reserve estimate. This is generally done to provide a 'conservative reserve estimate' which takes into account the many uncertainties associated with the deposit which cannot be adequately quantified. There is nothing wrong with this procedure, provided that the steps taken to arrive at the conservative estimate are adequately explained.

Efficiency

Efficiency refers to the variability of a resource/ reserve estimator. Once again if a deposit could be sampled independently a large number of times one would find that each estimate would vary from each other by some small amount (error).

If two estimators have no bias then it is reasonable to prefer the estimator that has the smaller error or variability associated with it for a given sample size. Although this may appear to be stating the obvious, it is quite common for geologists to choose inefficient estimating procedures. What is important is that the geologist understands the procedure and implications of the method being applied.

Consistency

Consistency refers to the desirable property that, as the number of boreholes increases, the reserve estimate becomes increasingly accurate. Although most estimators have this property, some estimators converge more rapidly than others. Consistency of an estimating procedure may also be dependent on how a deposit was sampled (ie the sampling pattern).

Other Factors

The above factors are important in a statistical sense but they are not the only factors that need to be considered in choosing a particular reserve estimation method. Other factors which may be important include:

- Whether or not the interpolation method honours the original data points
- The ability of the technique to model regional and local trends within the data
- The ability of the technique to extrapolate beyond data points
- Whether or not the interpolation technique produces a continuous surface or a discontinuous surface
- How easy it is to incorporate other geological factors into the model (eg faults, washouts, etc)
- The ease of implementing the method.

GEOMETRIC METHODS

Most geometric methods were developed before the advent of computers. Because geometric methods are extremely easy to implement they have proved to be extremely popular and were among the first methods to be computerised. An excellent summary of these techniques can be found in Patterson (1959). Most of the techniques allocate to a block of coal the thickness and quality parameters of a bore hole or sample within that block. The following is a brief summary of the more common geometric methods.

SQUARES

This method is commonly used where drilling has been undertaken on a square grid. Each borehole is allocated an area of influence which extends halfway toward the adjacent boreholes (figure 1a). If the grid is not uniform the technique can still be used to form rectangular blocks of varying sizes around each sample point (see figure 1b).

POLYGONAL BLOCKS

A popular method of constructing blocks is commonly known as 'polygons'. The technique consists of constructing perpendiculars at the mid points between holes to form the boundaries of a polygon (see figure 1c). For a square grid the polygons would be squares as in figure 1a.

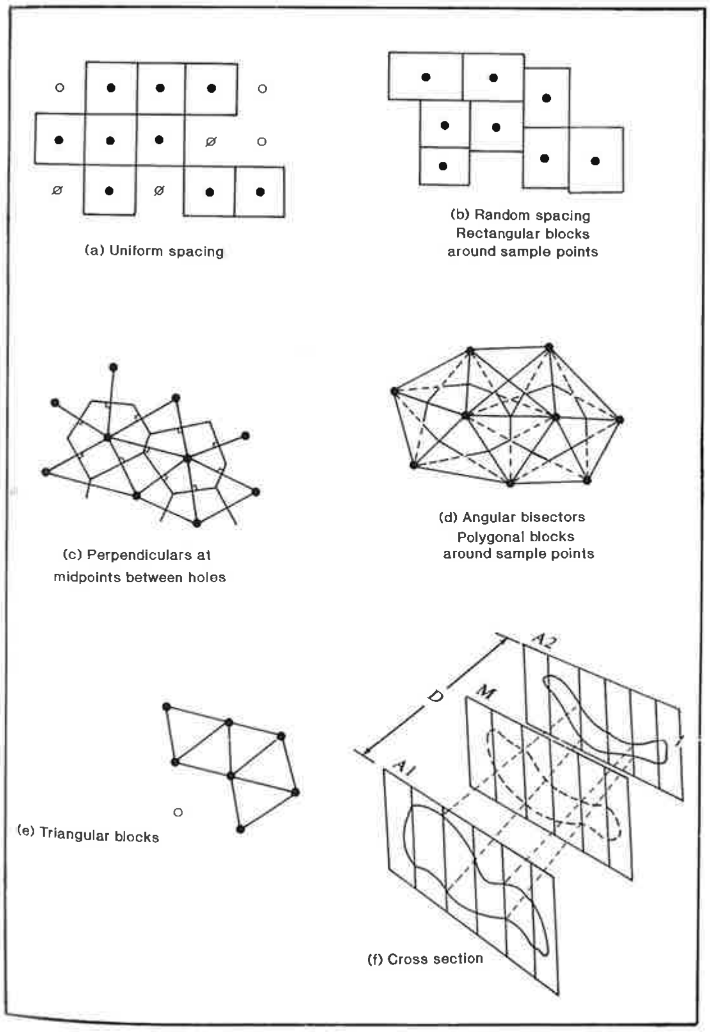


Figure 1. Geometric methods of ore reserve estimation

A variation of this technique uses the bisectors of the angles formed on the other corners of the triangles formed by lines connecting a hole and its adjacent holes (see figure 1d).

TRIANGULAR BLOCKS

Where drilling has been undertaken on an equilateral triangular grid, triangular blocks can be constructed with a sample point being located at the apex of each corner. The triangular block is then given a value found by averaging the three surrounding bores. Where the triangles vary from the equilateral condition, a correction can be made by adjusting borehole weights proportionately to the angular variation from a 60 degree angle (see figure 1e).

CROSS SECTIONS

Although this method is not generally used for coal deposits it may be useful where rows of holes have been drilled across a deposit and the distance between the rows is considerably larger than the distance between holes within a row (see figure 1f).

GENERAL PROPERTIES

The major problem with geometric methods is that they model the deposit as a series of discontinuous blocks. This is especially important where the blocks are large in size in comparison to the area being modeled. In these circumstances it is possible to give undue weight to extreme data points and effectively bias the estimate.

Whether or not geometric methods provide a biased reserve estimate is heavily dependent on the nature of the drilling pattern. A properly planned drilling programme with representative sampling should not introduce significant bias. Geometric methods are not recommended for deposits with poorly planned sampling patterns.

Geometric methods are not particularly efficient. This results in part because a block of coal is assigned the value of an individual borehole. It is important to note that it is difficult in many cases for a small sample, such as a borehole, to accurately sample a block of coal. Assigning the value of such a small sample to a large block of coal multiplies the effect of the sampling error associated with the borehole.

Geometric methods do not follow trends in the data beyond the range of the data points. During extrapolation, geometric techniques generally assign to an extrapolated area the value of the closest sample point.

With the exception of averaging techniques such as the triangular block method, geometric methods always honour borehole data.

The chief advantage of geometric methods is that they are very easy to implement and to understand. This in part accounts for their popularity and it is likely that they will continue to be used by geologists in the future.

DISTANCE WEIGHTING METHODS

Most practical methods of modelling a coal deposit involve estimating grid values by multiplying the nearest hole values by weights which are a function of the distance from the point to be estimated to these surrounding data points. These techniques can be grouped collectively under the title of distance weighting methods.

A large number of commercial modelling packages employ distance weighting methods of varying design. It is not possible for proprietary reasons to go into any detail of their construction, however there are several general techniques on which many commercial systems are based.

INVERSE DISTANCE METHODS

The inverse distance method of interpolation operates in the following manner:

1. A limited number of data points which surround the point to be estimated are selected
2. Weights are derived for each data point by determining the inverse of the distance separating the data point from the point to be estimated
3. Each data point value is then multiplied by its relevant weight
4. The products of each data point value and its inverse distance weight are then summed
5. This sum is then divided by the sum of all of the weights to arrive at an estimated value.

With inverse distance methods the weights can be varied by using distance squared or cubed, or by weighting using functions of higher powers. In general, the higher the power the less effect more distance data points have on the point to be estimated.

The weighting technique is very popular for modelling analytical data which has a relatively small zone of influence. The contours produced by the method are characterised by closures around data points.

Because most distance weighting methods consider only a limited number of data points surrounding the point to be estimated they can be classified as moving average techniques. An example of a computer programme which implements an inverse distance algorithm can be found in Davis (1973).

GENERAL PROPERTIES

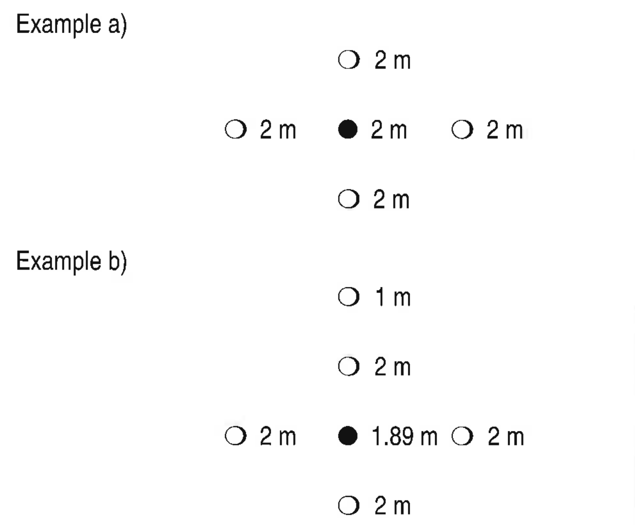
The inverse distance technique is a biased estimator where data points are clustered. In these circumstances it is incapable of giving the correct wieghting to the data points. In order to overcome these problems most commercial systems employ a directional searching technique. Generally an octant search (ie in eight segments) is undertaken around the point to be estimated in order to ensure a balanced representation from all directions. In addition to the search direction the geologist may also have control over the search radius. This allows the exclusion of distant data points where it is felt that they should not have an influence on the point to be estimated. Figure 2 shows how the inclusion or exclusion of data points can affect interpolated values when using an inverse distance weighting method.

Distance weighting methods tend to be more efficient than geometric methods. This is due in part to the fact that they are a moving average technique which places limits on the influence of any single data point. How efficient they are is dependent on the effectiveness of the searching routines.

The surfaces generated by inverse distance methods are generally continuous and honour the original data. Exceptions can occur where the searching routine excludes bores which should in fact have an influence on the point to be estimated. In these circumstances discontinuities can arise.

Inverse distance methods generally do not follow trends beyond the range of the data and it is possible to obtain contour closures which are not around data points.

Inverse distance methods are very easy to implement and do not involve excessive amounts of computer time.



In example a) the method of inverse distance has been used to interpolate thickness values to a central point. The surrounding data all have the value of 2 metres. Therefore, a value of 2 metres is interpolated for the central point.

In example b) one additional point having a thickness of one metre has been added to the data. Even though this data point is effectively masked from the central point, it nevertheless reduces the interpolated value from 2 metres to 1.89 metres.

Figure 2. Inverse distance interpolation — effect of addition of extra data

KRIGING

Kriging is a moving average technique which, in addition to providing estimates of unknown points, also allows an assessment to be made of the error associated with that estimate. In principle this allows a geologist to place confidence limits on a reserve estimate. Kriging comes under a broader heading of methods which are known as geostatistical techniques. An excellent description of geostatistical procedures can be found in David (1977).

Before kriging can be performed it is necessary to describe the relationship between data points. It should be apparent that the closer that two sample points are to each other the more likely they are to have similar values. As the distance between data points increases, a point is reached where there is no relationship between the data points. The distance at which this occurs is known as the range. This concept can be considered as the zone of influence of a data point.

The zone of influence of a sample can be displayed graphically in a diagram known as the variogram which is essentially the plot of the interrelationship between pairs of data points at various distances.

The information contained within the variogram is then used to derive weights to be used on each data point to arrive at an estimated value for each grid point.

The procedure described above is generally known as simple kriging and is only suitable where there is no significant trend in the data.

GENERAL PROPERTIES

Under certain conditions kriging can be shown to be the best linear interpolation method. A major advantage of the method is that it is an unbiased estimator. This is achieved by placing a constraint on the weights so that the sum of the weights are equal to one. As a result, clustering of data points does not present a problem to the technique as it ensures that the correct weighting is given to each data point.

The surfaces generated by kriging are continuous and can be made to honour the original data points.

If the data contains a significant trend then a technique known as universal kriging should be used. Kriging can be used to extrapolate beyond the data but as the extrapolated distance exceeds the 'range' (ie zone of influence) an extrapolated value approaches the average of the data points.

The method is quite difficult to implement and requires considerable expertise on the part of the geologist. The technique is also demanding in its use of computer processing time.

TREND SURFACE ANALYSIS TECHNIQUES

Any assessment of contoured map data will disclose two components to the variation observed. These are a regional component (or regional trend) and a local component. The local irregularities can often obscure the regional trend in the data. Trend surface analysis is a method for separating out a regional trend from the local irregularities.

The technique involves fitting a mathematical function (or surface) to the data in order to model the regional trends. Two types of functions are generally used — polynomials and fourier series. Descriptions of trend surface analysis techniques can be found in Davis (1973) and Mullard (1984).

The simplest type of trend surface in three dimensional space is a plane.

The linear trend surface of this type has an equation of the form:

$$y = a + b \times E + c \times N$$

where y = the variable of interest

a = a constant

b = a constant east–west component

c = a constant north–south component

E = map easting

N = map northing

In order to find the appropriate trend surface, it is necessary to find values for the three unknowns a, b and c.

If necessary, more complicated surfaces can be fitted to the data by using higher degree polynomials.

Once a trend surface equation has been found, it is a relatively simple matter to generate as many points as required to form a basis for contouring the component surface.

Trend surface models are not normally used to calculate coal reserve estimates. However, there is nothing inherently wrong with using a trend surface to derive a global reserve estimate as the surface generated is in fact an average surface through the data points.

GENERAL PROPERTIES

Polynomial trend surface methods fit a surface to the data which minimises the deviation of the data points from the surface to be generated.

The technique is moderately biased. Extreme data values can have an excessive influence on the shape of the surface. As a result, it may be necessary to take action to limit the effect of extreme data values.

Care should be taken to ensure that an adequate number of data points cover the area of interest. In general the data should cover an area in excess of the size of the area to be modeled. If this is not done, there is virtually no control on the form of the trend surface near the edges of the model. This creates edge effects, where extrapolated values may reach ridiculous levels. The distribution of data points also has a pronounced effect on the model. Data where possible should be evenly distributed.

The surface generated by trend surface techniques is continuous and does not honour the original data.

The contours generated by the method have a very mathematical appearance. The technique is particularly suited to data values which contain a large trend component such as structure and isopach data.

The technique is relatively easy to implement and understand. Its demands on geologist's and computer time are very low.

COMPUTER INTENSIVE METHODS

Computer intensive statistical methods are not an interpolation or modelling method in their own right. They are used in conjunction with standard methods to assist geologists in developing better models. They can also be used to quantify how confident one should be about a particular reserve estimate.

Modelling and reserve estimation procedures can be regarded as relatively complex statistical methods. A reserve estimate derived by the application of these methods can be considered a statistical property of a coal deposit, similar in a way to an average. Because of their complex nature, modelling and reserve estimation procedures are currently beyond exact mathematical analysis. It is for this reason that it is generally not possible to place confidence estimates on reserve estimates.

To understand why most modelling methods are currently beyond exact mathematical analysis, it is necessary to realise that the majority of statistical methods in use today were developed before the advent of the computer. At that time it was very important to minimise the computational effort involved. As a result, the methods developed tended to concentrate on the properties of a limited number of probability distributions. These properties were derived by the use of simplified formulas which gave values for statistics such as the average, standard deviation and correlation coefficients. By concentrating on a limited number of probability distributions, certain unverifiable assumptions about the data needed to be made before statistical analysis could begin. These assumptions often included the concept that the data conforms to a normal distribution where it is assumed that errors in the derived data are scattered symmetrically about the true value. Geological data however almost never follows one of the common probability distributions and as a consequence the results obtained can only approximate the real values.

The advent of the computers resulted in a fundamental change in the way data are processed. Computation became fast and cheap and in the last few years, new statistical methods have been developed which make full use of the computer's capabilities. These new methods require only minimal assumptions to be made about the data and can be used for small as well as large data sets. They belong to a class of statistics known as non-parasitic or distribution-free procedures.

These new statistical methods allow the assessment of complex statistics by means of numerical methods which may require the expenditure of millions of calculations in the analysis of only a few data points. Efron (1979) gives an excellent review of some of these new statistical procedures. One of the main common computer intensive techniques is known as cross-validation.

CROSS-VALIDATION TECHNIQUES

How does one go about selecting the best modelling technique for a particular deposit? If one was applying the scientific method to the problem then the process might be as follows:.

1. Examine the data and form a hypothesis as to the nature of underlying geological variability
2. Having a tentative notion as to what is required, a modelling technique is chosen which best fits the available data and the perceived nature of the geology
3. The model's predictive ability is tested against a fresh sample drawn from the same deposit.

The above procedure works very well where it is possible to go out and obtain a fresh independent sample. However, the high cost of exploration programmes in most cases would prohibit such a verification procedure.

Fortunately, there is an alternative. Cross-validatory choice and assessment procedure is the simple concept of setting aside part of the data without any examination. The remaining data is then used to develop the modelling procedure and the set aside data is used to provide an unbiased assessment of the efficiency of the modelling technique.

The size of the set aside sample can be as small or large as required. In addition, the procedure can be repeated any number of times. Several authors proposed setting aside an individual sample, optimising for the remaining samples, and then testing the model using the set aside value. This procedure can be repeated for every sample. Although computationally difficult, this procedure effectively squeezes the data dry and qualifies the method as a computer intensive procedure.

David (1977) advocated the use of cross-validation techniques to select the best variogram model for a deposit. There is, however, no reason why cross-validation techniques could not be applied more generally in the selection of modelling techniques and modelling parameters.

GENERAL PROPERTIES

Computer intensive methods are characterised by the enormous computational effort involved in their implementation. This is a major impediment to their wide acceptance but the continuing trend towards computers with increased processing power is expected to reduce this problem to manageable terms.

Computer intensive techniques offer enormous advantages. They are multi-purpose tools which are reliable under wide general conditions. They can also be used in conjunction with established modelling procedures.

CONCLUSIONS

A commonly asked question is 'which of the available modelling methods gives the best results?'.

Although it may be possible to give a very general answer to this question, it could be argued that the approach behind this question is fundamentally wrong.

The choice of a modelling procedure should only be undertaken after the geologist has carefully considered the options available. The geologist should be fully familiar with the operation of any modelling system he is planning to use. He should also monitor and check the modelling procedure for any unexpected complications.

The process of obtaining a valid geological model is not just a matter of looking up a formula. The more geology that the geologist can input into the model the better the estimate is likely to be. It is unfortunate that the majority of modelling packages on the market tend to treat geology as if it were a matter of defining mathematical functions.

The trend in recent years has been for the geologist to collect large data sets. As a result, the data handling capabilities of the computer are rapidly becoming indispensable.

If geologists are to avoid taking a black box approach to modelling, then it is essential that they take the time to understand the computer techniques that they are using.

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GUIDE TO THE SYSTEMATIC EVALUATION OF OPENCUT COAL RESERVES

B. Mullard; B. Preston; R. Davis; J. Beckett & C.R. Weber

INTRODUCTION

General concepts for reporting coal resources were established with the publication of the 'Australian Code for Reporting Identified Coal Resources and Reserves' in February 1986. This Code was deliberately broad in nature to accommodate the wide range of coal deposits — in terms of rank, quality and geological environments — that are present in Australia.

This Guide to the Systematic Evaluation of Opencut Coal Reserves refers to those Indicated and Measured Resources that have been identified as Opencut Coal Reserves (refer figure 1).

The Guide details the assessment of opencut coal reserves with regard to levels of reliability and specifically relates to:

1) The type of deposit
2) The mine planning phases from conceptual to operational
3) Prime defining factors
4) The exploration/evaluation procedures and checklist
5) The exploration strategy
6) Opencut coal reserves definition and reporting.

1 TYPE OF DEPOSIT

Although each opencut coal deposit must be evaluated independently there are three basic deposit types which are representative of Australian shallow coal reserves (figure 2). These were identified by the Warren Centre study on advanced surface mining technology (1985) and include both current opencut coal mine and potential opencut coal reserves.

1.1 TYPE 1 SINGLE SEAM

This type is represented by a small number of thick seams with shallow dip. Structural disturbances are minor and allow long mineable strike lengths. Topography is relatively flat. Most of the Bowen Basin deposits and some of Hunter Valley deposits are of this type.

1.2 TYPE 2 MULTIPLE SEAM

This type has multiple seams, generally three or more, with dips ranging up to 20 degrees (1 in 5 grade).

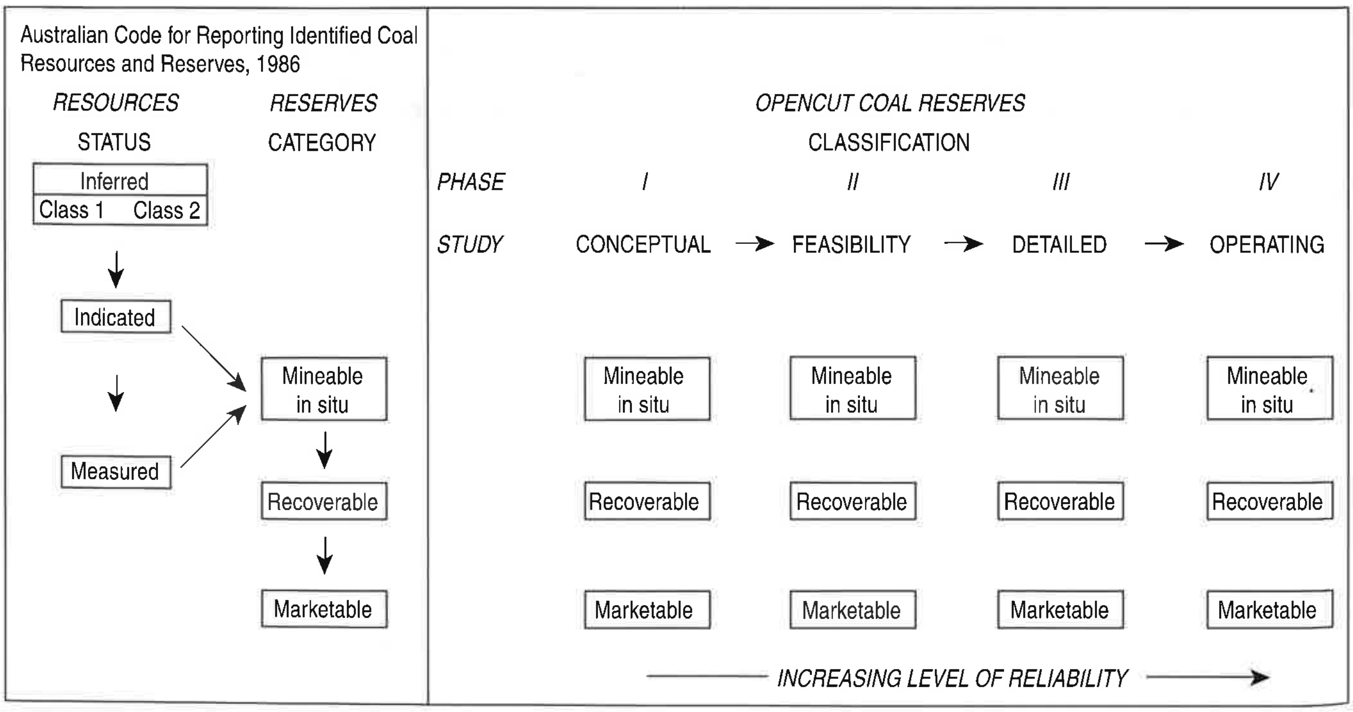

Figure 1. Opencut coal reserve classification

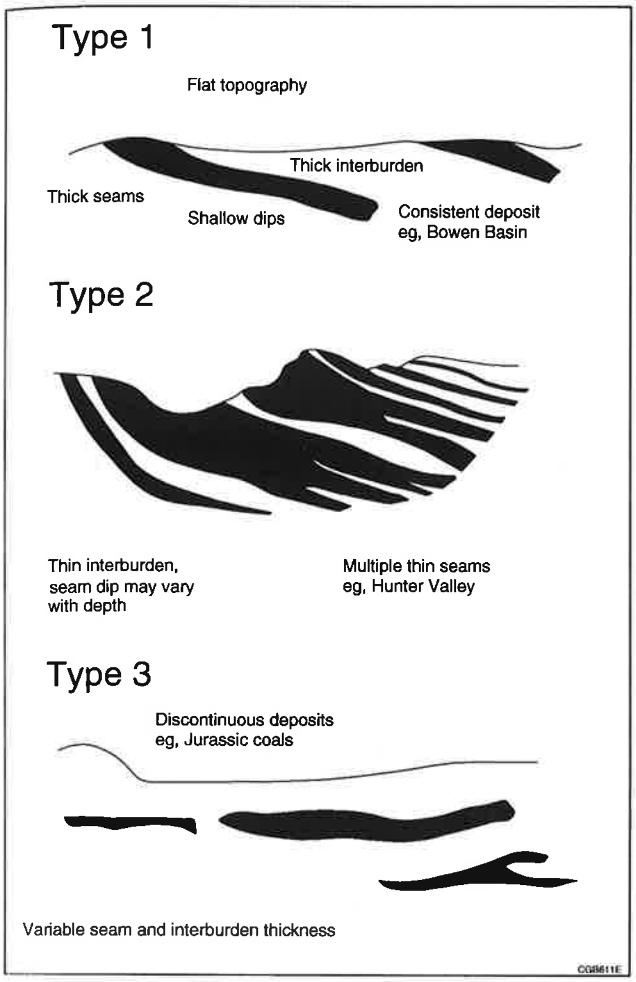

Figure 2. Australian shallow coal — deposit types

Type	*Dip (°)*	*Seam Thickness*	*No of Seams*	*Geological Structure*
1	*Low 3-10*	*<10 m*	*1-3*	*Low Disturbance*
2	*Steep*	*<5 m*	*>3*	*Moderate Disturbance*
3	*Flat*	*>10 m*	*1*	*Insignificant*

Seam and interburden thickness are less than in Type 1. Lateral changes in thickness and lithology occur rapidly and seam splitting is common. Mineable strike length is constrained by seam geometry as well as environmental and lease factors. Topography is usually undulating.

Most of the Hunter Valley and Gunnedah Basin deposits are of this type.

1.3 TYPE 3 DISCONTINUOUS THICK SEAMS

These deposits have very thick, shallow dipping seams. The seams are often banded and they may be limited laterally by deterioration of coal quality. Mineable areas are irregular and discontinuous. The Jurassic coals of the Surat Basin are an example of this type.

2 RELIABILITY OF RESERVES EVALUATION AND RELATIONSHIP TO MINE PLANNING PHASES

The reliability or degree of confidence of an opencut reserve evaluation increases in accordance with the phases of mine planning. These phases in order of increasing detail are:

Phase 1 – Conceptual
Phase 2 – Feasibility
Phase 3 – Detailed
Phase 4 – Operations.

The fundamental objective of each phase is the comparison of mining cost against product value.

The level of reliability and detail required by mine planning and mine design at each phase will determine the requirements of the exploration program (refer figure 3).

2.1 PHASE 1 CONCEPTUAL

This level of study is used for resource identification and ranking of the reserve in the market place. Obvious potential warrants further assessment. If the project is marginal for any reason, further assessment is postponed or the deposit is rejected. Market status is based on product type, geographic location and approximate cost of standard mining methods and transport.

Market prices will partly determine the minimum annual tonnage required and maximum transport distance to be viable. Any reserve not meeting this criteria will be rejected.

If the reserve requires establishment of independent mining facilities, the marketable reserves must sustain a mine life of at least 20 years.

Mining methods are based on deposit type.

2.2 PHASE 2 FEASIBILITY

This level of study is used for market identification and competitor analysis and is based on product specification and mining costs.

Mine design based on the selected mining method requires more details of the geometry of the reserve. Mine scheduling is required for a 20 year life of mine, in increments of 5 years.

2.3 PHASE 3 DETAILED

This level of study is used for funding the project. If competitor analysis indicates that the project is strongly competitive it will require detailed mine planning.

Mine scheduling should be developed to a 20 year life of mine and include details of each year of the first 5 year developmental plan. Details of overburden characteristics and coal handling facilities, and detailed quality assessment of a bulk sample, are required. A trial mining operation and a pilot plant may be required, especially if a new product/area is proposed to be developed.

2.4 PHASE 4 OPERATIONS

This assessment is used for forecasting operating and developmental plan budgets.

PHASE	I	II	III	IV
PROJECT STUDY	CONCEPTUAL	FEASIBILITY	DETAILED	OPERATING
Objective	Dependent on deposit type General market potential Product type Minimum annual tonnage Maximum transport distance	Competitor analysis Market identification	Project funding Market contracts	Budget forecasting and monitoring
Exploration	Establish minimum marketable reserves required for project. Establish approximate resource limits by slimcore drilling	Define geometry of reserves and quality limits by large diameter drilling Establish overburden to coal ratios	Define product quality and handling specifications Establish overburden characteristics	Oxidation limit drilling Monitor variability of physical parameters
Mine Planning	Review appropriate mine types and overburden removal methods	Sensitivity analysis of possible mining methods	Bulk sample Trial mine	Production scheduling and assessment
Mine Scheduling	Nil	20 year schedule 5 year increments	Yearly increments of next five years' production requirements	Details of requirements for next year's production

Figure 3. Reliability of opencut coal reserve assessment — relationship to mine planning phases

The operating mine plan requires full definition of the reserve for the current year's operating plan and some detail of the 5 year developmental plan. This necessitates regular updates of detailed structural and quality information on the coal deposit through inpit mapping and close spaced (<250 m grid) pre-production drilling. Quality control of run-of-mine ash and product coal (yield and ash) should include reconciliation of actual against predicted results and dictate any ameliorative measures to be taken. A similar reconciliation should apply to the coal and overburden quantities mined.

3 PRIME DEFINING FACTORS

The prime defining factors in the evaluation of open cut reserves through these phases are:

Geological continuity and quality
Drilling pattern
Mining method, including overburden removal.

The type of coal deposit (figure 2) determines the emphasis required in each of these prime defining phases described below.

3.1 GEOLOGICAL CONTINUITY AND QUALITY

Definition of geological conditions and structure is essential as these factors will dictate the coal mining method used. They include:

Faulting
Intrusions
Seam splitting
Variability of seam quality.

Knowledge of the structural assessment of other operating mines in close proximity, or in similar geological environments, is essential. With particular regard to Type 2 deposits (Hunter Valley and Gunnedah Basin), geophysical surveys may be necessary. For all deposit types, mapping should be intensified from regional to local area definition.

3.2 DRILLING PATTERN

The drillhole pattern should ideally be orientated on a north–south grid so as to enable a systematic and sequential drilling order to be used. Drillhole spacing will progressively decrease from the conceptual stage to commencement of operations (refer 4.5 Slimcore Drilling).

Deposit Type 1. A single seam will require a drilling pattern preferably based on a north–south grid. Such a grid will still enable section lines perpendicular to strike and tied with base lines to be constructed. Seam characteristics have only slight variation and drill spacing is regular.

A relatively constant weathering profile is characteristic of the flat topography and limits of seam oxidation are usually regular. Drilling to test oxidation will only be required for the first few mineable seams and will be located on grid lines.

Deposit Type 2. Multiple seams will require a similar grid pattern, but with more section lines and closer drillhole spacing to assess the greater variability of the seams. The undulating topography and variable zones of weathering require detailed drilling to determine oxidation limits.

The oxidation drilling programs for each mineable seam may follow along the line of subcrop, but should still be grid orientated.

Deposit Type 3. Thick discontinuous seams will require a similar grid pattern but drillhole spacing will be influenced by seam continuity.

3.3 MINING METHODS

Overburden removal constitutes the largest and most limiting cost component in opencut mining. Mining methods are determined by a combination of factors, viz

- Extent, number, thickness and spacing of seams
- Dip of seams.

The number and disposition of seams dictates the overburden/coal ratio for the deposit, as well as the mining section and the stripping capacity for target tonnages. In addition, these factors prescribe the equipment capable of handling the various interburden and parting materials.

The degree of seam dip and the disposition of the seams are the most significant factor in determining the point at which the dragline method is replaced by a multistage operation with pre-stripping.

The deposit type determines the emphasis required on each of the prime defining factors, particularly the definition of geological structure and type of drilling pattern.

4 EXPLORATION PROCEDURES AND CHECKLIST

In order to achieve definition of the primary factors that are required to evaluate an open cut reserve (section 3.0), a checklist of procedures and evaluation methods can be used.

Figure 4 illustrates the primary factors, the checklist of procedures and the general emphasis required for each phase of mine planning.

These procedures and methods are outlined below.

4.1 LITERATURE SURVEY

Prior to any exploratory work, a review of all available information about the proposed area is essential. The objective of this review is to:

- Establish the geological setting of the area
- Collate data on any previous mining activities
- Establish land ownership and titles
- Delineate cultural and cadastral features, including survey control data
- Collate existing coal quality information.

This survey should include the generation of base maps and plans at a scale appropriate to the level of detail required.

4.2 SURVEYS

Aerial photography is necessary to establish topographic control, locate property and cultural features and to interpret geological structures during Stage 1 assessment. Regional (government) air photographs are generally suitable for geological assessment but current (proprietary) coverage may be required to accurately establish property and cultural features.

Cadastral surveys are necessary to locate property boundaries and for drill site location and topographic control.

4.3 REGIONAL GEOLOGICAL MAPPING

The literature survey will assist in defining the level of detail required in field mapping. Field mapping may include the tracing of marker beds associated with coal seams, measuring stratigraphic sections, locating faults and surface indications of igneous or volcanic activity and any other feature which may affect coal seam continuity or development. In areas of poor outcrop trenches or costeans may be necessary. Regional mapping is essential during the

PHASE	*I*	*II*	*III*	*IV*
PROJECT STUDY	**CONCEPTUAL**	**FEASIBILITY**	**DETAILED**	**OPERATING**
Primary Factors to be defined	Geological continuity, drilling pattern, mining parameters (see three detailed deposit types)			
Checklist				
Literature Survey				
Surveys	Photography	Cadastral		
Geological Mapping				
Geophysical Surveys	Aeromagnetic	Seismic		
Slim Core Drilling		Reduced hole spacing →		
Large Diameter Drilling				
Open Hole Drilling				
LOX Line Drilling				
Coal Quality	Coal type	Seam quality	Product specification	
Geotechnical		Indicative	Detailed	
Groundwater		Indicative	Detailed	
Deposit Modelling	Increasing detail →			
Environmental Assessment				

Figure 4. Factors to define opencut resources and reserves

conceptual stage as it provides the framework for successive stages of assessment.

4.4 GEOPHYSICAL SURVEYS

Regional geophysical surveys of the area are required to delineate a variety of geological hazards which must be defined in the early stages of assessment of reserve recovery and the proposed mine plan. Air or ground magnetic surveys in particular are necessary to help define the nature and extent of any igneous or volcanic activity. Seismic reflection surveys are particularly necessary where early drilling and/or geological mapping has identified potential fault zones or trends.

Downhole geophysical logging — see sections 4.5 (Slimcore Drilling) and 4.10 (Geotechnical Analysis) for downhole geophysical logging requirements.

4.5 SLIM CORE DRILLING

Slim core hole spacing should decrease from about 1 km for conceptual studies to a maximum of 500 m for detailed studies for all deposit types. Hole spacing should decrease where significant quality changes occur. All core holes should be geophysically logged to allow qualitative comparison of core loss, coal quality and rock types and strength with adjacent non-cored open holes. Slim core can be used for coal quality analysis, structural and geotechnical evaluation and coal seam correlation. For adequate sample volume core size should not be less that 65 mm in diameter (HQ).

4.6 LARGE DIAMETER DRILLING

Large diameter cores provide samples sufficient for detailed washability assessment which is essential for preparation of plant design. Nominal diameter of core is 200 mm.

4.7 OPEN HOLE DRILLING

Open hole drilling should be employed after slim core drilling during the detailed phases to bring overall hole spacing down to 250 m to ensure reliable mine scheduling. All open holes should be geophysically logged to enable comparison with the cored holes. Closer spaced drilling may be necessary in structurally complex deposits.

4.8 LIMIT OF OXIDATION (LOX) LINE DRILLING

During the detailed and operating stages, definition of the limits of oxidation can be undertaken by open hole drilling using chip samples. For deposit types requiring this type of testing, drill-line spacing should be no more than 100 m. The hole spacing along lines depends entirely on the disposition and thickness of the seams. Samples of cuttings can be analysed for crucible swell, inherent moisture and specific energy. Supervision is critical to ensure accurate sampling procedure.

4.9 COAL QUALITY

Different analytical programs will be required at each phase of deposit assessment. At the conceptual phase with core samples at 1 km centres, detailed ply by ply analysis including washability should be carried out to delineate the general coal type, rank and likely product range (Australian Standard 2519-1982). Such detailed ply by ply sampling will facilitate seam correlation and the determination of potential working sections.

At the feasibility/detailed phase, slim core drilling will be at 500 m spacing or less. If appropriate, the emphasis on ply analysis can be shifted to the evaluation of working sections. Float/sink analysis on working sections can simulate a likely market product and indicate the coking/thermal properties of the coals.

During the feasibility/detailed phase, large diameter (200 mm) drilling will provide sufficient sample volume for size analysis and preparation plant design and hence more accurate determination of product coal yield. Bulk samples obtained from test pits, costeaning or shafts may be necessary.

At the detailed phase, product specification can be formulated effectively.

4.10 GEOTECHNICAL ANALYSIS

Geotechnical studies involve rock strength and degradation characteristics. These relate to high wall/spoil pile stability, and assessment of blasting/ripping characteristics.

During the slim core drilling programs, rock properties such as fracture type and spacing and hardness should be systematically recorded and if necessary the Rock Quality Designation (RQD), an index of general rock strength, determined.

Core samples covering the full range of rock types and seam overburden/midburden ranges should be subjected to compressive and tensile strength tests and their elastic properties determined. Point load tests can be incorporated into the field logging of core. Slake durability testing will be necessary to establish the susceptibility of rock types to degradation.

Borehole geophysics, particularly sonic, neutron and gamma logs, can be correlated with the physical testing of core samples. These tools respond to density, fracture spacing, rock strength and porosity. The cored hole test results and geophysical logs can then both be applied to the closely spaced open hole drilling of the detailed/operations phases of mine planning.

4.11 GROUND WATER

Coal seams are generally the main aquifers for all deposit types. Groundwater studies are essential and influence:-

- Highwall and spoil pile stability and hence affect reserve recovery

- Blasting requirements
- Mine equipment, operations and preparation plant requirements
- Environmental treatment and containment.

During the feasibility phase, drill holes may be left open for ground water sampling purposes. By the detailed mine planning phase, specific ground water studies must be completed. These will involve the determination of the aquifers, their permeability, hydraulic conductivities and water quality.

4.12 COMPUTER PROCESSING AND DEPOSIT MODELLING

Computer processing of exploration data is necessary for large projects, particularly Type 2 deposits where multiple seams are involved. Initial data that can be input includes survey, lithological, geophysical and analytical data.

Such input enables production of graphics, eg sections for correlation purposes, and development of models for seam attributes both physical and analytical. It also enables facies analysis of sediments and statistical summaries of coal quality parameters and hence development of product specifications.

Proprietary software modelling techniques usually involve the generation of regularly spaced grids of values based on original borehole data. When computer modelling the deposit, the geologist must have the freedom to place his/her interpretation on seam structure and apply constraints both physical and qualitative.

4.13 ENVIRONMENTAL CONSTRAINTS

The likely impacts of any mining operation on the existing environment must be identified at the earliest conceptual stage. Such impacts predominantly involve water quality, dust, noise and infrastructure requirements. Those areas where other land uses are potentially incompatible must be identified. Environmental impacts of exploration activities must be considered and ameliorative methods adopted.

All aspects of the environment must be assessed progressively from the conceptual to the operational phase.

5 EXPLORATION STRATEGY

The overall goal of exploration is to evaluate effectively the opencut reserves and this depends solely on the exploration strategy. To determine the appropriate exploration strategy the type of deposit (refer 1.0 above) and phase of mine planning (refer 2.0 above) must be established. This enables the prime defining parameters (refer 3.0 above) to be quantified and exploration methods (refer 4.0 above) suitable for the deposit put in place. Note that the results of each stage of exploration will often determine particular needs for successive stages. Using this philosophy, general guidelines can be outlined for each deposit type and mine planning phase in terms of the three defining factors. These guidelines are summarised in figures 5,6,7 and are discussed below.

5.1 TYPE 1 DEPOSIT — SINGLE SEAM EXPLORATION STRATEGY (figure 5)

Literature studies and regional mapping are essential at the conceptual phase. Drill hole spacing should be in the order of 1 km to gauge broad consistency of seam in terms of physical characteristics and coal type. Types of overburden should be described and the likely impacts on mining assessed. Similarly, environmental constraints affecting the reserves should be identified.

PHASE		*I*	*II*	*III*	*IV*
PROJECT STUDY	**BASIC PARAMETERS OF DEPOSIT TYPE**	**CONCEPTUAL**	**FEASIBILITY**	**DETAILED**	**OPERATING**
Geological Continuity	Low disturbance Low number of seams	Review regional maps	Assess adjacent operations	Confirm regional trends of physical characteristics of deposit within mine design	Define, map and assess impact of any discontinuity or trend encountered in mine
Drilling Pattern	Section lines along and across strike	Regular spaced regional drilling pattern No greater than 1 km spacing	Drilling spacing and extent to establish limits of reserves to required confidence level No greater than 500 m spacing	Determine depth and variability of oxidation line Close-up drilling, spacing no greater than 250 m	Define limits of oxidation for full seam oxidised and unaffected with closely spaced drilling across strike of subcrop
Mining Method	Dragline	Type of overburden Check for overlying basalt or Tertiary sandstone cover	Definition of overburden thickness Determine overburden to coal ratios and mining limits Indicative overburden characteristics	Definition of overburden characteristics Trial mining	Production recording and assessment Assess and trial other overburden removal methods

Figure 5. Deposit type 1 — single seam

Feasibility studies require the cored drill hole spacing to be reduced to a maximum of a 500 m, preferably on a north–south oriented grid. Mining limits and coal quality trends can be delineated and an indicative geotechnical and hydrology assessment made. Large diameter drilling may be necessary to confirm coal washability, product yields and preliminary preparation plant concepts.

Detailed studies call for the delineation of the oxidation line as well as large diameter drilling and bulk samples to determine product specification and final preparation plant design. Drillhole spacing should be reduced to a 250 m grid.

The operating phase calls for the continued detailed delineation of the limits of oxidation and reconciliation of predicted against actual reserves mined. Monitoring of the physical parameters of the deposit and coal quality is ongoing (refer 2.4 Phase 4 Operations).

Through all phases the computer model is progressively updated.

5.2 TYPE 2 DEPOSIT — MULTIPLE SEAMS EXPLORATION STRATEGY (figure 6)

As in the case of Type 1 deposits, literature studies and regional mapping together with assessment of adjacent operations are essential at the conceptual phase. Drillhole spacing should ideally be on a 1 km grid basis and broadly define seam quality, overburden/midburden type and hence impact on mining method. Environmental issues should be identified.

At the feasibility phase, cored drillhole spacing should not exceed a 500 m grid and may need to be less in order to define major structural features or seam splitting characteristics. At this phase geophysical studies may be needed to define faulting and intrusions affecting the mine plan. Indicative geotechnical and hydrology assessments can be made. Large diameter drilling is necessary to outline coal washability, likely product types and preliminary preparation plant design.

The detailed phase requires drilling on a 250 m grid basis; usually open holes geophysically logged providing the necessary data. All geotechnical and hydrological parameters are assessed. Large diameter drilling and/or test pits are necessary for preparation plant design and product specification. Limits of seam oxidation can be determined usually with open hole drilling at a line spacing of about 100 m across the subcrop. Holes drilled along these lines may vary considerably in spacing depending on the number and thickness of seams to be explored.

The operation phase requires ongoing determination of seam oxidation limits if required and, obviously, reconciliation of actual against predicted reserves. The geological quality and structural database and model require continual upgrading.

5.3 TYPE 3 DEPOSIT — THICK DISCONTINUOUS SEAMS EXPLORATION STRATEGY (figure 7)

As in Types 1 and 2 deposits, literature and mapping studies are mandatory for these deposits in the conceptual phase. Drilling should be on a grid basis to suit the continuity of the seams and likely variability and structure.

The feasibility phase requires closer spaced drilling to define the limits of the reserves and cored drill spacing should be no greater than 500 m. A seam development model should be developed at this stage. All geotechnical and hydrology parameters need to be assessed and large diameter drilling will

PHASE		*I*	*II*	*III*	*IV*
PROJECT STUDY	**BASIC PARAMETERS OF DEPOSIT TYPE**	**CONCEPTUAL**	**FEASIBILITY**	**DETAILED**	**OPERATING**
Geological Continuity	Moderate disturbance Faulting and splitting Variable quality	Review regional and local maps Assess adjacent operations	Define faults and intrusions Conduct field mapping Conduct geophysical surveys	Incorporate drilling results into geological model Establish physical parameter databases	Map exposures and discontinuities Upgrade structural, geological and quality databases
Drilling Pattern	Section lines LOX drilling	Regular, regional drilling programme generally at no greater than 1 km spacing	Drilling pattern and density to define limits of reserve and structural discontinuities to required level of confidence, generally to no greater than 500 m spacing	Define structure and physical parameters of reserve Close-up drilling, spacing no greater than 250 m Determine oxidation lines of seam subcrops	Incorporate refined geological model into mine plan Define full seam oxidation and unweathered full seam subcrop lines
Mining Method	Combination — dragline and/or truck and shovel	Overburden and interburden lithologies Interburden thicknesses	Definition of seam splits and spacing Cumulative overburden to coal ratios Indicative overburden characteristics	Definition of interburden and overburden characteristics Trial mining	Production recording Assessment of methods and efficiency of interburden removal

Figure 6. Deposit type 2 — multiple seams

PHASE		I	II	III	IV
PROJECT STUDY	BASIC PARAMETERS OF DEPOSIT TYPE	CONCEPTUAL	FEASIBILITY	DETAILED	OPERATING
Geological Continuity	Discontinuous Variable quality High ash–high volatile	Review similar operations Review regional geology Assess seam variability	Determine seam development model Determine overall quality limits	Define seam physical characteristics and quality models	Refine model and assess implications with production data
Drilling Pattern	Grid	Regular drilling grid at spacing determined by assessment of continuity of seams	Drilling extent to cover limits of reserves and define discontinuities to required confidence level	Increase level of confidence of physical parameters and quality variation within mine plan area	Review and update geological models with production data
Mining Method	Dragline/bucketwheel	Type of overburden Thickness of overburden and interburden	Determine overburden characteristics Determine overburden to coal ratios	Define overburden characteristics Trial mining	Monitor efficiency of mining method Trial alternate overburden removal methods

Figure 7. Deposit type 3 — thick discontinuous seams

be necessary for coal quality studies. The detailed phase will again rely on close spaced grid drilling (about 250 m) or as required to define seam quality and physical characteristics. Trial mining for quality evaluation and assessment of mining characteristics may be necessary.

At the operational phase ongoing pre-production drilling would continue and the model of the deposit continually updated. The efficiency of the mining method would be monitored continually.

5.4 EXPLORATION STRATEGY SUMMARY

The intention of these deposit exploration guidelines is not prescriptive but rather to provide a framework for opencut reserve evaluation. Obviously each deposit will have particular attributes that require a certain emphasis. Within the Wittingham Coal Measures of the Hunter Valley emphasis may be placed on seam continuity and correlation brought about by splitting coal plies. Thus over parts of the deposit drillhole spacing may be reduced to a 250 m grid at the early feasibility phase. Similarly, exploration in structurally disturbed zones may require drill spacing to be reduced to 20 m or less during the detailed and operations phases.

Some attributes of a deposit will attract attention because of cost sensitivity. This can be illustrated with product coal yield where any variation can impinge on profitability and hence considerable importance must be accorded to drillhole spacing and analytical results.

6 OPENCUT COAL RESERVES DEFINITION AND REPORTING

6.1 RESERVES DEFINITION

Opencut reserves will be defined by a technical or economic limit (Advanced Surface Mining Technology 1985). Technical limitations, such as spoil stability or equipment limitations are often less significant than economic factors. The opencut depth limit is specific to a particular deposit and will often be the depth at which underground mining becomes more economic.

For reporting purposes the Australian Code for Reporting Identified Coal Resources and Reserves (February 1986) categorises reserves thus:

CATEGORY	CONSTRAINT
Mineable in situ	Pit design
Recoverable	Recovery factor (seam losses)
Run-of-mine	Dilution (by roof and floor)
Marketable	Product yield: Theoretical yield applied to recoverable. Practical yield applied to run-of-mine

Each following category is a subset of the previous category and is calculated by applying the appropriate constraint.

Opencut reserves should be reported in these categories against each phase of mine planning from conceptual through to operations.

Reserves should be stated for each seam.

The minimum mining thickness should be stated (normally 0.3 m) together with the thickness range. Where a seam contains a non-coal band thicker than 0.3 m the two coal splits (provided they each exceed 0.3 m) should be considered as separate seams and tonnages should be reported for each.

Reserves should be stated on a depth basis and should include the depth to which mining is planned. Alternatively, if the project is in the conceptual phase reserves can be reported on a depth increment basis, eg. 0-100 m, 100-200 m and <200 m.

On a quality basis the raw coal ash range should be stated (with the accepted maximum usually set at 35%). Only that coal which can be beneficiated or used at an acceptable yield should be included.

The basis for product yield together with a product specification must be stated.

All factors used to calculate the reserves must be stated explicitly including the relative density values used and any areal limits. Tonnage figures should be rounded commensurate with the accuracy of the estimation.

6.2 RESERVE REPORTING

Using the information outlined above, a typical reserve statement is illustrated below.

Mine Project	'Mt Coal' project	
Deposit Type	Type 2 multiple seams	
Mine Planning Phase	Detailed	
Mining Method	Truck/shovel	
Drillhole Spacing	<250 m grid	
Mining Depth	<100 m	100-200 m
Seams	Thickness range (m)	Thickness range (m)
Alpha	6.0–8.0	6.0–9.0
Beta	1.0–1.3	1.0–1.8
Delta	0.3–0.5	0.3–0.9
Reserves (Mt)		
Mineable in situ	50.5	150.5
Recoverable	43.2	-
Run-of-mine	40.1	-
Marketable	30.8	-

Detailed mine planning has delineated 40.19 Mt of run-of-mine reserves with less than 100 m cover to be mined over the 20 years scheduled period. A further mineable in situ reserve of 150.5 Mt between 100 and 200 m depth and beyond the 20 year mine plan is reported.

Reserves are based on a minimum mining thickness of 0.3 m with a maximum in situ ash content of 35%.

Quality specifications to define the position the coal occupies in the market should be stated.

This illustrated example conveys only the very basic information and can be expanded to suit circumstances appropriate to particular deposits.

6.3 MAPS

As indicated in the Australian Code for Reporting Identified Coal Resources and Reserves (February 1986), any report of Opencut Reserves must be substantiated to the relevant Government authority by maps at scales appropriate to the accuracy of the reserves showing all relevant data including the areas considered for each category of Reserves, the limits imposed (eg cover lines, seam isopachs and isoash), areas of prohibition and seam thickness and structure.

6.4 PUBLIC STATEMENT

A public statement of Reserves claiming the authority of this Guide to the Systematic Evaluation of Opencut Reserves should be in the format described in section 6.2. The qualifications of the person(s) responsible for this reporting should be stated.

7 REFERENCES

Australian Code for Reporting Identified Coal Resources and Reserves (February 1986)

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ENVIRONMENTAL CONSIDERATIONS FOR COAL GEOLOGISTS

H.N.Bowman; R.C.Nolan; B.Mullard, C.Ward; P. Wootton; G.Holt; M. Fahey & C.R. Weber

FOREWORD

In 1990 the Coalfield Geology Council of NSW, an independent advisory committee to the NSW Minister for Mineral Resources & Fisheries, decided to investigate the issues involving Environmental Geology as it affects coal geologists. It was recognised that a need exists for practising coal geologists to have available a guide to acceptable industry practice in environmental matters.

The resulting papers constitute such a guide. It is hoped that they will encourage coal geologists to conduct their operations during the several phases of the exploitation of a coal deposit in a way that is both environmentally responsible and supportive of their employers' or clients' best interests.

The papers are designed both to raise the awareness level of geologists and to provide a practical guide to field operations.

The geologist is typically the first professional on a site or involved in a problem. As such, he or she needs to have a general knowledge of the issues, both to forewarn of possible problems and to know when specialist advice is needed. The papers follow this theme in relation to environmental matters and consequently reinforce the generalist aspects of the geologist's role.

The first section points out that the geologist, as one of the first professionals on a site, is ideally placed to do initial monitoring of those environmental factors which will at a later stage be used in environmental impact statements. Factors which could be monitored include:

- air quality
- water quality
- noise level
- potential visual impact
- potential problems with coal transport
- impact of mining on flora and fauna
- social and economic impacts
- waste disposal problems and solutions
- archaeology
- potential competing land uses.

At a later stage the geologist will need to liaise with environmental specialists who may require some investigations to be carried out in more detail.

Explorationists need to be aware of the various Acts and Regulations on environmental matters that affect the way geologists carry on their business. Employers' and clients' needs are best served if geologists take an active role in dealing with both contractors and landowners and wherever possible addressing concerns that arise. For example:

- access tracks should be established sensibly
- drill sites should be developed with minimal impact
- soil erosion should be minimised
- topsoil should be correctly stored for rehabilitation of drill sites
- drill site wastes such as oil should be disposed of correctly
- dirty water should be isolated from the drainage system
- geophysical activities should be designed to minimise impact.

To perform their role effectively, coal geologists need a general understanding of the impact that competing land uses have on the exploitation of a resource. Land use conflicts may be lifestyle or economically based, such as farming, or heritage and amenity based such as national parks. They may also have an environmental or social basis. Visual impacts of a mine and subsidence associated with mining are factors which must be taken into account. Early awareness of the potential for impacts will help in planning programs to minimise disruption and to optimise rehabilitation or restoration.

Geologists have a role in dealing with subsidence, a critically important environmental consideration. There are many important tasks geologists can do to assist in the prediction and control of subsidence.

Rehabilitation after mining requires suitable material. Geologists have a role to play during both exploration and mining. Stockpiled topsoil is always insufficient for rehabilitation. A geologist can be very helpful in suggesting other sources, often located during exploration programs. An understanding, however, of what constitutes suitable material is necessary.

The quality of a coal resource can impact on the environment. The impact varies from the global impact of greenhouse gas production to local effects caused by the trace elements present in the coal.

Geologists need to have an understanding of air, water and noise pollution and they have a role in collecting appropriate information during exploration and mining. Exploration, which is generally under the control of geologists, should be undertaken with knowledge of the requirements relating to air, water and noise.

If, as a result of these papers, coal geologists take a greater interest in environmental matters, the Coal Geology Council will be satisfied that the papers have achieved a worthwhile objective.

ROLE OF THE COAL GEOLOGIST IN ENVIRONMENTAL ASSESSMENT

R.C. Nolan

INTRODUCTION

Coal geologists have an important role to play in environmental assessment for mining.

In 1989 the NSW Department of Planning published a paper entitled 'Environmental Impact Assessment Guidelines – Coal Mining'. The purpose of those guidelines was to

- 'Assist developers in identifying relevant environment issues when preparing Environmental Impact Statements (EIS) for coal mining projects
- guide consent authorities in their assessment and decision-making process
- inform the community in understanding the relevant issues associated with such developments.'

The main aim was

> '<u>to ensure an efficient decision-making process</u> which accounts for the need for orderly coal mining developments and environment protection'.

An efficient decision-making process requires

- assessment of the existing environment,
- assessment of the proposed mining plan. and
- resulting from those interactions, the impact of the mine plan on the existing environment.

That impact of the mine plan on the existing environment is the basis of, and the reason for, an Environmental Impact Statement. Such statements used to be prepared by environmental scientists as an assessment of an existing mine plan. In latter years the industry has realised, and the environmentalists have insisted, that the mine plan and its assessment must be prepared together so that the mine plan can then be adjusted prior to finalisation in order to cater for and/or reduce any significant environmental impacts.

A coal geologist is normally the first technical person on a coal exploration site. Initial geological reports describe the geography and geology of an area. Later versions of geological reports are incorporated into the EIS, which supports the Development Application for the mine.

The coal geologist has an initial and continuing role not only in the exploration and mine planning phases but also in the environmental studies which should accompany them. During exploration the geologist should initiate and/or conduct many of the basic environmental assessments and identify the potential environmental problems. During the mine planning and mining phases, the coal geologist will normally be part of a mine planning team and, as part of that team, may be involved in planning and supervising the long-term environmental monitoring and assessment required for the EIS.

REQUIRED MONITORING PROGRAMS

The Department of Planning (1989) lists the 'Environmental Impact Issues for Coal Mining' as

- Location of coal mining
- Air quality
- Water quality
- Noise
- Visual impact
- Transportation
- Impact on vegetation and animals
- Social and economic impact
- Waste disposal
- Archaeology
- Future land use

Location

The location of coal mining depends, in NSW, on the Authorisation Area granted for exploration. However, the initial geological reports on the area should have identified any major environmental impacts and the exploration programs should have been modified accordingly. The results of exploration would then have defined the location of economic reserves. Associated environmental monitoring can then allow for finetuning of the mining methods and, in particular, the optimum locations for the main surface structures and any likely limitations on surface or underground extraction.

Identification of the prime mine location results from a consideration of all the environmental impact issues listed above. Although many of these issues are discussed in detail elsewhere, a brief introduction to them follows.

Air Quality, Water Quality and Noise

Baseline studies of air quality, water quality and noise levels should commence early in the exploration phase, should continue during mine planning and preparation of the EIS and should be part of a Management Plan which continues throughout the extraction period. Similarly, the coal geologist's role for environmental issues changes from that of an exploration geologist to that of an important member of the mine planning team and finally to that of a mine geologist throughout the life of the mine.

Visual Impact

Visual impact will particularly determine the location of the main mine installations. Normally, the environmental assessment will guide the mine planning with regard to location and design of the mine structures, so it is vital that the assessment and the planning proceed concurrently.

Other visual impacts during the mining phase can include dust, smoke and/or 'smog', disturbed landscape, etc. The visual impact of 'disturbed landscape' such as spoil piles or bare rock faces exposed during mining operations will also guide the mine planning team, of which the coal geologist should be an important member as geological and/or geotechnical advice is vital to mine design.

Transportation

Transportation aspects do not normally require separate environmental monitoring programs. The design and operation of transport systems, both within a mine lease and outside to connect to any other system, can affect all the environmental factors but essentially they are designed, during the mine planning phase, to suit the existing environmental parameters. As with most environmental issues, an early identification of potential problems by the coal geologist will assist in their resolution.

Impact on Vegetation and Animals

Early in 1992 the NSW Government imposed even stricter regulations under the Endangered Species Act. The National Parks and Wildlife Service now requires full assessment of areas proposed for mining in order to prove or disprove the existence of, and to protect, any flora and/or fauna listed as Endangered Species.

Monitoring of the flora and fauna is required over a full year, so that all part-time inhabitants can be identified. This requires specialist botanists and biologists but, as with other monitoring programs, the coal geologist will need to make early observations. Even prior to exploration, the coal geologist, if Endangered Species are suspected, should request preliminary surveys by specialists. Currently, coal exploration is not prescribed nor was it proposed to be prescribed when the Department of Environment and Planning prepared 'Environmental Guidelines for the conduct of Coal Exploration Programs' in 1984. However, unless the mining industry critically assesses the areas proposed for exploration —in particular for Endangered Species — coal exploration may become a prescribed activity under the Environment Protection Act.

Social and Economic Impact

One of the major requirements of an Environmental Impact Statement is the assessment of the social and economic impacts of the proposed mine. That assessment is made by specialists prior to and during preparation of the EIS and the coal geologist will not have any direct input. However, an awareness of the issues may enable an early identification of problems requiring assessment.

Waste Disposal

Identification of the problems of waste disposal and the design of suitable treatment systems are carried out by specialists. The operation of waste disposal systems can affect all the environmental factors and normally they are designed, during the mine planning phase, to suit the existing environmental parameters.

As with some of the other environmental issues, the coal geologist can assist with early identification of potential problems.

Archaeology

Archaeology requires early monitoring so that, as for endangered species, the exploration and mine planning programs can be modified, if necessary. The location and nature of significant archaeological sites with European and/or Aboriginal significance are best known prior to the exploration stage. Such sites certainly need to be identified prior to mine planning. Significant sites can render an area unsuitable for coal mining (eg for opencut extraction or damageable by subsidence following underground extraction). If such sites exist in the project area, part or all of the prior expense of exploration would have been wasted if their existence was not recognised prior to exploration.

The preliminary assessment and the later full-scale investigation for the EIS and mine plan will be conducted by a specialist. However, the coal geologist should acquire some knowledge of archaeological features so that he/she can recognise possible archaeological sites and arrange for expert assessment. During that assessment, and later full-scale investigations, the coal geologist will need to provide guidance as he/she will always have the best knowledge of any coal exploration/mine planning area.

Future Land Use

The intended future use of an area may impose significant costs on the exploration of a resource. A geologist would be negligent of his/her employer's interests if he/she failed to identify future land use as a potential problem in these circumstances.

LIAISON WITH ENVIRONMENTAL SPECIALISTS AND MINE PLANNERS

During environmental monitoring programs, the coal geologist will need to liaise with environmental experts, preferably those who will later prepare the final EIS In fact, good practice for environmental monitoring and assessment programs suggests that such experts should be employed from the commencement of the exploration program. If not, the coal geologist should act effectively as their representative under their technical guidance. The nature and degree of liaison between the coal geologist and the environmental experts depends on the training and experience of each. After all, a coal geologist could be the person responsible for an EIS prepared in accordance with Clauses 34 and 35 of the Environmental Planning and Assessment Regulation 1980.

Whatever the degree of relationship between the coal geologist and environmental experts, geologists should have significant input into the planning of a coal mine to suit the existing environment. Although a coal geologist should have reported all the pertinent data, the geologist's first-hand knowledge is vital, at least in the initial planning stage and at review stages of that planning. The very close and very complex relationship of the existing geology with many environmental issues makes a geologist's observations and findings very important. A few examples of such geology/environment relationships are

- the nature and variation of the rocks determine the slope of the land, part of the climate, the rainfall and its run-off, etc
- underground water, if present, is likely to be in the coal seams and to be rich in salts that may not be environmentally friendly
- the hardness, thickness, jointing, grainsize, etc of coal seams and inter-seam strata determine the preferred mining methods and can affect the noise (blasting or ripping), dustiness, visual impact, social impact, etc of the planned mine.

ENVIRONMENTAL MANAGEMENT AND AUDITING

Once development consent has been given, an environmental management plan must be developed and implemented. This plan covers rehabilitation and control of air, water, noise, dust, subsidence and other environmental impacts. It is approved by the relevant authorities and compliance with it is reported on annually in the form of a compliance audit report. The coal geologist may be involved in the planning and reporting process.

CONDUCT OF EXPLORATION PROGRAMS

B. Mullard

INTRODUCTION

The very nature of geology, the study of the earth, gives geologists a ready awareness of environmental factors when carrying out exploration programs, and places concern for the environment as a high priority in overall considerations.

Geologists recognise that the natural flora and fauna should be interfered with as little as possible by minimising the impact of operations on surface soil, vegetation, wildlife, drainage and aesthetics. This concern translates to a number of principles to which geologists should adhere when conducting exploration programs. These principles are:

- Areas known to contain sites of scientific, natural, Aboriginal or non-Aboriginal heritage significance should be identified early and avoided if possible in development plans
- The explorer should be active in promoting site restoration following disturbance, and be prepared to undertake further remedial work should that restoration subsequently be found to be insufficient
- All activities undertaken by the explorer should aim to minimise the risk to health and safety of exploration and mine personnel as well as the general public
- The explorer should be aware of government regulations and industry codes designed to prevent pollution of land, water and air by physical impacts and chemical effluents.

GENERAL ENVIRONMENTAL CONSIDERATIONS

Access

The geologist should make direct contact with the landholder well before needing to enter a property. Discussion should include the nature and likely duration of the exploration program as it affects the land and improvements. Where possible, the field program should be made flexible enough to fit in with the often more rigid timetable of the landholder.

The geologist will need to negotiate with the landholder the terms and rates of compensation for specific exploration activities, particularly for losses caused by

- damage to the surface of the land and improvements on the land

- deprivation of the use of the surface of the land
- disturbance to stock on the land
- consequential damages.

A document reflecting the terms agreed upon by the explorer and landholder should be signed prior to the commencement of exploration activities.

The geologist should give to the landholder a detailed location map of planned activities. This map should be discussed with the landholder, seeking advice on likely problems such as the location of buried water pipes, contour banks, farm dams, levee banks, irrigation channels, shade clumps and erosion prone land, and the position of gates and fences.

All contractors and subcontractors should be made aware of company policy in the field and every possible step should be taken to ensure that this policy is adhered to. Liaison with the landholder should not be left to a contractor as the explorer has the responsibility for the operation.

Where possible, access to drilling operations should be along existing tracks and roads to minimise damage to vegetation and reduce the potential for erosion. The construction of parallel and multiple roads and tracks should be avoided.

Where provision of a new access track is unavoidable, the track should be constructed in a manner best designed to:

- minimise long term visual impact
- minimise land clearance and hence disturbance to soils, vegetation and wildlife habitats
- avoid unnecessary interference or blockage of natural drainage patterns
- support the intended traffic volume
- include erosion control structures, such as spur drains and check banks
- avoid steep cuts and fills which may cause landslides, erosion and slump problems
- avoid known sites of natural, scientific, Aboriginal or non-Aboriginal heritage significance.

It may also be necessary to clean vehicles entering exploration areas from areas known to be contaminated with noxious weeds. Geologists should also be aware of the possibility of introducing livestock disease and ensure they become aware of any quarantined properties in the area.

Site Preparations

Clearance of vegetation and hence disturbance to animal habitats should be minimised. Areas naturally devoid of vegetation or previously disturbed should be given preference for drill sites.

The above principle places a requirement on the explorer not to cut, damage or interfere in any way, with any tree, shrub or other vegetative cover except in circumstances where the operations may otherwise be directly obstructed or prevented. In such cases, trees, shrubs and branches should be spread over the disturbed site to promote seed spreading and revegetation.

Geologists should note that it is a requirement in NSW that an explorer must not fell any trees, strip bark or cut timber on any private land or crown land held under a pastoral lease within an exploration area, unless approval has been obtained from the owner. If the owner refuses permission, the licence holder may apply to the Mining Warden.

Soil Protection

There is a requirement on the explorer to conduct operations in a manner which will not cause or aggravate soil erosion.

Topsoil which may be disturbed during operations should as far as possible be removed separately for future replacement use. In general the term 'topsoil' refers to the 'A' horizon of the soil which is usually darker than the underlying soil because it contains organic matter. Whether it is darker than the underlying soil or not, the top 100-300 mm of soil should be recovered. It may be best to double-strip the soil, ie remove and save separately the top 50 mm of soil, which contains the majority of the seeds present.

Plan to reuse topsoil as soon as possible to minimise its deterioration through the buildup of humic acids and the death of seeds and beneficial microbes. However, if stockpiling cannot be avoided, then the following should be considered:

- Do not store topsoil in large heaps; mounds no more than 1 to 2 m high are recommended to avoid destruction of seeds and soil properties
- Revegetate the stockpile to protect the soil from erosion, to discourage the growth of weeds and to maintain active populations of beneficial soil microbes
- Locate the stockpiles where they will not be disturbed by future activities.

Soils should not be stripped when they are wet, as this can lead to compaction and loss of structure.

Excavations should be refilled and the saved topsoil replaced and levelled.

Erosion Control

The holder of an exploration title may be required to plant or sow suitable grasses, shrubs or trees in the replaced surface material as may be considered necessary to control or prevent erosion.

Any run-off from disturbed areas, including the overflow from any depression or ponded area, must be discharged in such a manner that it will not cause erosion.

Construction of diversion channels or holding structures such as banks, drains or dams will effectively limit the entry of water onto the site. This will reduce the potential for soil erosion on the site but may, by concentrating run-off, create offsite problems. Contour or graded banks are suitable for diverting or retaining run-off on moderate or gentle slopes.

Channels and waterways constructed to divert run-off or accept flows from the site should be designed to avoid scouring and erosion within the channel.

Slopes should be designed to reduce the velocity of run-off as the catchment of the slope increases. This usually means constructing concave profiles (see figure 1) and avoiding convex profiles.

Spur drains (see figure 2) are useful for diverting water away from road sides. Such drains are designed to limit the total distance travelled by water, and therefore reduce its erosive potential. Triangular or trapezoid cross-sections are preferred for drainage channels, and can be constructed with a small bulldozer or grader. Rectangular or similar shaped cross-sections which are produced by backhoes (figure 2) should be avoided.

Water

An explorer should put in place and maintain an efficient drainage system designed to prevent contamination, pollution and erosion or siltation of any stream, watercourse or catchment area.

There should be a general contingency plan for contamination control, and for subsequent removal and clean-up of any oil spillage. Fluids used by drilling rigs (eg engine oil, waste oil, grease and cleaning fluids) should be collected in suitable pits or containers for subsequent removal or burial.

All operations should be kept free from litter. Waste that does accumulate should be stored in suitable containers for removal or in pits for subsequent burial. Toxic, metallic and recyclable material, pallets and drums must be returned to a waste management depot.

Mud additives should be stacked, handled and used with care, to minimise the risk of spillage. Any hazardous spillage must be cleaned up or neutralised. Unused mud stocks should be removed on completion of operations.

All ablution and sewage effluent should be conveyed to pits specifically dug for this purpose. The pits must be located and operated to avoid contamination of surface water or groundwater.

RESTORATION OF DRILLING SITES

Sumps should be fenced and pumped out or allowed to dry, prior to backfilling and restoration to a condition compatible with the original terrain. Excess material should be slightly mounded over the sump to allow for compaction, and any additional material distributed over the rest of the site. The vegetation and associated topsoil should then be spread over the disturbed area.

Abandoned drill sites should be deep-ripped (to a minimum depth of 500 mm) on the contour. This is necessary to

- break up the compacted surface
- alleviate erosion
- promote natural revegetation.

Consideration should be given to installing erosion control structures (such as diversion banks, see figure 2).

Boreholes should be completely backfilled with cement to prevent mixing of aquifers and to eliminate the potential hazard of mining into a water filled bore underground. Artesian water flows may need to be controlled with a specially weighted cement mix. For effective sealing of the bore the water flow must be stopped, otherwise the cement will be washed out and the bore will leak.

All bores must be rendered safe. The bore survey marker should be clearly displayed once the rig has left the site.

Water storage dams should be backfilled, after removal of any plastic lining, and the land rehabilitated.

SEISMIC LINES

In planning a seismic survey, land sensitivity and potential environmental impacts should be assessed. A number of possible environmental and landowner concerns highlight the importance of the planning process in reducing the potential environmental effects of exploration. These concerns include areas of remnant native vegetation, the avoidance of fauna with a restricted range due to habitat depletion, the protection of cultural and archaeological Aboriginal sites and European heritage sites, the location of high-value crops and the protection of geological monuments.

The only effective way of avoiding damage to these features is to ensure that all areas and items of conservation value are identified before operations commence. The geologist should therefore ensure that identification of environmental concerns is an essential procedure which forms part of the planning process.

All available reference material, such as recent aerial photographs, topographic maps and other landform or survey maps should be used. The compilation of all environmentally sensitive areas on to a single base map or photograph is a useful tool for aiding the siting of each seismic transverse. If recent photographs are used, large trees and small environmental sites can be avoided by detailed preplanning in the office. Cleared areas should be selected rather than vegetated areas.

Access to an area of seismic operations should be by existing tracks or roads, or by way of the seismic lines only. Where cables are laid across or along a road, warning signs must be erected advising other vehicles to slow down.

Any load and height restrictions must be taken into consideration prior to using private tracks, roads and bridges across drains. If the structures are inadequate they should not be used.

Where provision of a new access track is required, the following parameters should be applied to its design and location, after due consultation with the property holder.

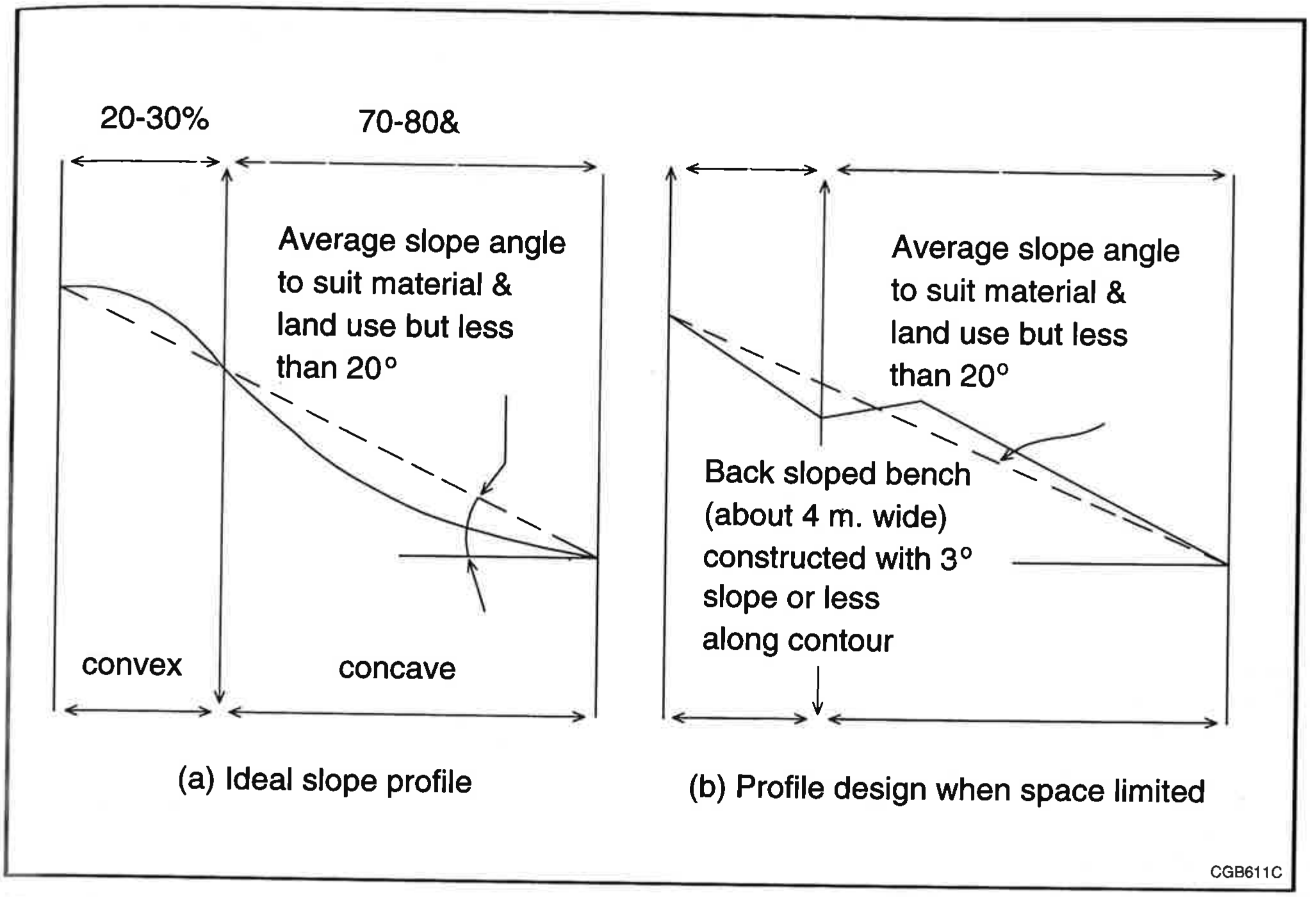

Figure 1. Run-off velocity reduction by slope design

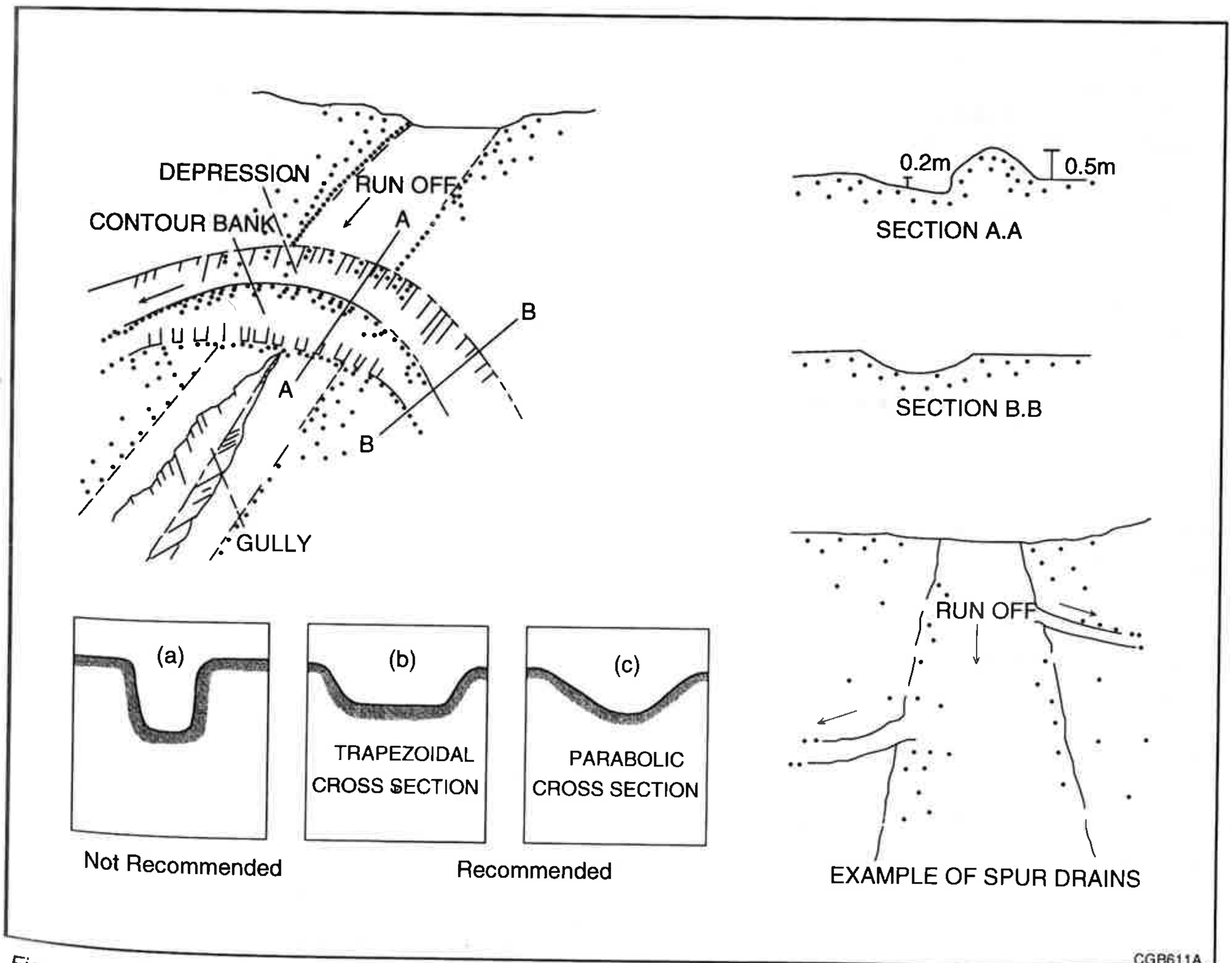

Figure 2. Design of spur drains

Land clearance, and hence disturbance to vegetation, soils and wildlife habitats, should be kept to an absolute minimum. The impact of line preparation can be minimised by removing vegetation only where necessary, and ensuring the root stock and topsoil with its seed load is left intact. Native vegetation clearance is unnecessary in many areas. Effective access preparation can often be limited to slashing. Slashing should only be undertaken where the areas cannot be avoided, and then only to the minimum extent necessary for access. It can also be used as a precaution where high grass or crops are a fire hazard.

Isolated trees and stands of vegetation should be avoided by weaving the line along the general line of traverse. This reduces the visual corridor effect.

Line intersections with drainage channels should avoid dense stands of vegetation and be offset from the general line of traverse. The clearing of line detours should be undertaken only where necessary to ensure safe travel. Existing seismic lines or access tracks should be utilised where possible.

LINE RESTORATION

To promote the success of restoration, seismic lines and all other disturbed areas must be cleared of all rubbish and work associated debris (such as fuel and oil drums, marker pegs other than permanent markers, used grease cartridges, detonator wires, explosive cases and reels) prior to abandonment.

As far as is practicable, lines should be concealed and rendered inaccessible to the public where they cross public roads and where lines lead to or are within designated environmentally sensitive areas (forest reserves, areas of remnant vegetation, conservation parks, aboriginal sites, etc), water and stock bores and private properties.

Methods used may include

- reinstating the initial profile to disturbed areas
- tyne-ripping or cultivation either side of an access track or road
- returning the cleared vegetation to the line where this is possible.

Windrow material that has been created unavoidably should be returned to the seismic lines, taking care to preserve permanent survey markers. In times of high fire danger cleared vegetation should be stored for subsequent respreading in such a way that it does not pose a fire hazard.

Any compacted soil should be ripped to provide seed and water catchment for native vegetation and to allow for ongoing agricultural programs to be re-established.

Shot holes and damage caused by any explosives used should be suitably plugged with dry unconsolidated fill and the disturbed area restored as near as possible to its original state.

Groundwater encountered should be protected from contamination by adequate downhole cementing.

AERIAL SURVEYS

Aircraft or helicopters should not be used for geophysical surveys without checking with all landowners likely to be affected by the flight paths. This is especially important during lambing and when mustering is planned or in progress. The landowner may also wish to move sensitive stock out of areas affected by aerial surveys.

LAND USE ISSUES

C. Ward & P. Wootton

INTRODUCTION

Land uses competing with coal mining can impact adversely on mineable coal resources. This impact can in some instances render a project non viable. It is a coal geologist's responsibility to be aware of land use issues when assessing coal resources and when involved in the mining of a deposit. Issues of land use affecting the exploitation of coal resources are discussed in the following paragraphs.

MINING IN RELATION TO OTHER LAND USE OPTIONS

Coal seams in flat-lying or essentially flat-lying strata, such as those that make up most of the deposits in New South Wales, cover relatively large areas of land for a given quantity of resources. Mining, especially opencut mining but also parts of underground operations, typically requires withdrawal of much of this land from other uses, such as farming or recreation, for at least part of the project life. Use of land for mining purposes, however, is only temporary in the long term, and can in many cases be integrated with other activities before and after mining in a process of multiple sequential land use.

For some lands however, eg wilderness areas, even temporary use for open cuts or other mining activities could not be undertaken without affecting their value for their designated (or similar) purpose. In the case of other lands, such as valuable agricultural areas or major built-up regions, the cost of withdrawal from existing use and later restoration to an appropriate form of use after mining can exceed the value of the coal to be recovered by the proposed mining operation. In such cases mining is best avoided, especially if it would involve opencut operations, and further expenditure on detailed site investigations for such sectors would probably not be warranted.

A domino effect can also be created. For example, if virgin land in another area is cleared for agriculture to compensate for production lost from a tract of agricultural land that is to be taken over for mining, the nett effect of the mining project is still a reduction in the extent of virgin land (including possibly rainforest tracts) in the region concerned. The cost of loss or displacement of agricultural production, relocation of living areas, diversion of roads, railways, rivers, etc and return of the land to a suitable form of use after mining must all be taken into account in assessing the economic feasibility of a proposed mining project.

Although lesser amounts of dedicated land are required for underground mines than for opencut developments, areas are still needed for surface installations, preparation plants, stockpiles and refuse emplacements. Apart from these areas, and provided ground subsidence can be tolerated in cases where full extraction of the seam is involved, mining can usually be carried out in other parts of the holding without unduly disrupting the existing pattern of land use. A number of coal mines in New South Wales, for example, have operated successfully with underground workings and surface installations in water catchments and similar sensitive areas. Special conditions may apply but their cost may not be uneconomic.

TYPES OF LAND USE ISSUES

The dedication of land to coal mining, even if only for a limited period, must be weighed against other existing or potential uses for the land in question and in some cases for some of the surrounding land area as well. An adequate information base or resource inventory on all relevant matters is necessary so that the optimum use of the land for the community as a whole in both the short and long term can be determined objectively. The information derived from coal exploration is an essential part of this information base, and a legally authorised and properly conducted exploration program should normally be encouraged to proceed unless it will be destructive to irreplaceable natural or historic features. Proving the presence and extent of coal resources does not necessarily lead to approval for mining; this must be sought separately, with due attention to the environmental impact of the proposed mining operation.

Economic, legislative, environmental and social issues in relation to land need to be considered. These are discussed separately below.

Economic Issues

Economic issues arise in situations where more than one industry or activity is possible on the same land area, such as a conflict between highly productive agriculture and mining. The merits of the various activities in such cases can usually be quantified in economic terms, and the value of the coal weighed against that of the other product(s) involved.

The geologist should establish the land usage for the different sectors of an exploration area and the surrounding buffer zone at the time the Authorisation was issued. Attention should be given to the type of usage (grazing, agriculture, housing, etc) and the location and nature of any clearing or existing improvements. Notes from field observations may be adequate, but specially flown air photos could be advisable as a record in some instances.

Improvements put in place by landholders after granting of an Authorisation may be regarded differently in assessing the environmental impact of the ultimate mining project to those that were already in place at the time exploration commenced.

Legislative Issues

Legislative based land use issues often arise because of a lack of knowledge regarding the mineral resources that exist in an area, and have provided a number of examples of otherwise avoidable resource sterilisation. Examples of legislative-based conflicts include those associated with the prohibition of mining in National Parks and similar areas, those associated with local government zoning, and conflicts associated with urban or residential developments. For soil conservation reasons, limitations may be placed on the mining of prime agricultural land, such as river flats in the Hunter Valley area.

In reality, many such conflicts are based on economic grounds, and can thus be assessed in an objective manner. Others arise more from social factors, and need to be addressed with due recognition of the specific interest groups involved.

Establishment of the legal situation regarding land title and use in and around the project area is an essential part of the site investigation. The rights of surface occupiers should also be respected, both in any negotiations that may take place and in the conduct of the exploration program and subsequent assessment of mining feasibility.

Environmental Issues

Environmental issues include those based on fear of pollution, those seeking protection of significant natural or historic features or ecosystems, and those based on a perceived degradation of the environment enjoyed by the current land occupiers or users.

Pollution issues can be addressed in part by obtaining objective data on aspects such as soil, air and water quality in the area before mining as part of an environmental baseline survey carried out in conjunction with the initial exploration program. They can also be addressed, in the light of this information, by use of appropriate planning and technology, and environmental auditing procedures, in the ensuing mining operation.

Significant natural and historic features in the area should also be identified as part of the environmental baseline study, along with the prevailing ecosystems and other aspects of existing land use. Objective geological mapping of particular land types, such as river flats and unstable slopes, using aerial photographs and/or ground studies, may also be required. Such information helps to establish the nature of the environment in the area as it exists for current land users, and to highlight any land use problems to be addressed in context by the Environmental Impact Statement for the project.

It is advisable, and in some cases a legal requirement, for explorers not to disturb any artefacts or sites of aboriginal significance that may be identified in the course of an exploration program. The location of such occurrences should be reported to the relevant authorities as soon as possible. Sites of significance to European history, such as remains of pioneer homesteads, cemeteries, and abandoned coke ovens or brick kilns, should also be recorded in the course of the geological assessment.

Social Issues

Social attitudes to coal mining are dictated by many factors, not all of which can be objectively assessed and dealt with as part of a technical investigation. Community pressure, however, is often stronger than legislative dictates, and concerns should be dealt with sensitively and honestly. Good public relations and attention to environmental matters in the course of the initial exploration program, as well as evidence of good practice generally by the local mining industry, can help break down some objections in this regard (McIlveen 1981).

To minimise social-based conflicts, the geologist should make and maintain contact with landowners in and around the Authorisation area, explaining the nature of the exploration program and discussing factors that may affect particular individuals, such as the location of, and access to, drilling sites. The geologist should bear in mind the need for his/her organisation to maintain continuing good relations with all landowners, not only for exploration but also with regard to issues arising in connection with the ultimate mining project.

VISUAL IMPACT OF MINE WORKINGS

A good appreciation of the topography of the site and the surrounding region is essential in assessing the visual impact of any mining project. Representation of proposed installations on aerial photographs or ground photographs, informed artist's impressions from particular view points, or the use of physical and computer graphics models are some of the methods by which visual impact can be assessed and communicated in environmental studies. Such topographic considerations can also be helpful in assessing patterns of wind movement around the site, and in evaluating noise and dust distribution.

The relation of features such as excavations, headframes, car parks, workshops, preparation plants, stockpiles, overburden dumps and refuse emplacements to the surrounding area as viewed from particular angles can be a major part of the environmental impact of a mining project for local residents and the general public, especially if the project is located near major towns or transportation corridors. Siting of facilities in unobtrusive places, or screening them behind embankments or plantations of trees, are alternatives that may need to be considered in the mine design process.

At the mine design stage of the project, the geologist should give consideration to the location of dams, excavations, washeries and other structures, as well as stockpiles and refuse emplacement areas, with respect to topography, in addition to the technical considerations on the siting of such facilities to ensure optimum resource utilisation.

Recommendations for acquisition and use of land outside the main coal deposit may be desirable in some instances to minimise any adverse visual impacts of these facilities.

SUBSIDENCE EFFECTS

When a coal seam is extracted from underground mine workings, the overlying strata subside naturally, with time, to fill the void created (Kapp & Williams 1972, Hargraves 1973). If the area of seam extraction is wide enough, the effects of this subsidence will reach the surface, causing lowering of the ground level and possibly, in some circumstances, dislocation of roads, railways, buildings, pipelines and other installations. It can also give rise to dislocations that generate rock falls on exposed cliff faces.

Subsidence results in a nett lowering of the ground surface, in some cases over a considerable area. This may affect drainage patterns or water flow in channels and pipes, but otherwise may have little visible effect on undeveloped ground above relatively deep mine workings. Local sinkholes, however, may develop above points such as roadway intersections in some shallow operations. The impact of subsidence is perhaps more strongly felt in the monoclinal flexure at the edge of the zone, where stretching, tilting and compression of the strata at the surface can place severe strains on buildings and other types of structures.

New surface structures in areas likely to be affected by subsidence may need to be designed specially to accommodate the strains anticipated (Kapp 1978), with the cost of doing so being offset by the value of the coal produced. To protect them from subsidence effects, partial extraction only, or in some cases no extraction at all, may be permitted in areas surrounding sites of particular importance.

Restrictions may apply to mining, for example, in a zone defined by angle of draw criteria around structures such as dams, railway lines and built-up areas or in towards a plateau from the upper edges of prominent escarpments and cliff lines. Similar restrictions may apply in respect to water stored by dams located above otherwise mineable coal seams (Holla 1989). Such limitations on coal recovery should be taken into account by the geologist, along with other restrictions, in assessing mineable in situ and recoverable coal reserves.

The location of man-made features such as major highways, railway lines, dams and reservoirs, bridges, water or gas pipelines, canals, high-voltage power lines, cemeteries and built-up areas (especially individual large buildings) should be noted in the relevant geological report, along with significant natural features such as foreshores, cliff lines, caves, watercourses and flood-prone land, forests and wetland areas. Fault lines, joint and shear zones, and dykes are important features that the geologist should delineate in subsidence investigations as such features may cause dramatic localised dislocations and major surface damage.

SOIL TYPES AND LAND REHABILITATION

Geological mapping of the different rock and soil types in and around the project area provides essential data to evaluate the different possible landuse options. The characteristics of the soil may be significant in regard to plant growth, and hence mapping of different soil types may be important in assessing the impact of the project on the area's agricultural productivity. Recognition and mapping of the different soil types may also serve to identify areas with particular geotechnical problems in relation to, for example, road construction or building foundations, and thus provide data for other aspects of the mine design investigation.

Apart from their role in land use before mining, the different topsoil materials in the project area may need to be set aside to be used as cover for exposed spoil piles and other rock surfaces to facilitate more effective re-establishment of vegetation in the land rehabilitation process. Buried soils in alluvial areas may also need to be considered for use in this regard. Knowledge of the specific soil characteristics, such as pH, salinity and nutrient availability (Hannan 1984, Hannan & Bell 1986, Bell 1987), coupled perhaps with planting trials of particular species, will allow the role of the different materials in revegetation to be assessed.

SUBSIDENCE

G. Holt

INTRODUCTION

Subsidence is a major community environmental issue. Unfortunately many in the community have an incomplete understanding of subsidence and its effects. The person best placed to recognise initially whether subsidence may be an environmental issue, in both new and existing operations is the coal geologist. Development of an early appreciation of subsidence as a likely issue of concern for new underground operations can assist in obtaining Development Consent and provide basic information for subsidence prediction and monitoring.

Most areas of underground mining in NSW are in declared Mine Subsidence Districts administered by the Mine Subsidence Board. The Board acts as an insurance body so that damage resulting from mining can be rectified.

NEED FOR SUBSIDENCE ASSESSMENT

There are a number of situations where subsidence impact assessments are needed. These include all new underground operations, significant expansion of existing mines, applications to mine within land controlled by the Dams Safety Committee, and applications to extract pillars or mine by the longwall method under Section 138, Coal Mines Regulation Act 1982.

Assessments usually require calculation of the likely levels of subsidence , strains and tilts, followed by assessment of the impact on the natural and built environment.

DATA COLLECTION

Much of the data required for environmental and engineering design is gathered by coal geologists during the regular processes of developing assessments of coal resources and reserves. The remaining information usually relates to mine planning, and this involves collaboration with mine planning personnel.

Data that can be recorded by coal geologists can be divided into two groups: coal and rock strata information, and environmental information. The overlap with other investigatory fields is obvious. The mine design engineer requires coal and strata information as a basis for mine planning and the environmental observations made by the geologist provide direction for environmental impact studies.

COAL AND ROCK STRATA INFORMATION

Geology and structure

More and more coal deposits involve mining multiple seams, and even though the geological target may be one particular seam, there will need to be sufficient information collected on other seams to at least develop a conceptual understanding of likely future subsidence impact. Geological description of rock units, particularly the relative disposition and abundance of arenites, lutites, rudites and igneous rocks, and the bedding characteristics of the sediments, for the full cover depth to the lowest seam is fundamental.

The amount and nature of subsidence varies according to the mix of arenites and lutites, and the nature of bedding strongly influences the way strata cave. Sequences with a predominance of massive sandstone and conglomerate tend to result in less subsidence at the surface than those with an even mix of thinly bedded sandstone and shale. Thick sequences of moderate strength sandstone, such as occur in parts of the Western Coalfield, can also result in lower surface subsidence.

Any observations on geological discontinuities cutting across bedding, and the orientation of such structures, are important. Any structure which may connect from seam to surface is of major importance, especially in areas prescribed by the Dams Safety Committee.

The scale of structures is very relevant to subsidence impact assessment. Structures are usually considered in relation to safe mine working, or mine layout, and subsidence considerations are often secondary to basic mine planning. Large scale structures, ie ones that can affect the caving behaviour of a considerable body of strata, are relevant to subsidence assessment.

Faults and dykes with a significant vertical extension affect caving behaviour. Faulting which has caused large transverse displacement in seams, but ramps up through interburden and overburden needs to be assessed. Such structures occur within the Hunter Coalfield. Large scale jointing, typical of the Western Coalfield, can also influence subsidence, and the pattern, distribution and vertical continuity of joint sets need to be determined in order to calculate whether there will be any influence on roof caving. Localised faults and discontinuous dykes affect localised roof movement but are less relevant to subsidence considerations. If cover rocks are massive and strong, such as the conglomerate of the Newcastle Coalfield, and some sandstones in the Southern Coalfield, subsidence is reduced.

Geotechnical information

The geological identification of non-coal strata is important as discussed above. Knowledge of rock mass properties further improves subsidence assessments. Basic rock mass information collected by coal geologists can include fracture logging, rock descriptions, including strength and weathering estimates, and optionally, Point Load Strength estimates. Visual estimates of strength have proven notoriously inaccurate, but if a qualitative estimation system is to be included in logging, it should be simple and with few terms, such as weak, strong, very strong. Visual strength classification systems developed in engineering geology, where far more detailed estimates are required, are available. In coal measures strata there is little need for such detail, and a simple system covering weak, strong and very strong strata is in most cases all that is necessary.

Geomechanical testing programs designed to assess strata caving behaviour and stability of workings also provide useful input to subsidence assessment. Commonly such programs are under the control of coal geologists. Programs should aim to develop a basic understanding of rock strength properties for all major lithologies, particularly those which are likely to directly impact caving behaviour. Typically a laboratory test program includes unconfined compressive strength, indirect tensile strength, elastic modulus and Poissons Ratio. Additional tests may include triaxial, shear box, slake durability, and clay mineral identification. Testing programs are usually site specific and are not designed with subsidence in mind; non-coal rocks at some distance from mining horizons are ignored. In any drilling program, a small proportion of the budget should be devoted to ensuring that the basic strength properties of all main lithological horizons are determined.

Cover depth

Knowledge of the three dimensional locations of coal seams over the area likely to subside is a primary requirement in calculation of subsidence. This is usually given by cross sections showing seam thickness, interburden and overburden thickness, as well as isopach maps showing seam thickness, seam floor, depth of cover, and surface topography. Most exploration and mining operators have access to geological data bases, from which the necessary plans can be generated.

The amount of subsidence at any location depends on the depth of workings, thickness of the worked section, and the dimensions of mining panels. This information is usually generated as part of an exploration program, but it is important to ensure that all the necessary information is generated.

If a computer data base is not available, the necessary data for subsidence calculations can be derived, with a lower order of accuracy, from published topographic maps, drill logs, and a layout of the proposed mine. Plans should be prepared to a standard scale. One that satisfies the statutory requirements is usually sufficient. However when working in areas with extensive improvements more detailed plans are required as subsidence assessment is commonly required to examine impacts on individual structures. Mine plans are sometimes prepared by geological personnel, especially at the conceptual planning stage, which is when subsidence impact needs to be considered.

If this is solely the province of engineering personnel, then liaison between geology and engineering staff needs to be firmly established. Additional information required for engineering analysis includes the proposed mine layout, sequence and timing of mining, as well as any previous subsidence experience in the region. This is normally the province of mine engineers, but early recognition of potential subsidence impact, ie the environmental impact, can play a significant part in development of a mine plan.

ENVIRONMENTAL INFORMATION

Introduction

Coal exploration and mining in New South Wales takes place in a wide variety of environments, ranging from densely populated to almost wilderness areas. These environments may be adversely affected by subsidence. Coal geologists are capable of reporting on virtually every aspect of the surface environment which may impact on an area of economic interest.

Early recognition of the surface environment which may be affected by subsidence is important. Reporting of these environmental features by coal exploration geologists will save time and money by reducing the delays inherent in the approval process, reducing the scope of baseline studies undertaken by environmental consultants, and warn of pending environmental problems associated with subsidence as early as possible in an exploration and development program.

Natural and heritage features

The nature of flora and fauna can be noted during exploration programs. It does not take specialist knowledge to recognise areas that may contain species likely to attract the interest of relevant government authorities and the public and which may be affected by subsidence. The Southern and Western Coalfields contain large areas of bushland with specialised habitats. High level swamps are increasingly being recognised as requiring preservation. Microclimates produce particular groupings of flora, which in turn result in specialised ecological niches.

Bushland areas left as remnants near urban development take on special significance to residents. Such areas should be delineated, even in cases where they may appear to be unlikely to be affected adversely by subsidence. The surface should be divided into domains which can then be assessed for possible subsidence problems.

Significant cliffs arouse interest from conservationists and government authorities alike. They should be delineated by the geologist at an early stage. In general, cliffs are considered significant if they are 10 m or more in height, although cliffs of a lesser height may also be significant if, for example, they are continuous and highly visible. Cliffs beyond the boundary of the coal title but within the angle of draw for the target seams should also be delineated.

Linked to cliffs are areas with outstanding scenic attributes, and areas within every day public view. An example would be the natural 'pagodas' of the Western Coalfield.

Flood plains are very sensitive areas, both from the point of view of flooding, and because they are usually prime agricultural land. To date only limited secondary extraction has been allowed under flood prone areas, and virtually none under flood plains used for agriculture. Full extraction under flood plains requires special approval and such areas need to be identified early.

Aboriginal and other heritage sites demand particularly close attention, although in many cases they are not affected by subsidence. All coal geologists should develop a basic knowledge of the features of aboriginal heritage.

Other government controlled lands have a range of limitations which need identification very early in an exploration program.

Mining under tidal waters is subject to restrictions imposed by the Chief Inspector of Coal Mines. The amount of coal which may be extracted is controlled by limits on the amount of subsidence under the water, in the tidal zone and near the high water line.

There are limitations on mining under watercourses, particularly the larger, permanent rivers.

Groundwater is part of the natural environment. In farming areas, any potential for the loss of groundwater must be taken into account.

Conditions of approval for new mining projects are increasingly being driven by the opinion of the affected communities and exploration programs need to take community opinions into account.

Improvements

Improvements on the surface may or may not be affected by subsidence. To arrive at a determination, prediction of likely subsidence levels and assessment of the ability of the improvements to withstand subsidence are required. However the existence of improvements must first be recorded either as individual structures or domains of similar improvements. Some areas may already be in declared Mine Subsidence Districts. Other areas may be added at a later date. Contact should be made with the Mine Subsidence Board at an early date.

Urban areas are obviously sensitive to subsidence, especially public works. Some residents may be poorly informed about subsidence. Public authorities take responsibility for improvements under their control very seriously and, disappointingly, often demonstrate a surprising lack of knowledge or interest in subsidence until structures are threatened. These include roads and related structures, pipelines, railways, public buildings, heritage structures and sites, water supply and sewerage services. An exception is Pacific Power which has for many years allowed power lines to subside as a result of mining. Other exceptions include the Departments of Agriculture, Forestry and Soil Conservation Services, which are usually helpful. Their advice should be sought early in assessment programs.

If prescribed dam structures are likely to be affected, early contact with the Dams Safety Committee is recommended. This body has firm policies in place to protect structures and impoundments, but is prepared to work with mining companies to reach a conclusion satisfactory to all parties.

All improvements within a prospective coal area need to be noted to enable a qualitative assessment of likely subsidence impact. It is recommended that this be carried out before drilling programs are established. Community attitudes are changing, and the grant of an Authorisation can be resisted quite strongly. Early information on improvements may influence the development of exploration. Airphoto interpretation can be very useful in this regard.

COAL GEOLOGIST'S ROLE

Subsidence has traditionally been seen as a mine planning process, but it is now an environmental impact issue in urban, rural and natural areas.

The coal geologist is in a unique position to record very early in exploration programs the basic environmental/mining information necessary for subsidence assessment. The best information lies in maps produced, for example, from air photographs and notes. The notes need not be detailed. Brief notes can be invaluable in guiding the environmental impact process from preparation of the brief to EIS consultants, to shortening data gathering stages, and interfacing with mine planning aspects.

Basic geological data gathering needs to encompass the full stratigraphic section from surface to seam floor. This should be backed by sufficient geotechnical testing to ensure an understanding of the rock mass in order that subsidence predictions can be undertaken with a reasonable degree of confidence.

The particular features of the exploration area should be noted as early as possible in exploration and drilling planning. This information can be compiled during the geological mapping phase. There also needs to be a reporting system in place that can accommodate basic environmental reporting by geologists.

MATERIALS EVALUATION FOR MINE REHABILITATION

M. Fahey

INTRODUCTION

Geologists have a role which starts in exploration, continues through mining and concludes in rehabilitation. The main contribution that geologists make in rehabilitation comes from their access to subsurface information.

GUIDELINES FOR THE EVALUATION OF TOPDRESSING MATERIAL

The Soil Conservation Service of NSW provides a specification for soil surveys. Testing and description of materials by an exploration geologist should be consistent with, or complementary to, this specification.

The main pertinent points of this specification are:

- A free survey (a grid survey is not required) of the soils, used in conjunction with information from air photos, is to be used to prepare maps of the soils
- At least one soil profile per 25 ha, or for each major soil type (whichever occurs more frequently) should be examined and described
- Soil profile descriptions should extend to weathered rock or to a maximum of 2.5 m
- Each soil profile description should show, in the legend, the Northcote 'Extended Principal Profile Form', horizon depths, names, boundary shape and distinctness
- The suitability of soil for topdressing can be determined by the criteria described by Elliot and Veness (1981). Suitable soils are coherent wet and dry, are not mottled in colour, are fine grained and not strongly bonded, are not excessively sandy and are of low salt content. Soils which fail these criteria may be used if laboratory testing indicates suitability subject to special treatment, such as with gypsum, lime, etc.

Features used to describe soils (after Elliot & Veness 1981) are:

- *Structure.* The proportion of large peds (>10 cm) in the soil should be low. Large peds lower the pore space and the rate of water entry.
- *Coherence.* The surface soil should be crumbly but the crumbs should be large enough to avoid being blown away.
- *Mottling.* This indicates poor drainage and unsuitability of the soil for use in revegetation.
- *Macrostructure* (the form and orderliness of the arrangement of peds). The size of macrostructure gives an indication of void space when the soil is wet.
- *Ped strength* (the force required to disrupt peds). Strong peds indicate unsuitability for topdressing applications.
- *Texture* (eg sandy, sandy loam texture). This gives an indication of the soil's water retention capacity.
- *Gravel and sand content.* Combined gravel and sand contents in excess of 60% tend to retard plant growth.
- *Salt content and pH.* Electrical conductivity is used as an index of salinity and should, in a 1:5 soil:water suspension, be less than 0.0015 S/cm. The pH of a soil should be between 4.5 and 8.4, and preferably between 5.5 and 7.5.
- *Colour.* Red-brown soils tend to hold together in the presence of water and be less dispersive than yellow-brown soils.
- *Cutans* (coatings on peds). These provide an indication of permeability. Uniform distribution of cutans indicates that uniform and deep wetting of a soil will be achieved.

PRE MINING CONDITION OF LAND

Information apart from soil details should also be recorded. The condition of the land before mining is important, as it forms a benchmark to be achieved or improved on by rehabilitation. In this context it is worth noting the distinction between reclamation, restoration and rehabilitation: 'reclamation' is defined as 'winning back from waste condition', 'restoration' is defined as 'bringing back to original state by rebuilding or repairing' and 'rehabilitation' means 'to render useful or make fit for habitation' (Hannan 1979).

Comments on the condition of the land should address:

- *Land use patterns and productivity.* Although rehabilitated areas at a mine site may, for example, show a major increase in cattle carrying capacity, the land may not necessarily have been in its optimum condition prior to mining.
- *Erosion type* (such as gully and sheet erosion) *and severity.* Successful rehabilitation should eliminate existing erosion damage and reduce the potential for future damage.

- *Drainage patterns and density.* These can be improved to minimise undesirable effects such as saltpan formation while at the same time enhancing beneficial aspects such as surface water storage capacity. The rehabilitated landform topography should emulate, as closely as practical, the natural drainage patterns in order to minimise the likelihood of erosion.
- *Areas of degraded or contaminated land.* Areas such as saltpans, waste dumps, etc can be highlighted for correct treatment during mining.
- *Topography.* Note should be taken of the various types of topography present in order to emulate them during rehabilitation. For example, natural slopes typically have a profile which is convex near the top and concave near the base.

SOURCES OF DATA

For the purposes of evaluating rehabilitation material, the main sources of data at the exploration geologist's disposal are the drill hole sumps, material from open hole and core drilling, and soil profiles exposed in drainage channels.

Drill hole sumps, although considerably shallower than the 2.5 m profile recommended are typically sited at a greater frequency than full soil profile locations suggested in the Soil Conservation Service specifications. In any case, they provide a useful supplement to the full soil profile data.

Open hole samples are normally saved at 0.5 m or 1.0 m vertical intervals for the extent of the hole. It is unlikely that the soil structure can be determined from chip samples, although useful information on coherence, mottling, texture, sand and gravel content, colour, pH and salt content can be derived. Other soil and rock chemistry analyses are also possible.

Samples from core drilling are very valuable for the assessment of interburden resources and coal waste resources. Drainage channels and road and track cuttings are also an excellent source of information for exploration geologists.

POTENTIAL REHABILITATION RESOURCES TO BE EVALUATED

During the exploration program the geologist has the opportunity to define a variety of rehabilitation resources which will become available during the mining operation. These resources, which may require additional testing, fall into three main groups:

- Resources from the soil horizons
- Resources from burden removal
- Resources from beneficiation processes.

As exploration proceeds, a fourth group of resources, not associated with rehabilitation, should also be assessed. These are construction sand, gravel and roadbase resources.

When considering soil material for use in rehabilitation it should be noted that, while it is imperative to ascertain its physical properties, its chemistry is also important. One of the main problems is sodicity (the Sodium Absorption Rate), which is a function of the Na:Ca:Mg ratio. Excessive sodicity causes a cement-like surface crust to form. This crust is detrimental to plant germination and growth. The problem can be alleviated by the application of gypsum.

The absence of the trace elements phosphorous, potassium and nitrogen is not considered to be a serious problem when assessing topdressing material. These elements can be introduced during rehabilitation. Problems can arise, however, if the rock absorbs and 'locks up' these trace elements. Occurrence of this problem is a function of the pH and the cation exchange capacity of the soil.

Resources from the soil horizons

In the past, topsoil removal operations have normally collected the top 500 mm or so of the soil horizon and stockpiled it separately for later use. Recent studies have shown that in many cases the lower soil horizons, in some cases even weathered rock, are more suitable for use in rehabilitation. Present soil survey practice is to identify the most suitable 'topdressing material' rather than simply 'topsoil'.

Sand, gravel and other alluvium can fall into the category of 'topdressing material'. Through use of a drilling rig the exploration geologist is in a position to assess these materials to a greater depth than the 2.5 m normally studied by a soil scientist.

It should be noted that some soils and topdressing materials are contaminated (usually with sodic salt, sometimes with other toxic materials) and are unsuitable for use in rehabilitation. If these materials cannot be treated to eliminate their toxicity they should be marked for suitable disposal.

Resources from burden removal

Almost all burden materials constitute a resource in terms of their use in spoil pile reprofiling. Some elements of the burden have attributes which are either useful or to be avoided. Whether or not these materials can be differentially handled depends on the practicality of removing them separately during mining operations.

Some examples of these materials are:

- *Claystones and tuffs.* These may have some application in sealing certain horizons against toxic material, groundwater movement, drainage, etc.
- *Mudstones and siltstones.* The 'frettability' of these strata may make them useful as topdressing material, but they can also be a source of deleterious sodic salts.
- *Pyrite and other sulphur-bearing rocks.* Placement of these materials near the surface can result in the sulphur being leached *out to produce an acid environment which is toxic to vegetation.*
- *Other toxic materials.* Rocks which contain other toxic materials (arsenic, uranium, etc) or trace elements in toxic concentrations or combinations should also be avoided.

- *Limestone, gypsum, calcite, etc.* These may have uses in treating topdressing materials to correct acidity, salinity and other soil problems.

Resources from beneficiation processes

'Chitter' (coarse washery reject) has been successfully used as a topdressing material to promote tree growth from seedstock. However, the use of 'chitter' for rehabilitation to pasture is controversial. Potential future land uses must be considered when contemplating the use of 'chitter'. Care must also be taken to assess the chemistry of potential 'chitter'; in many areas this material has a significant sulphur content.

'Tailings' (fine washery reject) often have a high sulphur content, which makes them a 'resource' to be avoided. If sulphur content is not high then 'tailings' from coal preparation may have application as a fine topdressing material.

ENVIRONMENTAL ASPECTS OF COAL PROPERTIES AND COAL UTILISATION

C. Ward & C.R. Weber

INTRODUCTION

Environmental concerns that need to be addressed as a routine part of coal exploration and mining projects include those associated with the end use of the coal itself, as well as with processes associated with handling of stockpiles, overburden and refuse emplacements. Although issues associated with the siting of plants which use coal, such as power stations, or with the transport of coal to market, usually involve factors other than the geology of the coal deposit, some aspects of coal quality in relation to the way the coal is used can have a significant impact on processes such as local, regional or even global water supply and atmospheric systems.

Potential problems can be identified and addressed from:

- an awareness of the physical and chemical properties of the coal to be mined
- the nature and chemical properties of the overburden, interburden and non-coal bands within seams
- data gathered as part of the overall resource assessment process.

Such properties may also, of course, affect the suitability of the coal as an economic resource in general, and therefore the viability or otherwise of the total mining project.

GREENHOUSE GAS PRODUCTION

The generation of carbon dioxide from the use of coal in electric power generation and industry contributes to its concentration in the atmosphere and hence may affect global retention of radiated solar heat through the 'greenhouse effect'. Other gases associated with coal mining, notably methane ventilated to the atmosphere from underground workings, also contribute to this effect (Sullivan 1989). Methane is even more significant as a greenhouse gas than carbon dioxide.

The history of the Earth has shown repeated development of ice ages, sea-level fluctuations and other climate changes due to natural agencies, such as perturbations of the Earth's orbit (Milankovitch cycles), since the beginning of geologic time. These changes have also included changes in atmospheric CO_2 levels. The significance of man-induced factors in relation to this overall pattern is not clear.

Current climate model studies indicate that a continuation of current trends in greenhouse gas emissions may result in an increase in the earth's average temperature. If this happens the earth's mean sea level could be expected to rise due to thermal expansion of the oceans and melting of ice on land.

The most recent internationally endorsed climate change studies were published by the Intergovernmental Panel on Climate Change (IPCC) in 1992. The IPCC was jointly set up by the United Nations Environment Programme and the World Meteorological Organisation in 1988.

In relation to global warming, the IPCC concluded:

> 'It is still not possible to attribute with high confidence all, or even part of the observed global warming to the enhanced greenhouse effect. On the other hand, it is not possible to refute the claim that greenhouse-gas-induced climate change has contributed substantially to the observed warming.'

Coal combustion world wide appears to be responsible for about 10% of the total man-made input to greenhouse gas production (Sullivan 1989). It is worth noting that even complete cessation of coal mining and combustion throughout the world will have little impact if the gap in energy demand is simply taken up by other carbon-based fuels. The 'no regrets' policy adopted by many governments including the Australian Government has as its objective the stabilisation of greenhouse gas emissions through actions that should be taken even if in the final analysis there is no problem with a greenhouse effect.

The Australian Government has committed itself to ensuring that the growth of emissions will be much less than would otherwise be the case in a 'business as usual' scenario.

It will still be necessary to continue the worldwide use of coal as a major part of the energy mix for at least 30 years, until renewable energy or other new technology is sufficiently mature to replace coal.

One of the main quality factors affecting coal combustion is the specific energy of the coal, particularly the nett specific energy on an as-received basis. This determines the mass of coal required to produce a given heat output, and hence factors such as the amount of CO_2 produced per megawatt hour

TABLE 1 GUIDE TO ENVIRONMENTALLY SIGNIFICANT COAL QUALITY PARAMETERS

Analysis or Test	Coal Market	Preferred Limits	Acceptable Limits	Discussion
Ash (air dry %)	Fuel	10 to 22	Max 35	High ash reduces specific energy, increases CO_2 output per GWh and increases ash disposal requirement
	Coke	6 to 10	Max 10	Low ash reduces limestone consumption and slag production per tonne of steel
	Cement	12 to 17	Max 30	High ash reduces nett specific energy and increases CO_2 production per tonne of cement clinker
Total Sulphur (air dry %)	Fuel	Max 1.0	Max 2.0	Dependent on pollution control requirements where the coal is to be burned
	Coke	Max 1.0	Max 1.2	The sulphur should be as low as possible
	Cement	0.7 to 3.5	Max 4.0	Sulphur in clinker is normally required to be less than 1.3%
Nitrogen (dry, ash free %)	Fuel	Max 1.8	Max 2.0	Low figures preferred by some users
Chlorine (air dry %)	Fuel	Max 0.1	Max 0.3	Should be low to reduce tendency for fouling
	Cement	Low	Max 0.1	Chlorine in clinker is expected to be less than 0.03%
Ash fusion (deformation temperature °C)	Fuel	High	Min 1 100	Dry bottom furnaces. Actual figures depend on power station design

of electricity. Low rank coals also require considerably larger combustion plants for a given output of electric power than higher rank materials (see eomparison below), and this is more demanding on mining infrastructure and construction resources generally.

Brown coal : 1150 t Co_2 emitted per GWh
Black coal : 985 t Co_2 emitted per GWh

Australian pulverised coal power stations are already among the most efficient in the world. Similar improvements in combustion technology, fuelled by coals with a high specific energy such as those from New South Wales mines, represent a viable short term means for helping to reduce CO_2 emissions associated with power generation in some other countries.

COAL QUALITY AND THE COMBUSTION PROCESS

Information on coal quality parameters that are environmentally significant are given in table 1.

Moisture and *ash* act as diluents to the coal's energy output, and therefore are significant in the day-to-day operation of a combustion plant. The ash content also indicates the amount of material that needs to be handled by the precipitators or filters and stored in areas such as ash ponds. Ash and moisture, for coal of a given rank, are generally required to be maintained within acceptable limits for effective plant operation because short term quality fluctuations can cause problems in heat output control.

Hardgrove grindability index is a measure of coal hardness and affects the design and capacity of the coal pulverising equipment. Hard coals (low HGI) require more grinding mills to provide an equivalent coal throughput relative to soft coals, and this can be a minor factor in plant design and operating cost. Excessive abrasion of grinding mills by hard minerals such as coarse quartz grains in the coal and abrasion of the metal boiler surfaces by hard particles such as quartz in the fly ash are also cost factors.

High sulphur coals can be expected to produce a greater proportion of SO_2 in the flue gases per tonne of coal than low sulphur coals. Some of this may be captured by calcium in the fly ash. Environmental factors, however, may require the SO_2 to be reduced by passing the flue gas through a scrubber unit, typically based on contact with wet limestone, prior to discharge to the atmosphere through the furnace stack. Limestone selection for such scrubbers, and for a similar role in fluidised bed combustion facilities, may also be one of the coal geologist's responsibilities.

High nitrogen coals. Some users of coal prefer a low nitrogen content in order to minimise emissions of nitrogen oxides with the stack gases. However, it should be borne in mind that coal is burned in an atmosphere that itself contains 80% nitrogen. Much of the nitrogen derived from high temperature coal combustion is probably derived from the air used, rather than from nitrogen in the coal itself (Cudmore 1984).

Other combustion problems of a geological nature include changes in coal reactivity (emissivity) caused by free quartz in the coal.

In some cases, the ash may melt partly, or fuse, and attach itself as slag to the heating surfaces in the main part or radiative section of the combustion chamber. This process, called slagging, is related mainly to ash composition; in low rank coals, for example, it can be brought about by interaction of organically associated calcium or iron and some of the aluminosilicate minerals. The tendency for slagging to develop is not always indicated satisfactorily by otherwise relevant properties such as ash fusion temperatures.

The slagging potential of a coal is best determined by first calculating the base to acid ratio of the ash as below:

$$\text{Base/Acid Ratio} = \frac{F_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

The slagging index is calculated by multiplying the Base/Acid Ratio by the percentage of S (adb — air dry basis) in the coal.

Slagging index	Tendency to slag
< 0.6	low
0.6 - 2.0	medium
2.0 - 2.6	high
>2.6	severe

From the above it can be seen that coals with high amounts of iron, calcium, magnesium, sodium, potassium and sulphur tend to slag.

More volatile inorganic constituents, such as sodium, may pass from the main part of the combustion chamber but condense in the slightly cooler convection section to form deposits on the economiser and superheater surfaces. This process is known as fouling. Some of the volatile inorganics may also be corrosive, and react with exposed metal in different parts of the combustion system. Slagging and fouling propensity can be indicated, to some extent, by indices derived from the coal's ash analysis and related quality data.

A guide to the fouling potential of a coal is given by the percentage of Na_2O in the ash as below.

Fouling Potential	Na_2O% in Ash
low	< 0.5
medium	0.5 - 1.0
high	1.0 - 2.5
severe	> 2.5

SPONTANEOUS COMBUSTION

Coal undergoes an exothermic chemical reaction when exposed to oxygen, such as in stockpiles, ventilated goafs or refuse emplacements and even possibly in situ at the mine face. The rate of reaction increases with temperature and if the heat of reaction results in continuing temperature build-up in the coal, slow to rapid combustion of the entire mass may result.

The ease with which the oxidation reactions proceed is greater in low rank than high rank coals, and thus special precautions including minimal stockpiling are needed when dealing with lignites and subbituminous materials. Cudmore (1984) quotes relative ignition temperatures of 120° to 170°C, depending on the rank of the coal concerned. Pyrite oxidation also produces an exothermic reaction, but Stach et al (1975) indicate that this is much less significant, especially in low rank coals, than the heat produced by the organic matter. Sulphur content seems to be of little consequence in the rate of oxidation. The carbon–oxygen reaction remains the major heat generating reaction.

Spontaneous combustion of coal at the mine site not only destroys part of the valuable coal resource, but also causes significant amounts of air pollution through smoke and gas generation. It is hazardous in underground mine workings. It also impacts on spoil pile rehabilitation measures. It can be minimised by

- use of larger particle sizes (to reduce total surface area)
- better packing of the spoil (to reduce porosity)
- reduction of stockpile height
- elimination of steep faces exposed to prevailing winds
- sealing of the stockpile with clay, fly ash, soil or bitumen (to prevent access of oxygen).

Batter slumps have been recognised as very important to self-heating; such slumps induce fractures which allow easy access of oxygen. Temperature monitoring at key points in a stockpile (Cudmore 1984) can give warning of potential combustion problems.

TRACE ELEMENTS IN COAL

Trace elements can occur in one or more of four major modes within coal, viz

- combustible organic matter (coal itself)
- carbonate minerals and salts (commonly found in cleat)
- sulphides such as pyrite
- silicates, including quartz, clays and apatite (commonly in stony bands).

Eastern Australian black coals have a worldwide reputation for their low sulphur content and for their low levels of environmentally sensitive trace elements. However, the recent trend has been for regulatory authorities to monitor trace elements more closely.

Particular attention should be paid to those elements considered to be of the greatest environmental concern by the U.S. National Research Council (1980), viz

arsenic,	mercury,	boron,	molybdenum,
cadmium,	selenium,	lead,	uranium.

During combustion some elements become gaseous at furnace temperatures and can be absorbed into ash particles as cooling takes place. This is particularly the case for those elements which were originally located in the sulphides and organic matter in the coal.

CARBON DIOXIDE

Carbon dioxide emission rates can be related to tonnages of coal burnt to provide a measure of carbon dioxide generated per tonne of 'as received' coal, to thermal energy released to derive carbon dioxide generated per Gigajoule (GJ) and to thermal energy generated at power stations in terms of Gigawatt hours (GWh).

The coal quality parameters used in determining the quantity of carbon dioxide emissions are moisture (%), ash (%), specific energy (MJ/kg) and ultimate carbon (%).

Coal received by power stations contains surface moisture from various sources. In order to compare power stations at a standard moisture content, coal quality data must be converted to a common basis.

Specific energy (SE), measured in terms of megajoules per kilogram is the amount of total heat energy provided on combustion of a kilogram of coal. When burned in a power station furnace, carbon and hydrogen in the coal react exothermically with oxygen to form CO_2 and H_20. This combustion reaction is confined and occurs under constant pressure conditions. Water vapour and compounds such as sulphuric acid are passed into the atmosphere. It is not possible to reproduce these conditions in a laboratory so the determination of SE should be corrected in its application to furnace conditions.

In the laboratory, SE is determined in a closed system bomb calorimeter. The resultant value is the gross SE, which includes the heat given off by condensation of the water vapour in the sample.

Coal gross SE is used to derive figures for carbon dioxide emission on a thermal energy basis. The gross SE is usually not realisable in furnace conditions, a conversion to nett SE would provide a closer, more relevant estimation of SE in open system power station furnace conditions.

The ultimate carbon content is a measure of the total carbon content in all components of the coal.

Carbon dioxide is produced by the oxidation of carbon in the following reaction

$$C(solid) + O_2(gas) \longrightarrow CO_2(gas)$$

Considering the atomic weights of these elements ($C = 12$, $O = 16$, $CO_2 = 44$), 12 kg of carbon equates to 44 kg of CO_2, and 1 kg of carbon equates to 3.667 kg of CO_2.

As the total carbon content in coal is given by the ultimate carbon content (Ult C%), 3.667 x Ult C% tonnes = tonnes CO_2/tonne 'as received' coal.

The gross SE has been used to relate carbon dioxide emission to thermal energy released in terms of tonnes per gigajoule (GJ) with the following relationship

$$(3.667 \times \text{Ult C\%})/\text{SE (gross)} = \text{tonnes } CO_2/\text{GJ}$$

Carbon dioxide emission can be related to the energy generated at a power station in terms of tonnes per gigawatt hour (GWh). Given that carbon dioxide emission from a given power station is proportional to the energy generated, the relationship is given by the equation

$$3\,600 \times (3.667 \times \text{Ult C\%})/\text{SE (gross)} \times E/100 = \text{tonnes } CO_2/\text{GWh}$$

where E is the power station efficiency (sent out) derived from gross SE.

AIR, WATER AND NOISE FACTORS

G. Holt

INTRODUCTION

Exploration and mining should be compatible with community expectations for clean air, clean water and acceptable noise levels.

Clean air, clean waters and noise control Acts are in force in New South Wales, and cover all activities associated with coal exploration. Coal mining operations are licensed under the relevant Acts, and all activities within a coal lease, granted prior to coal mining, must comply with the various licence conditions. In exploration areas not covered by a coal lease, the general provisions of the pollution control Acts apply.

Apart from compliance with provisions of the Acts, coal exploration geologists are in an ideal position to gather and coordinate collection of environmental data necessary for the environmental impact assessment process, whether for a greenfield site or for extension of existing operations. Their training and experience makes them aware of the factors and processes operating in both the natural and 'improved' environments.

Consideration of the pollution potential of exploration and mining is driven by the requirements of extensive legislation, which includes the Heritage Act, the National Parks and Wildlife Act, Coal Mines Regulation Act, Environmental Hazardous Chemicals Act, plus the requirements of the Environmental Protection Act and the Environment (Administration) Act (1991), and the Environmental Offences and Penalties Act. In addition numerous Government Departments, Authorities and Corporations can set air, water and noise controls over land or facilities under their control.

For the exploration geologist the problem is one of being aware of the requirements of specific legislation and regulations, and their relevance to the site under examination.

LEGISLATION

In the 1980s environmental protection legislation replaced the State Pollution Control Commission with the Environmental Protection Authority, and at the same time widened the Authority's areas of responsibility. The legislation provides additional obligations for the protection of the environment, as well as commitment to sustainability of the environment.

Current legislation provides for the issue of combined licences and for three tiers of offences. Penalties range from on-the-spot fines through to penalties for all the various offences under air, water and noise legislation to the very high penalties for individuals and corporations which commit the most serious environmental vandalism.

The three operational Acts, which are administered by the Environmental Protection Authority, are the Clean Air Act (1961), Clean Waters Act (1970) and Noise Control Act (1975). These Acts are directly concerned with prevention of pollution and provide for the imposition of penalties for offences, which are set by means of the Environmental Offences and Penalties Act.

Clean Air Act 1961

The Clean Air Act 1961 controls the pollution of the atmosphere. Under the Act coal industry works capable of handling coal or carbonaceous material in excess of 200 t/day, or storing coal or reject material in dumps containing more than 5 000 t, are 'scheduled premises'. For such scheduled premises approval must be obtained for the alteration of the method of any trade, industry or process, or installation, or alteration or replacement of any industrial plant, if by doing so air pollution is likely to be caused or increased.

A licence must be held by the occupier of scheduled premises, and air pollution plant and control equipment must be operated satisfactorily and maintained to prevent or minimise air pollution.

In addition, Section 21 requires the owner of a mine or opencut workings to employ all practicable means for preventing combustion of any refuse deposited from the mine or opencut workings at the surface, and for preventing or minimising air pollution.

Although exploration done in areas other than mining leases is not scheduled under the Clean Air Act 1961, it is subject to Section 18 of the Act which relates to unscheduled premises. In effect, the standards that apply to scheduled premises apply also to unscheduled premises. Consequently, excessive burning off, for instance, should be avoided.

Clean Waters Act 1970

The Clean Waters Act 1970 controls the pollution of surface and ground water. As with the Clean Air Act 1961, mines are scheduled premises.

Under Section 19 of the Act approval is needed for the installation, construction or modification of any apparatus, equipment or works for the discharge of pollutants into waters, the treatment of pollutants prior to, and for the purposes of their discharge to waters and for the storage, treatment or disposal of wastes arising in the course of any process or operation carried on or in connection with any mine or open cut working by using a lagoon, pond, irrigation area, disposal field, well bore, mine shaft, pit, quarry, or trench.

As with the Clean Air Act, premises must be licensed, and water pollution plant and control equipment must be maintained satisfactorily.

Exploration other than on colliery holdings is in general not undertaken on scheduled premises. However, the Act requires no pollution of ground or surface water during exploration operations.

Noise Control Act 1975

Excessive noise is prohibited by the Noise Control Act 1975.

Under Section 27 of the Act, approval prior to construction is required for any premises which could be described as scheduled premises. This includes coal mine operations. Approval is also required for alteration of plant, or installation of new plant in scheduled premises if it is likely to cause or increase noise from those premises.

The occupier of scheduled premises must be licensed, and plant must be maintained in a satisfactory manner.

Exploration done on colliery holdings is done on scheduled premises. Exploration away from colliery holdings is subject to the general provisions of the Act. These provisions define, for instance, the hours of operation to be between 7.30 am and 10 pm.

Environmental planning and assessment legislation requires an Environmental Impact Statement as part of the planning approval process for new coal mining operations, or significant expansion of existing operations, before a coal mining lease can be issued.

It is important to be aware of the cross-links with coal mining legislation. For completeness, relevant provisions of the Coal Mining Act and Coal Mine Regulation Act are repeated in this paper.

Mining Act 1992

Part VII, Clauses 93 to 96 cover protection of the environment. Clause 93 is the operative clause, giving the Minister wide environmental powers. In deciding whether to invite or grant any form of coal concession the Minister shall take into account the need to conserve and protect the environment in or on the land over which the authorisation or concession is sought, and may require such studies (including environmental impact studies) as may be deemed necessary.

Remaining sections cover rights of entry for environmental studies.

Environmental Planning And Assessment Act 1979 (and Regulation 1980)

This Act provides the focus for environmental impact assessment in New South Wales. Coal mines are designated developments, and as such require not only Development Approval under local government rulings, but also Ministerial consent. Under Part IV, an environmental impact statement (EIS) must meet certain requirements. Clause 34 of the Environmental Planning and Assessment Regulation 1980 determines the contents of an EIS, and Clause 35 states that the Director of the Department of

Environment must be consulted, and any requirements set down by the Director must be complied with. Such requirements are usually set out on a case by case basis.

ENVIRONMENTAL CONTROL PROGRAMS AND TECHNIQUES

Environmental protection and pollution control mechanisms should be programmed into overall strategies to assess and mine coal deposits. Procedures appropriate to corporate objectives with regard to environmental protection should be in place prior to commencement of any field activities, and all personnel involved acquainted with the procedures. The overall environmental protection program should cover the issues listed below.

Air quality

The main potential pollutant is dust. Emissions from plant and combustion of materials rarely cause problems with coal exploration activities, although vehicle emissions are also controlled by regulations issued under the Clean Air Act.

Dust is an unavoidable result of coal exploration activities, just as it is from farming. However the community accepts dust resulting from farming, whereas it shows considerable concern over dust generated by coal mining and related activities.

Dust generated during exploration can be of local nuisance value. Since little nuisances often form the basis for greater resistance to proposed mining activities, close attention to the potential for generating nuisance dust is warranted. Construction of site access, drilling and vehicle movements during exploration cause localised nuisance dust, which needs to be minimised.

Wetting of unsealed tracks can reduce vehicle generated dust. Flexibility in locating access tracks and drilling sites can also reduce impact on neighbours. Communication with neighbours likely to be affected can also help to reduce the perceived nuisance level.

Drill site construction and rehabilitation need to be timed to minimise dust generation.

Recording of the location of properties and people who may be affected by future dust generation should be undertaken during exploration. Early identification of local wind directions will assist later detailed wind direction studies. Qualitative observations of wind speeds and variations can also guide future studies. Observations on local weather patterns may assist in identifying propensity for atmospheric inversions. Generally atmospheric inversions are more likely in flat country than in hilly terrain. When they occur, such inversions can cause significant atmospheric pollution problems.

Dust deposition gauges should be installed at the commencement of exploration, and analysed on a monthly basis. This should be done in consultation with environmental specialists, or at least after sensible assessment of likely dust sensitive areas and likely future locations of potential dust sources.

Seam gas

Early indications of the likely gas content of the coal seams to be mined are imperative for both mine planning and environmental control purposes. Current interest in the 'Greenhouse Effect' requires measures to limit methane emissions to the atmosphere,
with due regard for the need to control the mine environment and to utilise a valuable fuel source if possible. In opencut operations the release of gas from coal cannot be controlled, but in underground mines methane and CO_2 emissions can be controlled.

Exploration programs should include provision for gas collection and testing. Assistance can be obtained from coal testing laboratories and gas consultants. Coal geologists need to be familiar with seam gases, as well as the methods of gas detection and analysis and interpretation of results.

With the accelerating trend toward longwall operations the need for knowledge of seam gas properties and quantities has assumed critical importance. Early
test data will indicate the need for gas drainage investigations. Pre and post mining gas drainage are high cost procedures.

The propensity for spontaneous combustion can be determined from borecore analyses. Study of these is a prime requirement for mine planning purposes, but it also provides information on the likelihood of future coal combustion both in mine workings and reject emplacements.

Water pollution control

The requirement to avoid pollution of waterways is strict. Although it is impractical to carry out policing of each and every drill site and exploration activity, there is an obligation on geologists to act within the intent and spirit of the clean water regulations.

Absolute conformance with the requirements of the Clean Waters Act requires no discharge of pollutants, no additional erosion and no contamination of existing waterways from activities associated with exploration and mining.

A new classification of all waterways in New South Wales is expected to bring about tighter restrictions than those currently in force.

During conduct of exploration work, there are opportunities to record waterway locations, note use of water downstream from the site, observe signs of existing waterway degradation such as salinity, and note any features of waterways that may warrant further attention.

Initial water sampling should be undertaken at waterway junctions, bores, and large standing bodies of water. Sampling of dams needs to be treated with caution, as water quality in dams can vary according to stock use. The basic aim of such sampling is to determine water quality within and surrounding the site under examination.

Areas with unusual waterway conditions, such as swamps, hanging swamps, salt laden areas or tidal areas, need to be defined before commencement of exploration activities. Protection measures need to be developed, and if necessary written into contracts.

Exploration activities must not pollute any waterways. All exploration activities should be based on the principle that any dirty water is to be isolated from normal run-off.

Site access tracks, drilling pads and settling ponds, as well as bush clearance, all contribute to degradation of waterways. The main pollutants from such activities are suspended solids, with 50 ppm non-filtrable residue the normal limit, and oil and grease.

Drilling contractors must be encouraged to minimise ground disturbance, and control use and reuse of drilling water. Dirty water must not be discharged into any watercourse. Drillers' settling ponds need to be rehabilitated in such a way that sediment laden water does not discharge into any waterway. Grease and oil must not be dumped, but disposed of properly.

Similarly, run-off from tracks and drill sites must be diverted to settling structures, and controlled to prevent erosion. The Soil Conservation Service has produced guides for run-off control.

Other contractors must be required to conform with erosion protection practices, and these can be written into contracts.

Noise control

The most relevant sections of the Act affecting exploration activities are those relating to noise and operating hours. Generally, noisy equipment is restricted to being operated between 7 am and 10 pm if it is likely to affect neighbours. Weekend restrictions are tighter. Councils have noise control powers, as do the NSW Police.

As a guide, noise levels up to 5 dbA above ambient background are considered acceptable, provided the noise does not contain annoying characteristics such as low throbbing or high frequencies. However, consideration of neighbours is paramount in locating machinery that is capable of producing loud noise.

Noise problems can generally be reduced during drilling operations by simple expedients. These include building a fence of hessian or wood around a rig, locating a hole in a gully or behind natural barriers or in vegetation.

In planning new operations, geologists are well placed to provide preliminary information on the location of people and properties that might be affected by the noise associated with mining.

Coal Geologist's Role

The activities most directly under the geologist's control are those related to coal exploration.

Exploration activities provide the opportunity to undertake qualitative assessments of the existing environment, assess likely impacts, and plan both control and amelioration measures. Opportunity also exists for quantitative data collection, particularly on air and water aspects.

The requirements for both pollution control and environmental assessment should be incorporated in the planning, development and operation of exploration programs. Particular attention should be paid to the rehabilitation phases of programs.

Exploration activities are not designated activities, or scheduled activities under environmental and pollution control legislation. Continued attention to concern for the environment, and attention to pollution control will maintain this situation.

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APPENDIX 1

NSW LEGISLATION RELEVANT TO ENVIRONMENTAL ASSESSMENT OF COAL EXPLORATION AND MINING AREAS

Mining Act, 1992

This Act allows for the granting of Exploration Licences to explore for coal (Group 9 minerals) and the tendering of exploration areas.

Private agricultural land can be referred to the Director-General of Agriculture to assess land use options — agriculture or mining.

The Act provides for conservation and protection of flora, fauna, fish, fisheries, scenic attractions and features of architectural, archaeological, historical or geological interest.

Coal Mines Regulation Act 1982

Environmental Planning and Assessment Act 1979 (and Regulation 415 1994)

Coal exploration is exempt from planning consent under the EPA Act because it is not a 'prescribed activity' under Part V of the Act. The Department of Mineral Resources is the determining authority for such areas; it will require preparation of an EIS if the proposed exploration is likely to significantly affect the environment.

Any resulting coal mine is a prescribed activity under the Act and requires a Development Application and an accompanying EIS.

Clean Air Act 1961

Coal industry works capable of handling coal or carbonaceous material in excess of 200 t/day, or storing coal or reject material in dumps containing more than 5 000 t, are 'scheduled premises' under the Clean Air Act. Coal exploration activities do not fall within this definition, but monitoring is required for baseline studies. Exploration, although not scheduled, is covered by Section 19 of the Act which controls the emission of smoke and impurities.

Noise Control Act 1975

Under Section 27 of the Noise Control Act, approval prior to construction is required for any premises which could be described as scheduled premises. This includes coal mining operations and any 'noisy' activities during coal exploration.

Clean Waters Act 1970

The Water Resources Commission, under the Clean Waters Act, imposes conditions to protect waterways during coal exploration (under conditions of Authorisations) and coal mining (as part of Development approval). Early monitoring programs are important in this regard.

Petroleum (Onshore) Act 1991

This Act controls coal seam methane.

Miscellaneous Acts

Acts administered by other Government Departments controlling such areas as Forestry, Agriculture, Roads, National Parks and Wildlife and Soil Conservation contain provisions to ensure that the Department of Mineral Resources refers to those Departments all proposed coal mine developments. In special circumstances, coal exploration proposals are referred, but Authorisation conditions include the general requirements of those Departments.

PERMIAN STRATIGRAPHY OF THE GUNNEDAH BASIN

N. Z. Tadros

INTRODUCTION

Over a history spanning more than half a century, and in contrast to the Sydney and Bowen Basins, only a few stratigraphic schemes have been established, for various areas and districts in the Gunnedah Basin (figure 1) (eg, Coonabarabran–Gunnedah area — Kenny 1928; 1929; 1964; the regions between Narrabri and Breeza — Hanlon 1949a, b, c; 1950a, b; the Gunnedah–Curlewis district — Manser 1965a, b; the Dubbo–Binnaway–Wollar region — Dulhunty 1973a, b; the Merrygoen–Digilah district — Higgins & Loughnan 1973; the Narrabri–Coonabarabran area — Bourke & Hawke 1977; and the Maules Creek area — Brownlow 1981; table 1 and figure 2).

It was not until Russell (1981) integrated the previous schemes that a simplified stratigraphic framework for the northern part of the Gunnedah Basin came into use. Russell's (1981) scheme was only a preliminary attempt based on limited information at the time. Detailed sedimentological studies of the rocks were not available to him and rigorous definition of many of the stratigraphic units was not possible. However, his scheme was useful as a framework for further studies which were undertaken when data became available as a result of extensive exploration by the New South Wales Department of Mineral Resources and coal exploration companies.

The Liverpool Range constituted a natural geographic barrier which influenced geological investigations in the Sydney–Gunnedah Basin. Areas to the south received greater interest from geologists than those in the north as a result of the intensive coal mining activities in the upper Hunter Valley and Western Coalfield regions. As a result, stratigraphic terminologies evolved separately north and south of the Liverpool Range. In the south, Sydney Basin stratigraphy and terminology have been used. Now that the Gunnedah Basin is a recognised entity, workers trying to establish basin stratigraphy to encompass the whole of the Gunnedah Basin, including areas to the south of the Liverpool Range, are faced with problems of terminology and the several stratigraphic schemes of the Sydney Basin.

Further, the terminologies used in the south are deeply entrenched and any attempt to change them will only create confusion. Therefore, this paper aims at:

(a) presenting an up-to-date comprehensive definition and description of the lithostratigraphy of the

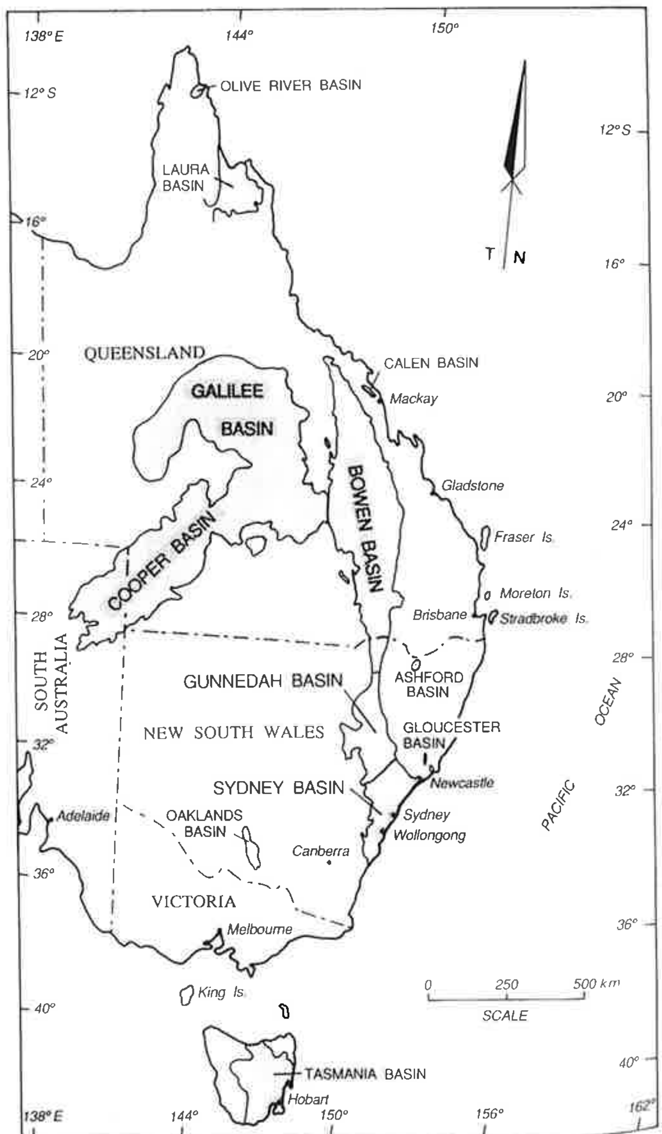


Figure 2: Location of Permian coal-bearing basins of eastern Australia

TABLE 1
PREVIOUS STRATIGRAPHIC NOMENCLATURE IN THE GUNNEDAH BASIN
(after Russell 1981)

Kenny 1928,1929	Hanlon 1949a	Hanlon 1949b	Hanlon 1949c	Hanlon 1950a	Hanlon 1950b	Kenny 1964	Manser 1965a,b	Dulhunty 1973a,b	Higgins & Loughnan 1973	Bourke & Hawke 1977	Brownlow 1981b	Russell 1981
Coonabarabran - Gunnedah	Gunnedah - Curlewis	Breeza	Southwest County Nandewar	Boggabri	Narrabri	Coonabarabran - Gunnedah	Gunnedah - Curlewis	Dubbo - Binnaway - Wollar	Merrygoen - Digilah	Narrabri - Coonabarabran (subsurface)	Maules Creek	Gunnedah Basin
Pilliga Series						Pilliga Beds		Pilliga Ss	Pilliga Ss	Orallo Fm Pilliga Ss		Orallo Fm Pilliga Ss
Purlawaugh Series						Purlawaugh Beds		Purlawaugh Fm Ballimore Fm	Digilah Fm Ukebung Creek Cs	Purlawaugh Fm		Purlawaugh Fm
Contemporaneous Lavas						Garrawilla Lavas		Garrawilla Volcanics*1		Garrawilla Volcanics*2		Garrawilla Volcanics
Napperby Series						Napperby Beds		Talbragar Fm	Wallingarah Creek Fm	Wallingarah Creek Fm		Napperby Fm
Digby Series	Digby Beds					Digby Beds	Digby Beds	Wollar Ss	Boulderwood Cglt	Wollar Ss		Digby Cglt
	Black Jack Fm	Black Jack Fm		Booromin Group	Upper Coal Measures	Gunnedah & Curlewis CM	Black Jack Fm	Ulan Coal Measures	Dunedoo Fm	Black Jack Fm		Black Jack Fm*3
	Gladstone Fm	Watermark Fm			Barra Group		Gladstone Fm					Watermark Fm
	Porcupine Fm						Porcupine Fm			Porcupine Fm		Porcupine Fm
	Lower Coal Measures		Nandewar Group - Vickery Cglt - Wean Fm		Nandewar Group*4		Condadilly Fm Gunnible Fm			Wean Fm	Maules Creek Fm	Maules Creek Fm
	Lower Marine Series (Boggabri Volcanics, Werrie Basalt)		Boggabri Volcanics	Boggabri Volcanics		Gunnedah Lavas	Werrie Basalt Gunnedah Volcanics			Boggabri Volcanics & Werrie Basalt	Leard Fm Boggabri Volcanics	Leard Fm Boggabri Volcanics & Werrie Basalt

*1 Garrawilla Volcanics introduced by Dulhunty (1967)
*2 Unnamed Triassic Section present in DM Moema DDH 1A above Wallingarah Creek Fm
*3 Black Jack Coal Measures used by Branagan (1969) and others
*4 Nandewar Coal Measures and Wean Coal Measures used in later works by Hanlon

Gunnedah Basin north of the Liverpool Range (table 2);

(b) retaining Sydney Basin terminology for those areas of the Gunnedah Basin south of the Liverpool Range; and

(c) providing correlations of equivalent stratigraphic units in the Sydney and Gunnedah Basins.

The expanded knowledge of the Gunnedah Basin sequences allowed correlation, not only of its stratigraphy but also of its depositional history, with those of the Sydney Basin. The correlation with the Sydney Basin is given in table 3.

Formal definition of coal units in this study has been limited to those units which are characterised by relatively minor amounts of intra-seam sedimentary rocks, clear boundary definition and where they coalesce with other coal units they maintain their identity. Two of these coal units have been most extensively studied and correlated with reliability: the Hoskissons Coal and Melvilles Coal Member. Locally, the coal seams may split, but without great loss of identity.

The new stratigraphy of the Gunnedah Basin has been published in Tadros (1993a, e; 1995). The new Gunnedah Basin Stratigraphy (table 2) is now widely used by workers from the coal and petroleum exploration and mining industries and from universities.

TABLE 2

NEW LITHOSTRATIGRAPHY FOR THE GUNNEDAH BASIN

NEW STRATIGRAPHY (Tadros 1993a, e; 1995 & herein)									DEPOSITIONAL SYSTEMS (modified from Tadros 1986b, Tadros & Hamilton 1991, Hamilton 1993a & herein)	DEPOSITIONAL EPISODES (modified from Hamilton 1993a, Hamilton and Tadros 1994 and herein)
PERIOD		PALY. ZONE	GROUP	SUBGROUP	FORMATION	MEMBER	SEAM	GAMMA low → high / NEUTRON low → high		
					GARRAWILLA VOLCANICS				GARRAWILLA VOLCANICS	GARRAWILLA VOLCANICS
TRIASSIC	MIDDLE				DERIAH FORMATION					
		A. parvinospinosus / C. senectus			NAPPERBY FORMATION				NAPPERBY LACUSTRINE SYSTEM	NAPPERBY DEPOSITIONAL EPISODE
	EARLY	P. walkomii / A. wollarensis			DIGBY FORMATION	ULINDA SANDSTONE; BOMERA CONGLO.			DIGBY ALLUVIAL SYSTEM	DIGBY DEPOSITIONAL EPISODE
PERMIAN	LATE	UP STAGE 5c	BLACK JACK GROUP	NEA SUBGROUP	TRINKEY FORMATION	SPRINGFIELD C.M.; CLIFT C.M.	DOONA		EASTERN FLUVIAL SYSTEM	EASTERN (UPPER BLACK JACK) DEPOSITIONAL EPISODE
					WALLALA FORMATION					
		UP STAGE 5		COOGAL SUBGROUP	CLARE SANDSTONE	BREEZA C.M.			LACUSTRINE & WESTERN FLUVIAL SYSTEMS	WESTERN (UPPER BLACK JACK) DEPOSITIONAL EPISODE
					BENELABRI FM.	HOWES HILL C.M.; CAROONA C.M.				
					HOSKISSONS COAL				HOSKISSONS PEAT-SWAMP SYSTEM	
				BROTHERS SUBGROUP	BRIGALOW FM. / ARKARULA FORMATION				ARKARULA SHALLOW-MARINE SYSTEM	UPPER WATERMARK-LOWER BLACK JACK/ ARKARULA DEPOSITIONAL EPISODE
		L.STAGE 5a-5c			PAMBOOLA FORMATION	MELVILLES C.M.			UPPER WATERMARK/ LOWER BLACK JACK DELTA SYSTEMS	
		L.STAGE 5b – L.STAGE 5c	MILLIE GROUP		WATERMARK FORMATION				PORCUPINE - LOWER WATERMARK MARINE-SHELF SYSTEM	LEARD-MAULES CREEK/ PORCUPINE-LOWER WATERMARK DEPOSITIONAL EPISODE
		UP.STAGE 4 – L.STAGE 5b			PORCUPINE FORMATION					
	EARLY	ST.3 – L-UP_ ST.4 / L.ST.4 ST.4	BELLATA GROUP		MAULES CREEK FORMATION		BROWN		LEARD - MAULES CREEK ALLUVIAL/LACUSTRINE SYSTEMS	
					GOONBRI & LEARD FORMATIONS					
		STAGE 2			BOGGABRI VOLCANICS WERRIE BASALT METAVOLCANICS & METASEDIMENTS				BOGGABRI VOLCANICS AND WERRIE BASALT	VOLCANIC EPISODES

TABLE 3

CORRELATION OF LITHOSTRATIGRAPHIC UNITS, GUNNEDAH AND SYDNEY BASINS

GUNNEDAH BASIN	HUNTER COALFIELD	NEWCASTLE COALFIELD	WESTERN COALFIELD	SOUTHERN COALFIELD
DERIAH FORMATION				WIANAMATTA GROUP
NAPPERBY FORMATION		HAWKESBURY SANDSTONE		HAWKESBURY SANDSTONE
DIGBY FORMATION	NARRABEEN GROUP	TERRIGAL & NEWPORT FORMATIONS; NARRABEEN GROUP	NARRABEEN GROUP	NARRABEEN GROUP
BLACK JACK GROUP — NEA SG.: TRINKEY FORMATION	SINGLETON SUPERGROUP — WOLLOMBI C.M.	NEWCASTLE C.M.	ILLAWARRA COAL MEASURES — WALLERAWANG SUBGP	ILLAWARRA COAL MEASURES — SYDNEY SUBGROUP
WALLALA FORMATION	Watts Ss.	Waratah Ss.		
COOGAL SUBGROUP: BENELABRI FORMATION; CLARE SANDSTONE	WITTINGHAM COAL MEASURES — Denman Fm.	TOMAGO COAL MEASURES — Dempsey Fm.	Baal Bone Fm.	Bargo Claystone
HOSKISSONS COAL	JERRYS PLAINS SUBGROUP		CHARBON SUBGROUP	
BROTHERS SUBGROUP: BRIGALOW FORMATION; ARKARULA FORMATION	Archerfield Ss.	Kulnura M.T.	CULLEN BULLEN SUBGROUP	
	Bulga Fm.		Marrangaroo Cgl.	Erins Vale Fm.
PAMBOOLA FORMATION	VANE SUBGROUP		NILE SUBGROUP	CUMBERLAND SUBGP
			SHOALHAVEN GROUP — Budgong Sandstone	SHOALHAVEN GROUP — Budgong Sandstone; Gerringong Volcanics
			Berry Siltstone	Berry Siltstone
MILLIE GROUP — WATERMARK FORMATION	MAITLAND GROUP — Mulbring Siltstone	MAITLAND GROUP — Mulbring Siltstone		Nowra Sandstone
PORCUPINE FORMATION	Muree Sandstone	Muree Sandstone		Wandrawandian Slst.
	Branxton Formation	Branxton Formation	Snapper Point Fm.	Snapper Point Fm.
BELLATA GROUP — MAULES CREEK FORMATION	GRETA C.M. — Rowan Formation	GRETA COAL MEASURES	METASEDIMENTS & GRANITE	Y.C.M.; YADBORO & TALLONG CGS.; PEBBLEY BEACH FORMATION
LEARD & GOONBRI FORMATIONS	Skeletar Formation			
BOGGABRI VOLCANICS & WERRIE BASALT; METAVOLCANICS & METASEDIMENTS	GYARRAN VOLCANICS — Farley Fm.	DALWOOD GROUP — Farley Formation		
	Rutherford Fm.	Rutherford Formation		
	Allandale Fm.	Allandale Formation		TALATERANG GROUP — CLYDE C.M.; WASP HEAD FM.; P.H.C. Sl.
	Lochinvar Fm.	Lochinvar Formation		
	Seaham Formation	Seaham Formation		

Y.C.M. = Yarrunga Coal Measures P.H.C. Sl. = Pigeon House Creek Siltstone

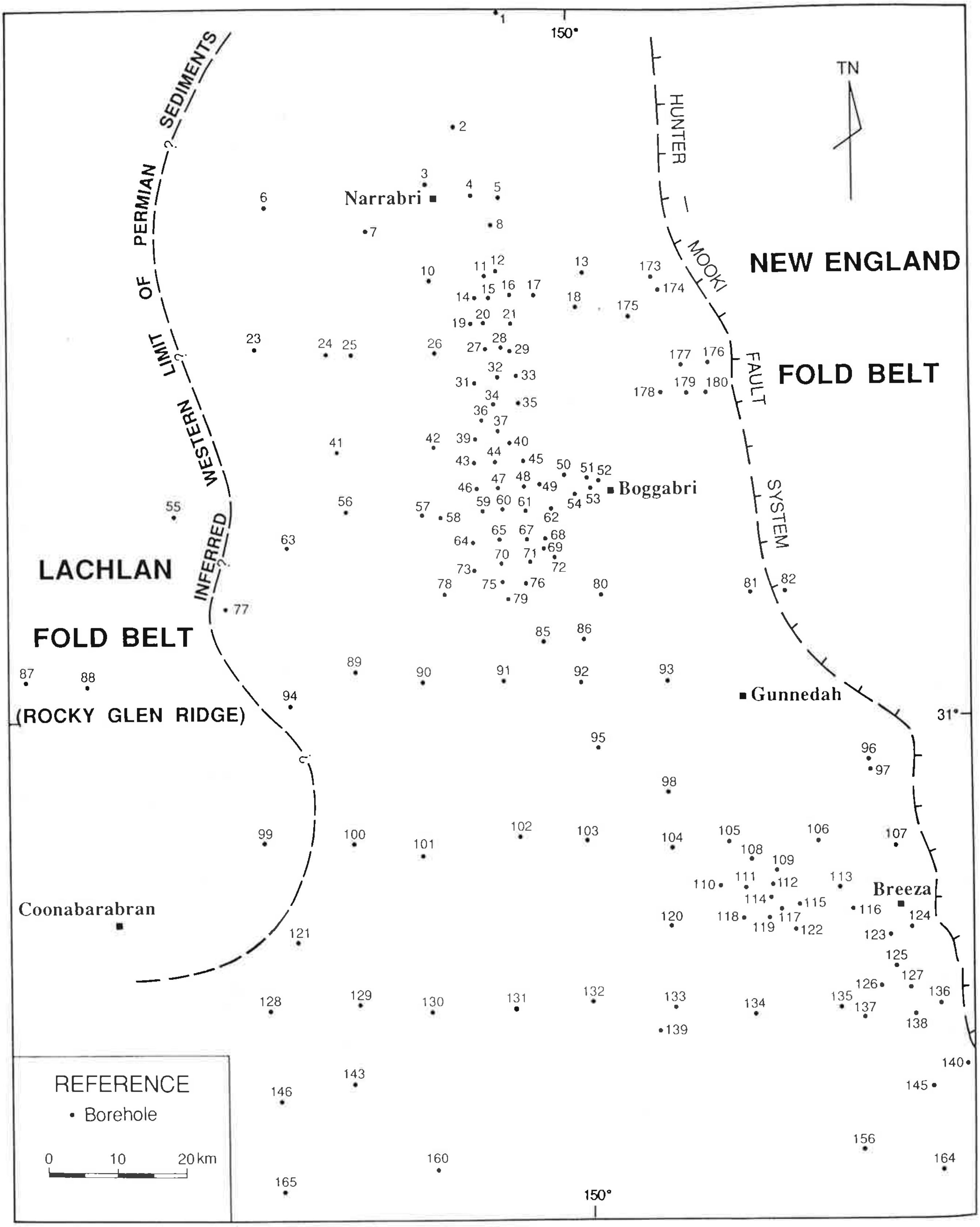


Figure 2a. Location of boreholes referred to in the text (see figure 2b for list)

In this paper, locations of boreholes referred to in the text are given in figure 2.

FLOOR OF THE GUNNEDAH BASIN

BOGGABRI VOLCANICS AND WERRIE BASALT

Late Carboniferous to Early Permian silicic to mafic volcanic rocks form the effective basement/floor for much of the Gunnedah Basin east of the Rocky Glen Ridge (Mullaley and Maules Creek Sub-basins, figure 3). The exposed parts of the Boggabri Ridge in the east provide the only documented outcrops of the basal volcanic units in the basin. Recently, however, Tadros (1993c) reported an outcrop north of Coonabarabran consisting of silicic volcanic rocks indistinguishable from the Boggabri Volcanics north

Borehole Name	Map Ref No.
DM Arrarownie DDH 1	55
DM Bando DDH 1 (BDO)	102
Amoseas Baradine West No. 1	84
Amoseas Baradine West No. 2	83
DM Benelabri DDH 1 (BLI)	92
DM Benelabri DDH 2 (BLI)	85
DM Benelabri DDH 3 (BLI)	86
DM Blake DDH 1 (BKE)	10
DM Boggabri DDH 1 (BOG)	50
DM Boggabri DDH 2 (BOG)	52
DM Boggabri DDH 3 (BOG)	51
DM Boggabri DDH 4 (BOG)	53
DM Boggabri DDH 5 (BOG)	54
Amoseas Bohena No. 1	24
DM Bomera DDH 1 (BMA)	131
DM Borah DDH 1 (BRH)	94
DM Breeza DDH 1 (BZA)	114
DM Breeza DDH 2 (BZA)	113
DM Brigalow DDH 1 (BGW)	90
DM Brigalow DDH 2 (BGW)	89
DM Brothers DDH 1 (BRS)	118
DM Brown DDH 1, 1A (BWN/BRN)	108
DM Brown DDH 2 (BWN/BRN)	110
DM Caroona DDH 1 (CRA)	137
DM Caroona DDH 2 (CRA)	140
DM Caroona DDH 3 (CRA)	125
DM Caroona DDH 4 (CRA)	136
DM Clift DDH 1 (CFT)	115
DM Clift DDH 2 (CFT)	119
DM Clift DDH 3 (CFT)	116
DM Clift DDH 4 (CFT)	122
DM Clift DDH 5 (CFT)	117
DM Coogal DDH 1 (CGL)	91
DM Cookabingie DDH 1 (CKE)	143
DM Coolanbilla DDH 1 (CBA)	133
DM Coolanbilla DDH 2 (CBA)	139
DM Curlewis DDH 1 (CWS)	106
DM Dampier DDH 1 (DMP)	23
DM Denison DDH 1 (DSN)	79
DM Denison West DDH 1 (DWT)	78
DM Dewhurst DDH 1	56
DM Digby DDH 1 (DGY)	105
DM Dight DDH 1	96
DM Dight DDH 2	97
DM Doona DDH 1 (DNA)	135
DM Emerald Hill DDH 1	80
DM Eulah DDH 1	13
DM Ferrier DDH 1, 1A	124
DM Ferrier DDH 2	123
DM Galloway RDH 1	63
DM Girrawillie-Bulga DDH 1 (GWE)	100
DM Goran DDH 1 (GRN)	104
DM Goran DDH 2 (GRN)	103
DM Gorman DDH 1 (GMN)	26
DM Gunnadilly DDH 1 (GOY)	145
DM Gunnedah DDH 1 (GDA)	93
DM Hall DDH 1 (HAL)	88
DM Howes Hill DDH 1 (HHL/HWL)	120
DM Jacks Creek DDH 1	25
MEO Kelvin No. 1	82
DM Killarney DDH 1 (KLY)	5
DM Maules Creek DDH 1	175
DM Maules Creek DDH 2	179
DM Maules Creek DDH 2	177
DM Maules Creek DDH 4	178
DM Maules Creek DDH 5	180
DM Maules Creek DDH 6	176
DM Maules Creek DDH 7	173
DM Maules Creek DDH 8	174
DM Millie DDH 1 (MLE)	95
DM Moema DDH 1	1
DM Morven DDH 1 (MVN)	165
DM Napier DDH 1 (NPR)	160
DM Narrabri DDH 1B (NRI)	3
DM Narrabri DDH 2 (NRI)	2
DME Narrabri DDH 1 (NRI)	73
DME Narrabri DDH 2 (NRI)	64
DME Narrabri DDH 3 (NRI)	59
DME Narrabri DDH 4 (NRI)	46
DME Narrabri DDH 5 (NRI)	43
DME Narrabri DDH 6 (NRI)	39
DME Narrabri DDH 7 (NRI)	70
DME Narrabri DDH 8 (NRI)	65
DME Narrabri DDH 9 (NRI)	47
DME Narrabri DDH 10 (NRI)	44
DME Narrabri DDH 11 (NRI)	34
DME Narrabri DDH 12 (NRI)	32
DME Narrabri DDH 13 (NRI)	27
DME Narrabri DDH 14 (NRI)	20
DME Narrabri DDH 15 (NRI)	15
DME Narrabri DDH 16 (NRI)	8
DME Narrabri DDH 17 (NRI)	71
DME Narrabri DDH 18 (NRI)	67
DME Narrabri DDH 19 (NRI)	61
DME Narrabri DDH 20 (NRI)	48
DME Narrabri DDH 21 (NRI)	45
DME Narrabri DDH 22 (NRI)	40
DME Narrabri DDH 23 (NRI)	35
DME Narrabri DDH 24 (NRI)	33
DME Narrabri DDH 25 (NRI)	29
DME Narrabri DDH 26 (NRI)	21
DME Narrabri DDH 27 (NRI)	16
DME Narrabri DDH 28 (NRI)	4
DME Narrabri DDH 29 (NRI)	31
DME Narrabri DDH 30 (NRI)	19
DME Narrabri DDH 31 (NRI)	72
DME Narrabri DDH 32 (NRI)	68
DME Narrabri DDH 33 (NRI)	62
DME Narrabri DDH 34 (NRI)	49
DME Narrabri DDH 35 (NRI)	17
DME Narrabri DDH 37 (NRI)	14
DME Narrabri DDH 38 (NRI)	12
DME Narrabri DDH 39 (NRI)	36
DME Narrabri DDH 40 (NRI)	75
DME Narrabri DDH 41 (NRI)	76
DM Nea DDH 1 (NEA)	109
DM Nea DDH 2 (NEA)	111
DM Nea DDH 3 (NEA)	112
DM Nombi DDH 1 (NBI)	101
DM Parkes DDH 1 (PKS)	57
DM Parkes DDH 2 (PKS)	58
DM Parkes DDH 3 (PKS)	42
DM Parsons Hill DDH 1 (PNL)	164
MEO Pilliga No. 1	41
DM Purlawaugh DDH 1 (PWH)	121
Alliance Quirindi No. 1	156
DM Springfield DDH 1 (SFD)	134
DM Terrawinda DDH 1 (TWA)	128
DM Texas DDH 1 (TXS)	107
DM Tinkrameanah DDH 1 (TKH)	129
DM Trinkey DDH 1 (TCY)	132
DM Tullamullen DDH 1 (TLN)	37
DM Tunmallallee DDH 1	77
DM Turrawan DDH 1 (TWN)	28
DM Turrawan DDH 2A	11
DM Ulinda DDH 1 (UDA)	146
DM Wallah DDH 1	18
DM Wallala DDH 1 (WLA)	126
DM Wallala DDH 2 (WLA)	127
DM Wallala DDH 3 (WLA)	138
DM Walla Walla DDH 1 (WWA)	60
DM Walla Walla DDH 2 (WWA)	69
Amoseas Wee Waa No. 1	6
CPA Wilga Park No. 1	7
DM Wilson DDH 1 (WSN)	130
DM Wondobah DDH 1 (WDH)	98
DM Worigal DDH 1	87
DM Yaminba DDH 1	99
DM Yarrari DDH 1	81

†		Boreholes listed in this table are those north of the Liverpool Range and were extensively used in this study. (Abbreviations of borehole names used in this study are shown in brackets)
MEO	=	Mid-Eastern Oil N.L.
Amoseas	=	American Overseas Petroleum Ltd
Alliance	=	Alliance Petroleum Australia N.L.
DM	=	New South Wales Department of Mines/Mineral Resources
DME	=	New South Wales Department of Mines/Mineral Resources and Electricity Commission (now Pacific Power)
MEO	=	Mid-Eastern Oil N.L.
CPA	=	Consolidated Petroleum
DDH	=	Diamond Drill Hole
RDH	=	Rotary Drill Hole
Map Ref No.	=	Map reference number shown on borehole locality map figure

Figure 2b. List of boreholes (with abbreviations of selected borehole names)

of Boggabri. Where intersected by drilling in the Mullaley Sub-basin, the basal volcanic sequence consists mostly of undeformed lavas, tuffs and intercalated sedimentary rocks. Mafic volcanic rocks were intersected in most drill holes except along the western margin of the Mullaley Sub-basin and in an area between Gunnedah and Narrabri in the north-east, where silicic volcanic rocks are present (figure 3).

Hanlon (1949a), Russell (1981) and Beckett *et al.* (1983) have correlated the silicic volcanic rocks with the Boggabri Volcanics (Hanlon 1949c), and the intermediate to mafic volcanic rocks with the Werrie Basalt, both of Early Permian age. On the basis of outcrop at Gunnedah, Hanlon (1949a) considered the Boggabri Volcanics and Werrie Basalt to be coeval. Leitch (1993) considered basal silicic volcanic outcrops (rhyolitic lavas and pyroclastic units) at Gunnedah, known as the "Gunnedah Volcanics" (eg, Manser 1965a, b), to be of similar composition and stratigraphic position to, and therefore the same unit as, the Boggabri Volcanics. Based on usage, the term Boggabri Volcanics is now preferred. A detailed discussion on the composition of the basal volcanic rocks was given by Leitch (1993).

The top of the basal volcanic units is deeply weathered, and this is taken to indicate an unconformity on top of the basal volcanic sequence.

LACHLAN FOLD BELT BASEMENT

Metavolcanic and metasedimentary rocks of the Lachlan Fold Belt form much of the basement underneath the Gilgandra Sub-basin west of the Rocky Glen Ridge in the western part of the Gunnedah Basin. Outcrops of Palaeozoic talcose schist, phyllite, slate and tuff are present to the north of Coonabarabran and represent the exposed part of the Rocky Glen Ridge. Ignimbritic volcanic rocks with affinity to the Lachlan Fold Belt were intersected at the base of DM Arrarownie DDH 1 located on the subsurface extension of the Rocky Glen Ridge, some 60 km north of Coonabarabran (figure 3; Leitch 1993). Low grade metamorphosed quartzose sandstone and argillites of the Lachlan Fold Belt were encountered in AMOSEAS (American Overseas) Baradine West Nos 1 and 2. Detailed descriptions of the Lachlan Fold Belt rocks forming the floor of the Gunnedah Basin were given by Leitch (1993).

BELLATA GROUP (Tadros 1993a, 1995)

Named after Bellata, some 50 km north of Narrabri, the Bellata Group (table 2; Tadros 1993a, 1995) contains all Early Permian lithostratigraphic units in the Gunnedah Basin (the Leard, Goonbri and Maules Creek Formations).

Type section

The type section for the Bellata Group is a composite of the type sections for the contained formations.

Lithology

The Bellata Group consists of three distinct lithological units: a flint clay, conglomerate, sandstone, siltstone unit commonly interbedded with coal (Leard Formation); a dark organic-rich siltstone to claystone laminite unit coarsening upward through to burrowed, graded siltstone–claystone to medium-grained sandstone (Goonbri Formation); and a third unit consisting of lithic conglomerate, sandstone, claystone, quartzose sandstone and coal (Maules Creek Formation).

Relationships and boundary criteria

This group unconformably overlies the basal volcanics, and the contact with the overlying Late Permian marine Millie Group varies from conformable to unconformable.

Age and evidence

Age of the Bellata Group is Early Permian Stage 3 to Upper Stage 4a (McMinn 1993).

Correlations

The Leard and Maules Creek Formations of the Bellata Group are broadly correlated with the Greta Coal Measures in the Sydney Basin, whereas the Goonbri Formation is time-equivalent of the uppermost part of the Dalwood Group (McMinn 1981; Thomson 1986a, b).

Palaeoenvironment

The Bellata Group comprises mainly colluvial, fluvial, lacustrine and coal measure deposits.

Leard Formation

(re-definition: Tadros 1993a; 1995)

The Leard Formation (Brownlow 1981) is the basal unit in the Gunnedah Basin sedimentary sequence (cf table 2). Named after the Leard State Forest, approximately 20 km northeast of Boggabri, the Leard Formation was informally introduced by Brownlow (1976; 1977) and formally defined by Brownlow (1981). The Leard Formation, as described by Brownlow (1981), comprises a lithologically distinctive Early Permian flint claystone (pelletal claystone) present in outcrops on the eastern side of the Boggabri Ridge and in drill core from exploration holes in the Maules Creek Sub-basin.

The only previously documented outcrops of the flint claystone sequence (Brownlow 1981) occur in the Leard State Forest, particularly along the eastern margin of the outcrops of the Boggabri Volcanics. The outcrops are sporadic and generally of less than two metres relief. They have a characteristic weathering pattern of small patches of angular claystone granules at the base of a small ledge, which marks the base of the overlying Maules Creek Formation (Brownlow 1981). Tadros (cf 1993h) mapped flint clay outcrops in the banks of a small creek to the west of Wondobah Road along the southwestern outskirts of Gunnedah.

The distinctive lithology was first specifically recorded by Loughnan (1975), who described Early Permian flint clays from the Wingen, Muswellbrook, Willow Tree and Gunnedah areas. Tadros (1982) described a 17.4 m section of similar claystone in DM Boggabri DDH 2 and extended the correlation to the western side of the Boggabri Ridge to the west of Boggabri. The term Leard Formation has since been used to encompass all pelletal claystones which rest on the weathered basal volcanic rocks in the Gunnedah Basin, north of the Liverpool Range.

However, Thomson (1986b) had considered the upper part of the Leard Formation to be astratigraphic unit transitional between the Leard Formation and Maules Creek Formation and named it the "Baan Baa Formation". He described the "Baan Baa Formation" as "massive to finely pelletoidal claystone ... minor interbeds of non-pelletoidal clastic detritus appear near the upper boundary" (appendix I in Thomson 1986b).

That description is almost identical to that recognised for the Leard Formation. Both formations have similar lithological characteristics and boundary relationships with the underlying basal volcanic rocks and the overlying Maules Creek Formation. They also have discontinuous distribution in the basin, and are of similar age (older than the Maules Creek Formation). The only remaining criterion for differentiation from the Leard Formation is based on the interpretation of environment of deposition of the "Baan Baa Formation" but not its lithology; "... it [the Baan Baa Formation] tends to be more alluvial (rather than colluvial) in character ..." (appendix I in Thomson 1986b).

It should be emphasised that both the Leard Formation and "Baan Baa Formation" consist of pelletoidal claystone of similar lithological and sedimentological characteristics and that the upper boundary for both formations is marked by the appearance of lithic units of the Maules Creek Formation.

Borehole control in the Maules Creek Sub-basin is superior to that in the Mullaley Sub-basin. This allowed Thomson (1986a, b) to decipher the relationship between the Maules Creek and Leard Formations. Thomson (1986b) found that clastic units and coal seams extend from the Maules Creek Formation into the Leard Formation, thus producing the interbedding near the top of the Leard Formation (by fluvial/alluvial reworking).

A similar process (fluvial/alluvial reworking) has been suggested for the upper parts of the Leard Formation in the Mullaley Sub-basin (Tadros 1982; Beckett *et al* 1983; Thomson 1986b).

For the above mentioned reasons, The term Baan Baa Formation should be abandoned and the term Leard Formation as defined and described below should remain. It should be noted that since its introduction, the term Baan Baa Formation has not been used by workers in the Gunnedah Basin.

Type section

Brownlow (1981) assigned the 8.63 m interval between 460.93 m and 469.56 m in DM Maules Creek DDH 5 (GR 315214, Manilla 1:250 000 map sheet) as the type section for the Leard Formation.

Reference section

Core from the interval 581.07 m to 594.00 m in DM Benelabri DDH 1 is taken as the reference section for the Leard Formation in the Mullaley Sub-basin (figure 4a).

Thickness

The Leard Formation forms a thin horizon a few metres thick in the Maules Creek Sub-basin. In the Mullaley Sub-basin, the Leard Formation is discontinuous and, where present, its thickness is variable — with a maximum ranging from 12 m to 17.5 m.

Lithology

Brownlow (1981) defined rocks of Leard Formation as consisting of buff coloured flint clay, conglomerate, sandstone and siltstone, commonly interbedded with coal. The clasts are kaolinite clay pellets, generally less than 25 mm in diameter and commonly containing relict volcanic textures (Loughnan 1975). The rock parts with a conchoidal fracture. A black carbonaceous matrix and interbeds of typically dull coal may be present, particularly towards the top.

Relationships and boundary criteria

The Leard Formation is a diachronous unit (Thomson 1984; 1986a, b), which overlies irregularly eroded and in part deeply weathered surfaces on the Boggabri Volcanics (and Werrie Basalt?, table 2). The formation is best described as forming a thin discontinuous veneer on the basal volcanic rocks.

The boundary between the Leard Formation and the underlying basal volcanic rocks in the Maules Creek and Mullaley Sub-basins is not readily distinguishable as the formation is in part a colluvial deposit derived mainly from weathering of the basal volcanic rocks. The upper boundary is taken at the lowermost occurrence of lithic sediments which constitute the overlying Maules Creek Formation (Brownlow 1981). In the Maules Creek area, the Leard Formation exists below the lower seams of the Maules Creek Formation distal to the Boggabri Ridge (Thomson 1986b). Close to the ridge the Leard Formation underlies the upper seams. In the Maules Creek Sub-basin, clastic units and coal seams extend from the Maules Creek Formation into the Leard Formation prior to onlap against the basal volcanics (figures 5, 6) indicating that a seam can be a member of both formations, as noted by Crosdale (1982). It follows that deposition of the Leard Formation and Maules Creek Formation occurred at the same time in different parts of the basin (Thomson 1986b). In the Leard Forest area, outcrop of the Leard Formation parallels that of the Boggabri Volcanics (McPhie

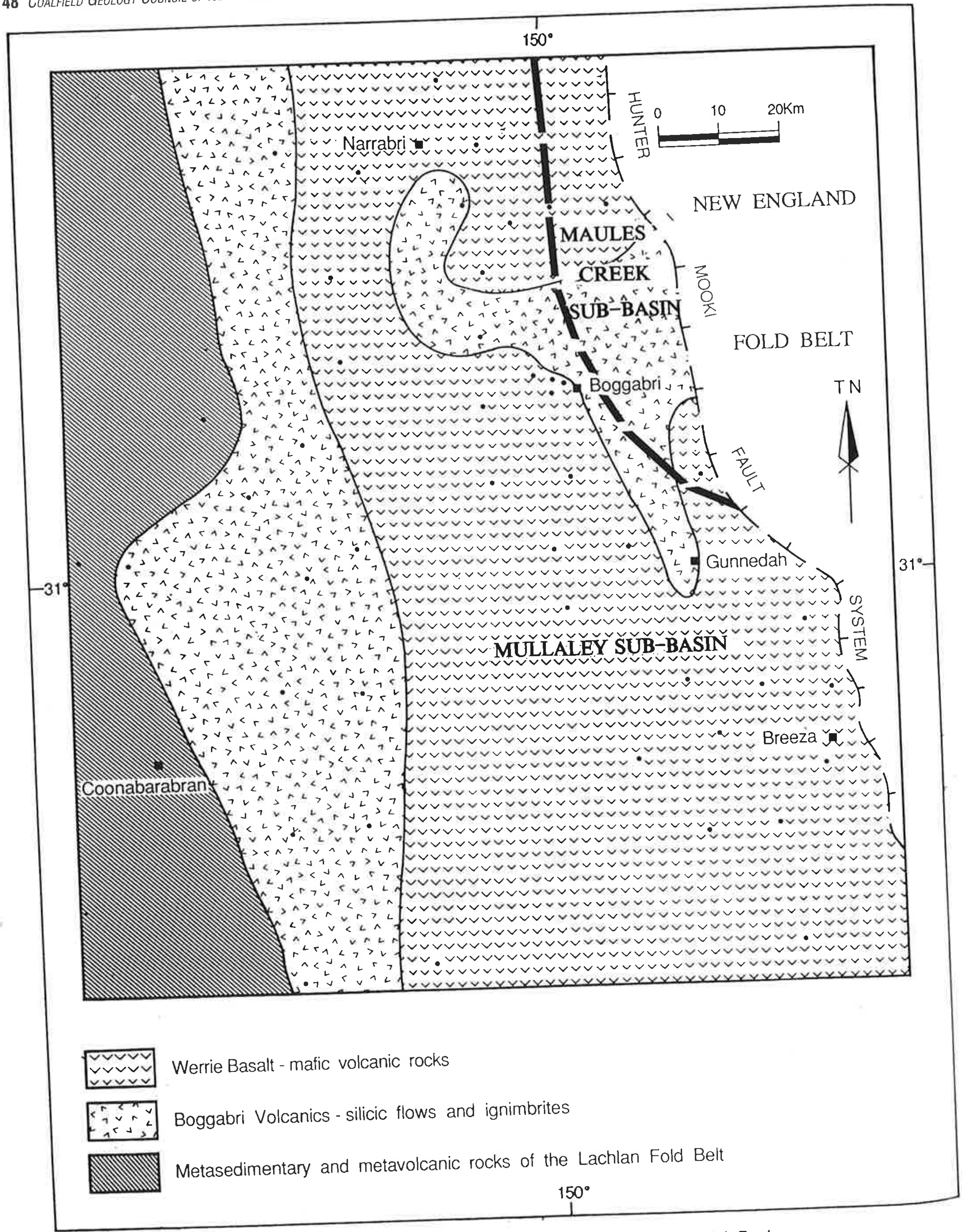
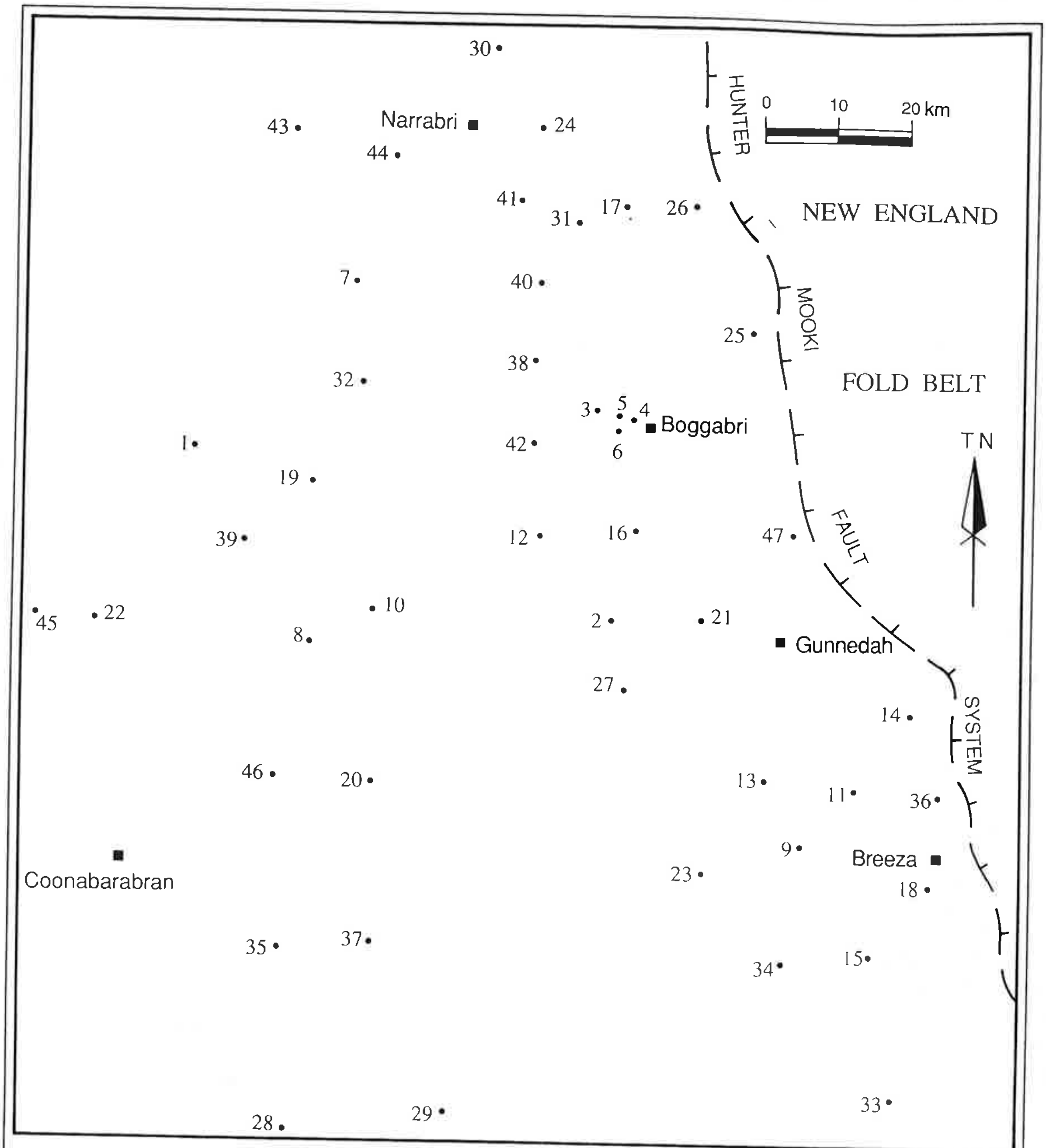


Figure 3a. Distribution of major lithological units of the floor, or basement, to the Gunnedah Basin



REFERENCE

Reference number	Borehole name	Reference number	Borehole name
1	DM Arrarownie DDH 1	25	DM Maules Creek DDH 5
2	DM Benelabri DDH 1	26	DM Maules Creek DDH 7
3	DM Boggabri DDH 1	27	DM Millie DDH 1
4	DM Boggabri DDH 2	28	DM Morven DDH 1
5	DM Boggabri DDH 3	29	DM Napier DDH 1
6	DM Boggabri DDH 5	30	DM Narrabri DDH 1
7	Amoseas Bohena No. 1	31	DME Narrabri DDH 35
8	DM Borah DDH 1	32	MEO Pilliga DDH 1
9	DM Breeza DDH 1	33	Alliance Quirindi DDH 1
10	DM Brigalow DDH 2	34	DM Springfield DDH 1
11	DM Curlewis DDH 1	35	DM Terrawinda DDH 1
12	DM Denison DDH 1	36	DM Texas DDH 1
13	DM Digby DDH 1	37	DM Tinkrameanah DDH 1
14	DM Dight DDH 2	38	DM Tullamullen DDH 1
15	DM Doona DDH 1	39	DM Tunmallalee DDH 1
16	DM Emerald Hill DDH 1	40	DM Turrawan DDH 1
17	DM Eulah DDH 1	41	DM Turrawan DDH 2A
18	DM Ferrier DDH 2	42	DM Walla Walla DDH 1
19	DM Galloway RDH 1	43	Amoseas Wee Waa No. 1
20	DM Girrawillie - Bulga DDH 1	44	CPA Wilga Park No. 1
21	DM Gunnedah DDH 1	45	DM Worigal DDH 1
22	DM Hall DDH 1	46	DM Yaminba DDH 1
23	DM Howes Hill DDH 1	47	DM Yarrari DDH 1
24	DM Killarney DDH 1		

Figure 3b. Boreholes that intersect basement beneath the Gunnedah Basin

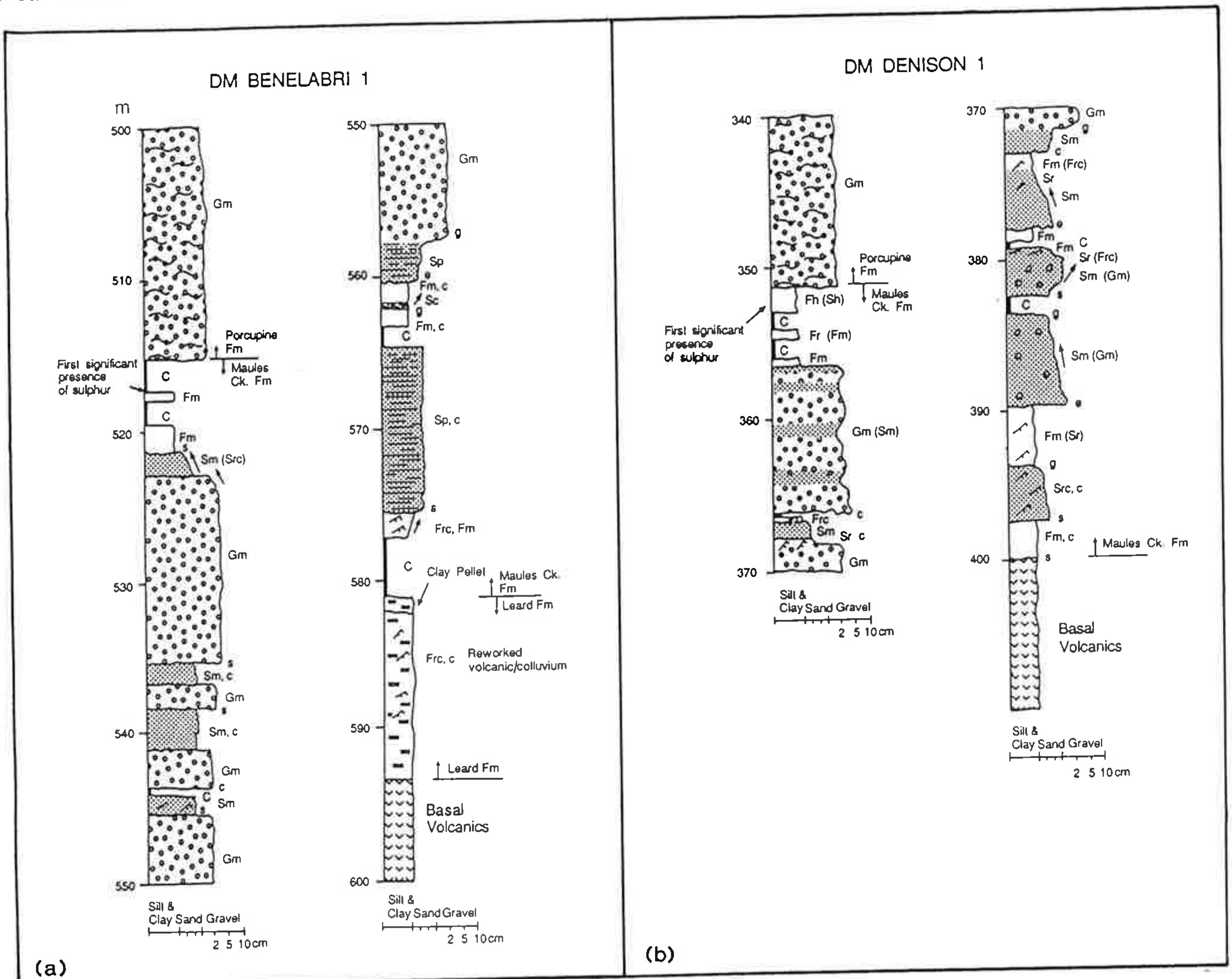


Figure 4. Reference sections of the Leard and Maules Creek Formations in DM Benelabri DDH 1 and DM Denison DDH 1, respectively

1984) because, as mentioned above, the Leard Formation forms a veneer on the basal volcanic rocks — but the Maules Creek Formation onlaps the Leard Formation and the Boggabri Volcanics where present.

Figure 6, a southwest to northeast section through the Maules Creek area, also illustrates the time-transgressive nature of the Leard Formation.

The upper boundary of the Leard Formation in the Mullaley Sub-basin is recognised by a contrast in

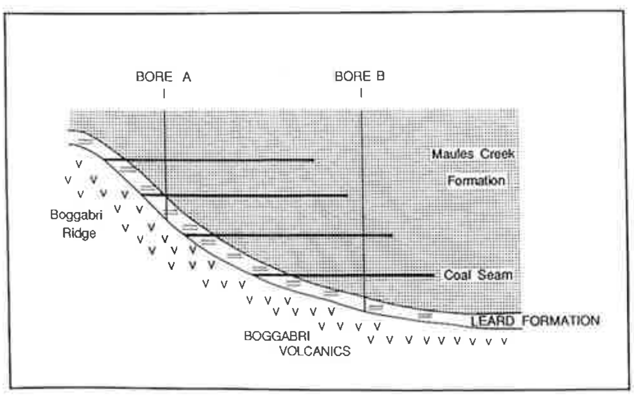


Figure 5. Diagramatic cross-section showing the diachronous nature of the Leard Formation and its relationship to the Maules Creek Formation

lithology between the pelletal claystones and the lithic sediments of the overlying Maules Creek Formation. Recognition of the boundary is not significantly hampered by thin intercalations of pelletal claystone which are locally present in some areas within the lithic sequence because the boundary is defined by the lowermost occurrence of the lithic sedimentary rocks above the pelletal claystone.

Age and evidence

Morgan (1976a, b) assigned an Early Permian Lower Stage 4 palynological zone age to the Leard Formation from DM Maules Creek DDH 2 and DM Maules Creek DDH 5. Thomson (1986b) suggested that the development of a deep weathering profile on the Boggabri Volcanics occurred from the Late Carboniferous through to the Early Permian, until the remnant volcanic highs along the Boggabri Ridge were finally covered during deposition of the Porcupine Formation.

Correlation

The Leard Formation is a lithological correlative of the Skeletar Formation, the basal unit in the Greta Coal Measures in the Hunter Valley of the Sydney Basin (table 3).

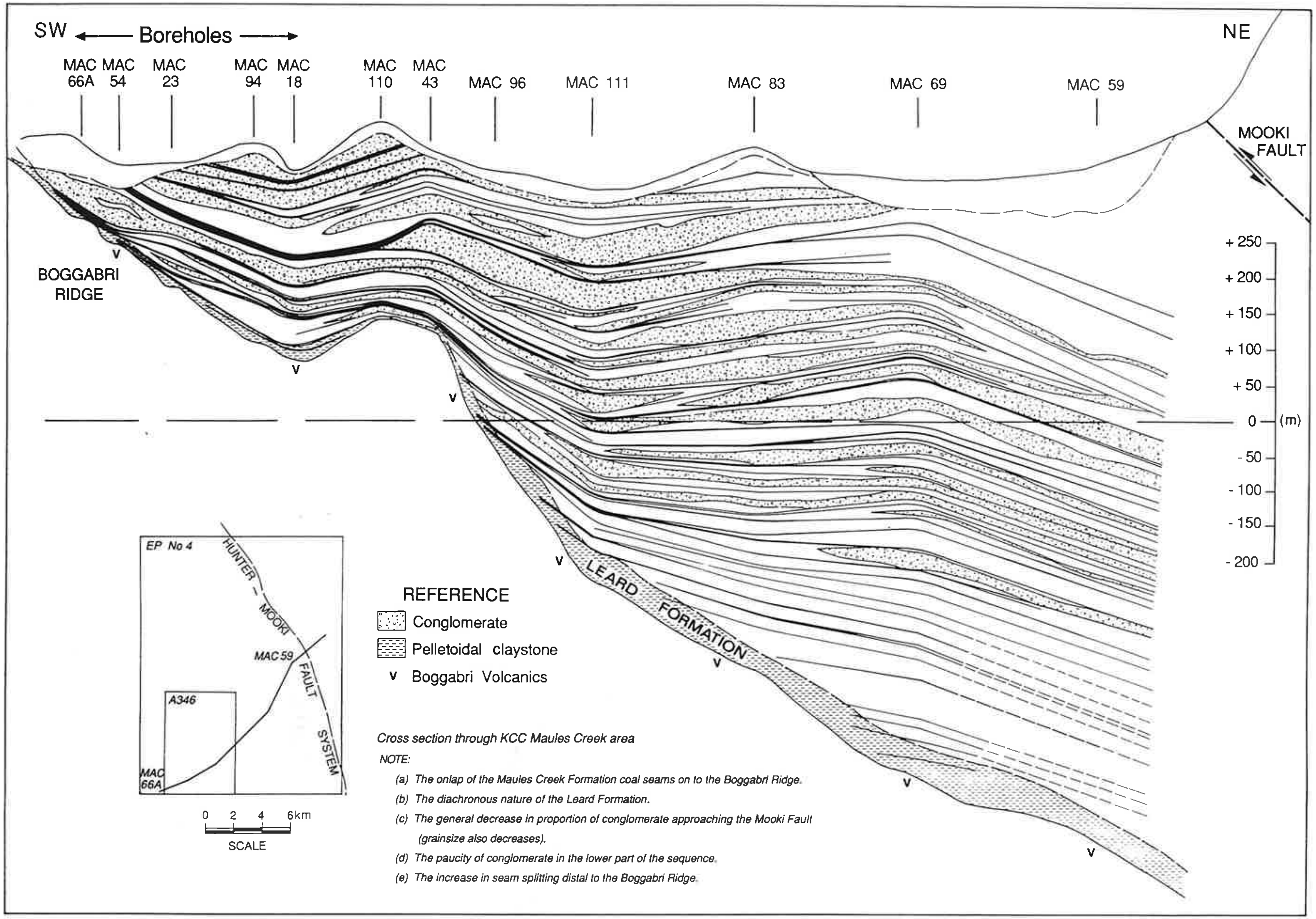


Figure 6. Cross-section through KCC (Kembla Coal and Coke Co.) Maules Creek area

Palaeoenvironment

Both colluvial and alluvial pelletal claystones are present in the Mullaley Sub-basin (Tadros 1982; Beckett *et al* 1983). Tadros (1982) recognised that, in the area west of Boggabri (figure 7), colluvial claystone occupies topographic lows on the surface of the basal volcanic rocks and forms discontinuous lenses overlain by thinly bedded alluvial pelletal claystone. Later, Thomson (1986b) considered the pelletal claystone in the Mullaley Sub-basin to be dominantly alluvial.

Goonbri Formation (re-definition: Tadros 1993a, 1995)

The Goonbri Formation (Thomson 1986b; table 2) is named after Goonbri Mountain (GR 334092, Boggabri 1:100 000 map sheet). The formation, as originally defined by Thomson (1986b) exists in the Maules Creek Sub-basin in the subsurface over 12 km^2 in the central northern portion of the Boggabri 1:100 000 map sheet area around longitude 150°12'E, latitude 30°34'S, north of Goonbri Mountain. No surface outcrops are reported for the Goonbri Formation.

Subsequent work by Etheridge (1987) and Tadros (1993a, b, d, e) has indicated that, in the Mullaley Sub-basin, the Goonbri Formation is present in the central parts of the Bellata and Bohena Troughs, respectively.

Type section

Thomson (1986b) assigned the interval from 145.04 m to 340.73 m intersected with a dip of 50° in Kembla Coal and Coke Pty Ltd (vertical) borehole KCC Maules Creek MAC DDH 44 (ISG coordinates 224951 mE, 1616906 mN) as the type section for the Goonbri Formation. A corrected thickness in excess of 125 m is postulated. However, drilling terminated within the unit so the lower boundary has not been identified. Tadros (1993a) assigned a new type section for the Goonbri Formation from DM Bellata DDH 1 (located 5 km west of Bellata) between 1007.1 m and 1112.7 m (figure 8).

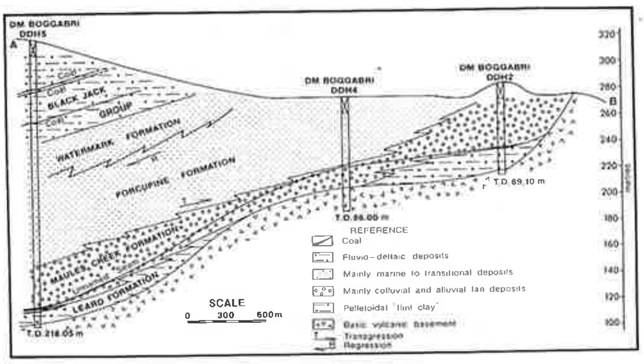


Figure 7(a). East–west cross-section in the area west of Boggabri

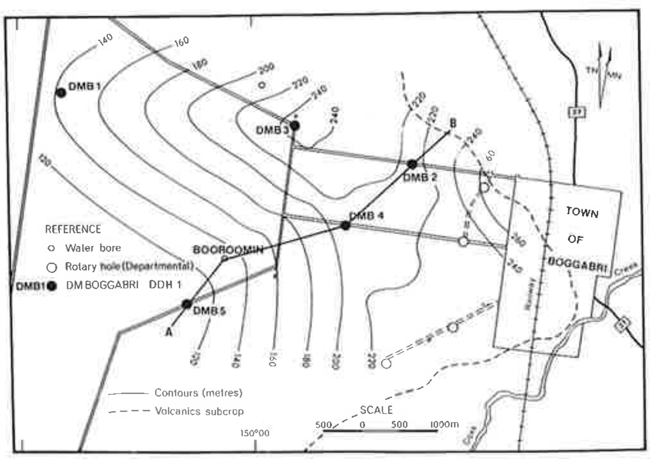


Figure 7(b). Structure contours on the basal volcanic rocks and location of cross-section AB in (a)

Thickness

In the Maules Creek Sub-basin the Goonbri Formation is in excess of 125 m thick. In the Bellata Trough the Goonbri Formation is 105.6 m thick in DM Bellata DDH 1. In the Bohena Trough, the sequence is about 79 m thick in AMOSEAS Bohena 1, and 35 m thick in MEO Pilliga 1, some 14 km to the south, and wedges out towards the surrounding basement highs (American Overseas Petroleum Ltd 1963; 1964).

Lithology

Etheridge (1987) described the Goonbri Formation sequence from DM Bellata DDH 1 as consisting of mainly dark organic-rich siltstone, thin layers of coal, and graded siltstone–claystone laminite, coarsening upward through burrowed, graded siltstone–claystone and laminated fine-grained sandstone and siltstone to fine and medium-grained, moderately well-sorted sandstone. The sandstones are up to 3 m thick, overlain in places by coal and root-penetrated and disturbed siltstone and very fine sandstone. The sandstones are composed of approximately equal proportions of angular quartz and rock fragments, with between 3% and 5% feldspar (microcline). The formation has interbeds of pelletal reworked weathered volcanic rocks near its base.

Relationships and boundary criteria

Thomson (1986b) suggested that in the Maules Creek Sub-basin the Goonbri Formation unconformably overlies and onlaps the Boggabri Volcanics (of Hanlon 1949c) and the Leard Formation, if present. The presence of pelletal clay interbeds near the base of the Goonbri Formation in DM Bellata DDH 1 indicates that the Leard Formation had been reworked by the lake processes which formed the Goonbri Formation. Thomson (1986b) suggested a conformable relationship with the overlying Maules Creek Formation, and the first appearance of coal marks the top of the Goonbri Formation. However, Etheridge (1987) considered the Goonbri Formation in DM Bellata DDH 1 to be disconformably overlain by the Maules Creek Formation. The disconformity (?non-deposition) is indicated by a palynological zone gap between the formations (absence of Lower Stage 4, McMinn 1986; Etheridge 1987).

Age and evidence

Microfloras in the Goonbri Formation are somewhat restricted, but can be assigned to the Early Permian Stage 3 of Price (1976) and McMinn (1981):

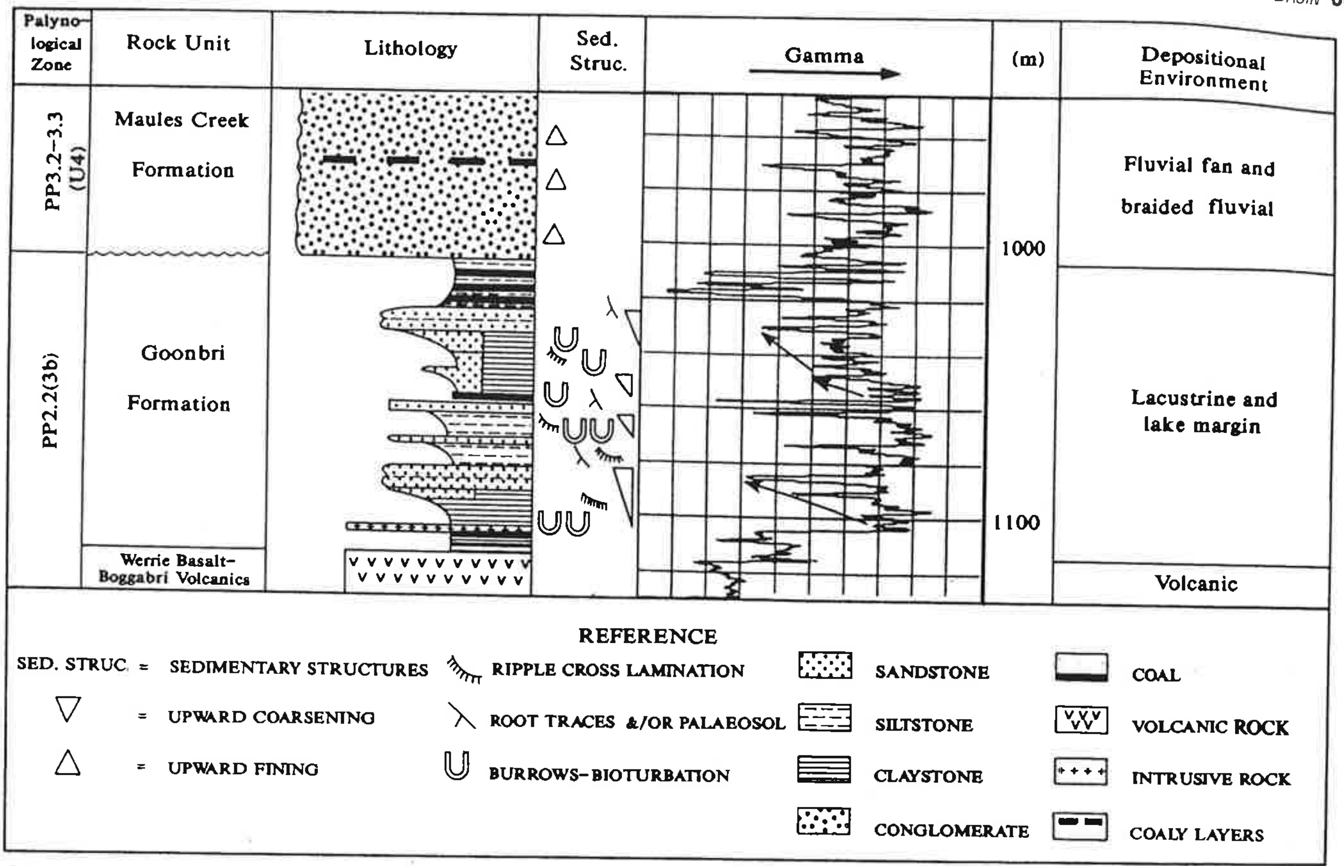


Figure 8. Type section of the Goonbri Formation

viz the interval between the first occurrence of *Granulatisporites trisinus* and *Thymospora cicatricosa*. The abundance of monosaccate pollen (ie, *Plicatipollenites* spp.) also indicates an Early Permian age (Thomson 1986b). The sequences in DM Bellata DDH 1, AMOSEAS Bohena No 1, Mid-Eastern Oil (MEO) Pilliga No 1 and DM Mirrie DDH 1 (in the Tooraweena Trough in the southern Gilgandra Sub-basin) are similar in age.

Correlation

The Goonbri Formation is approximately time equivalent to the uppermost part of the Dalwood Group of the Hunter Valley (cf table 3).

Palaeoenvironment

Thomson (1986b) suggested that the Goonbri Formation, in the Maules Creek Sub-basin, is an Early Permian lacustrine unit and that lacustrine deposition was terminated by prograding fluvial sedimentation of the Maules Creek Formation, mainly from the Boggabri Ridge in the west. Etheridge (1987) interpreted the Goonbri Formation in DM Bellata DDH 1 as a sequence of regressive lacustrine units. Tadros (1993a, b, d, e) has indicated that the Goonbri Formation is present in the deepest parts of the Bellata and Bohena Troughs in the Mullaley Sub-basin.

Maules Creek Formation

(re-definition: Tadros 1993a, 1995)

The name for the Maules Creek Formation is drawn from the village of Maules Creek (Brownlow 1981), some 24 km north-northeast of Boggabri. Sedimentary rocks of the Maules Creek Formation were previously part of the "Nandewar Group" (Hanlon 1949a, b; 1950a, b) (table 1), but that term was abandoned and replaced by the Leard and Maules Creek Formations (Brownlow 1981).

The Maules Creek Formation (Brownlow 1981) (table 2) onlaps the eastern and western sides of the Boggabri Ridge and crops out extensively between the Ridge and the Mooki Fault System and at Gunnible Mountain and Gunnedah. However, all outcrops represent discontinuous sections of the uppermost part of the Maules Creek Formation or the eastern and western "feather edge" on the Boggabri Ridge (figure 9). In the Maules Creek Sub-basin the Maules Creek Formation is possibly overlain conformably by equivalents of the Porcupine Formation on Timor Mountain (Brownlow 1981). In the Mullaley Sub-basin the Maules Creek Formation is present mainly in the subsurface, except for a few outcrops near Gunnedah.

Type section

Brownlow (1981) assigned the interval from the surface to 500.10 m depth in ABB (Amax/BHP/Boggabri) Boggabri DDH 2 (221785 mE and 1613414 mN) as the type section for the Maules Creek Formation. The upper portion of the Maules Creek Formation across the Maules Creek Sub-basin has been eroded, and the base is progressively onlapped onto the Boggabri Ridge and the Leard Formation. Hence no better type section for the

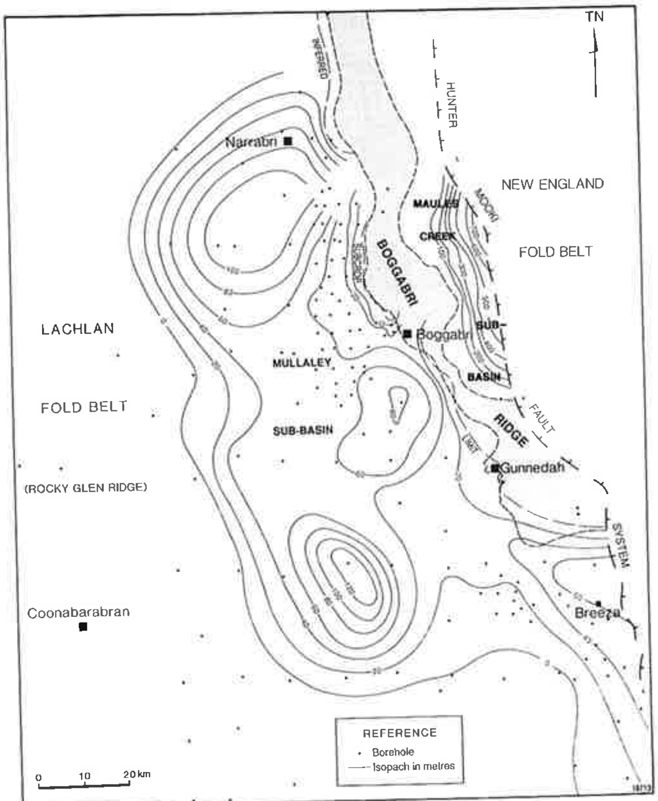


Figure 9. Isopachs (m) of the Maules Creek Formation in the Mullaley and Maules Creek Sub-basins

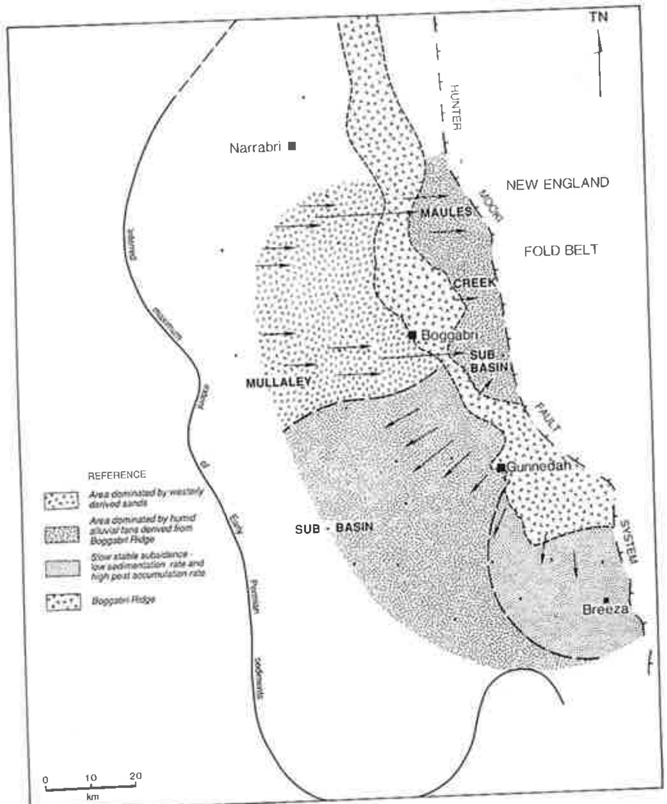


Figure 10. Schematic depositional setting for the Maules Creek Formation in the Mullaley Sub-basin

Maules Creek Formation is yet available for the Maules Creek Sub-basin (figure 6). The unit is much thinner in the Mullaley Sub-basin.

Reference section

Core from the interval 351.0 m to 400.0 m in DM Denison DDH 1 is taken as the reference section for the Maules Creek Formation in the Mullaley Sub-basin (figure 4b).

Thickness

The Maules Creek Formation is best developed in the Maules Creek Sub-basin east of the Boggabri Ridge, where it attains a thickness in excess of 800 m and is possibly thicker adjacent to the Mooki Fault. West of the Boggabri Ridge, however, the formation is generally less than 100 m thick (figure 9).

Lithology

In the Maules Creek Sub-basin, the Maules Creek Formation is dominated by conglomerate with lesser amounts of sandstone, siltstone, claystone and coal (Thomson & Flood 1984) (figure 4).

In its type area (Brownlow 1981) the Maules Creek Formation consists of lithic conglomerate and coarse sandstone (about 50% of the sequence), and lithic fine to medium sandstone, siltstone and claystone (about 40%). Typically, bright coals in beds up to 8 m thick (about 10% of the sequence) are present within the sequence. A sequence of silicified, laminated siltstones, with recorded thicknesses up to 10 m to 15 m, commonly occurs at the base of the formation in the Leard State Forest.

West of the Boggabri Ridge in the Mullaley Sub-basin, Thomson (1986b; 1993) subdivided the Maules Creek Formation into three distinct zones (figure 10) a northern zone containing quartz-rich sandstone; a central zone consisting of volcanogenic sediments; and a southeastern zone characterised by fine-grained sedimentary rocks rich in coal.

Relationships and boundary criteria

The Maules Creek Formation overlies and onlaps the Leard and Goonbri Formations and underlies the Porcupine Formation (table 2, figure 6). The lower boundary is taken at the base of the lithic sedimentary rocks above the pelletal claystone of the Leard Formation. There is a considerable contrast in composition between the Maules Creek Formation and the underlying Leard and Goonbri Formations, but definition of the boundary is sometimes difficult due to interbedding of the pelletal claystone and other clastic detritus. Thin pelletal claystone layers have also been observed in coal seams of the Maules Creek Formation (Thomson 1984).

The top of the Maules Creek Formation has generally been eroded in the Maules Creek Sub-basin. In the Mullaley Sub-basin the boundary between the Maules Creek Formation and the overlying Porcupine Formation is sharp and in the west of the sub-basin represents a disconformity (Manser 1965a, b; Evans 1967; Runnegar 1970; Bourke & Hawke 1977). In the central and southern parts of the Mullaley Sub-basin, the two formations interfinger (Beckett *et al* 1983), and along the eastern side of the sub-basin the Maules Creek Formation is overlapped by the Porcupine Formation.

Age and evidence

In its formal definition in the Maules Creek Sub-basin (Brownlow 1981), the Maules Creek Formation was assigned to the Early Permian Lower Stage 4 (Morgan 1976a, c). McMinn (1993) assigned the majority of the Maules Creek Formation in the Mullaley Sub-basin to Upper Stage 4, with only the base of the formation occasionally extending into Lower Stage 4.

Correlation

The Maules Creek Formation is a stratigraphic equivalent of the Rowan Formation which forms the larger part of the Greta Coal Measures in the Hunter Coalfield in the Sydney Basin (table 3).

Palaeoenvironment

In the Maules Creek Sub-basin to the east of the Boggabri Ridge (figure 2), the Maules Creek Formation is an alluvial–fluvial coal-bearing unit in which clastic sedimentation was dominated by braided streams of the Scott and Donjek types of Miall (1978). In the Mullaley Sub-basin to the west of the Boggabri Ridge, the formation is also an alluvial–fluvial sequence with three distinct zones different in composition and coal content (Thomson 1993).

MILLIE GROUP (Tadros 1993a, 1995)

Tadros (1993a) named marine sedimentary rocks of the Porcupine and Watermark Formations as the Millie Group (table 2), after the Parish of Millie, southwest of Gunnedah. Rocks of this Group have limited surface exposure, but extend in the subsurface over almost the entire area of the Mullaley Sub-basin.

Type section

The type section for the Millie Group is a composite of the type sections for the contained formations.

Lithology

Massive para- and orthoconglomerates characterise the basal part of the Millie Group. The middle part is a bioturbated mixture of sandstone and mudstone upward-fining to siltstone and mudstone. The upper part consists of a bioturbated sequence of siltstone, upward-coarsening to sandy siltstone and silty sandstone.

Relationships and boundary criteria

The boundary between the Millie Group and the underlying Bellata Group is conformable in the central part of the sub-basin, intercalating in the south and unconformable over basal volcanic rocks along the sub-basin margins. The upper boundary between the Millie Group and the overlying Black Jack Group is commonly gradational, but can be recognised by a change from well-sorted, clean fine- to coarse-grained sandstone to a coal-bearing, organic matter-rich lithic sandstone, siltstone, claystone and clay laminite (Hamilton 1985; 1987).

Age and evidence

The base of the Millie Group is diachronous, ranging from Late Permian Upper Stage 4 palynological zone in the southeast to Lower Stage 5b in the north and west (McMinn 1993).

Correlations

The Millie Group can be correlated with the marine Maitland Group in the Sydney Basin (table 3).

Porcupine Formation

(re-definition: McDonald *et al* 1993)

Named after Porcupine Hill, about 3 km south-east of Gunnedah, the term Porcupine Formation was introduced by Hanlon (1949a) and subsequently used by other workers (eg, Manser 1965a, b; Beckett et al 1983).

The Porcupine Formation (table 2) is present mainly in the sub-surface over much of the Mullaley Sub-basin area from Bellata in the north to Quirindi in the southeast (figure 11). In the Maules Creek Sub-basin, rocks of the basal part of the formation have been intersected in one drill hole only, in the north-east of the sub-basin. In outcrop the Porcupine Formation is present at the Porcupine Lookout near Gunnedah, Mills Ridge to the east of Curlewis and in the Deriah Forest area to the east of Narrabri. In addition, two isolated outcrops of the formation occur north of Mount Kaputar (Russell 1981).

Type section

The type section for the Porcupine Formation is defined (herein) to be in DM Ferrier DDH 2 (249066 mE, 1535912 mN) from 330.0 m to 502.4 m (172.4 m).

Thickness

The thickness of the Porcupine Formation ranges from 0 m to 10 m along the western margin of the Mullaley Sub-basin, 20 m to 60 m in the north and from 30 m to >170 m in the south and southeast (figure 11).

Lithology

The lithological sequence of the Porcupine Formation is characteristically upward-fining from a massive paraconglomerate at the base with a poorly sorted sandstone and siltstone matrix, through an orthoconglomerate with a moderately sorted lithic sandstone/siltstone matrix, to a homogeneous bioturbated mixture of sandstone and mudstone with a few clasts and traces of *Zoophycus* burrows (McDonald & Skilbeck 1991; Skilbeck & McDonald 1993). The conglomerate clasts are composed dominantly of silicic volcanic rock types. An upward-fining, bioturbated, silt-dominated homogeneous

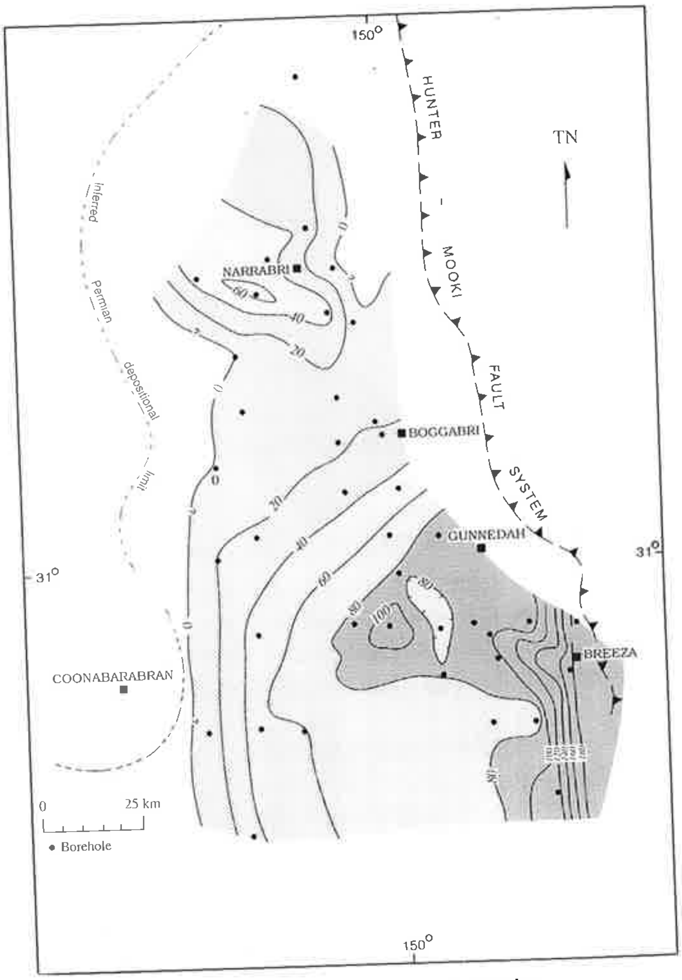


Figure 11. Isopachs (m), Porcupine Formation

mixture of siltstone and mudstone with rare clasts and indistinct lamination is present at the top. There are also sporadic traces of *Zoophycus* (McDonald & Skilbeck 1991; Skilbeck & McDonald 1993).

Relationships and boundary criteria

The Porcupine Formation overlies the Maules Creek Formation with a conformable boundary in the central part of the Mullaley Sub-basin. Along the sub-basin margins the lower contact is unconformable over basement rocks (cf figure 12.25 in Skilbeck & McDonald 1993). The upper boundary of the Porcupine Formation is gradational with the Watermark Formation. It is typified by a transitional facies consisting of a bioturbated homogeneous mixture of siltstone and mudstone with rare erratics ("dropped pebbles") and can be widely correlated across the sub-basin (McDonald & Skilbeck 1991). This transitional facies grades upwards to the basal part of the Watermark Formation, which is an intensely bioturbated and burrowed (*Zoophycus*) sandy siltstone and mudstone, with bryozoans and shell fossils (facies 4 of Skilbeck & McDonald 1993).

Age and evidence

The Porcupine Formation is diachronous, ranging from Permian Upper Stage 4 in the southern Mullaley Sub-basin to Lower Stage 5b in the north (McMinn 1993).

Correlation

The Porcupine Formation is equivalent to the Snapper Point Formation, Wandrawandian Siltstone and perhaps Nowra Sandstone (Herbert 1980) in the southern Sydney Basin and has been correlated with the Branxton Formation and Muree Sandstone in the northern Sydney Basin (Beckett *et al* 1983) (table 3).

Palaeoenvironment

The Porcupine Formation represents a predominantly Late Permian marine incursion in the Gunnedah Basin. Skilbeck and McDonald (1993) advocated an environment in which a transgressive fan delta complex developed adjacent to a lowland fault escarpment. The coarse-grained sediment was delivered to the marine environment and prograded irregularly by large-scale Gilbert-type foreset accretion.

Watermark Formation

(re-definition: Tadros *et al* 1993)

The name for the Watermark Formation comes from Mount Watermark, some 10 km west of Breeza. The term Watermark Formation was introduced by Hanlon (1949a) to describe a shaly marine unit in the area west and north of Mount Watermark Trigonometrical Station, but Russell (1981) and Beckett *et al* (1983) extended its application to cover the Gunnedah–Narrabri–Coonabarabran region. Herein the application of the term Watermark Formation (table 2, figure 12) has been extended to cover much of the area of the Mullaley Sub-basin north of the Liverpool Range.

Outcrop of the Watermark Formation is limited to a small area to the west of Gunnedah and to the Mount Watermark area. In the subsurface the formation is present over much of the Mullaley Sub-basin area from Narrabri in the north to south of Quirindi .

Type section

The type section for the Watermark Formation is contained in DM Brown DDH 1 (228989 mE, 1547008 mN), between 199 m and 377 m.

Thickness

The thickness of the Watermark Formation in its type section is 178 m, with a maximum thickness of 230 m in the Breeza–Quirindi area.

Lithology

The lower part of the Watermark Formation is characterised by an upward-fining sequence of sandy siltstone at the base, silty sandstone, dark grey siltstone, through to siltstone/claystone laminite at the top. Fossil zones containing brachiopod shells and bryozoans are common. Bioturbation is intense and has destroyed most of the primary sedimentary structures but, where preserved, parallel lamination predominates, indicating that sedimentation was principally from suspension settling (Hamilton 1987).

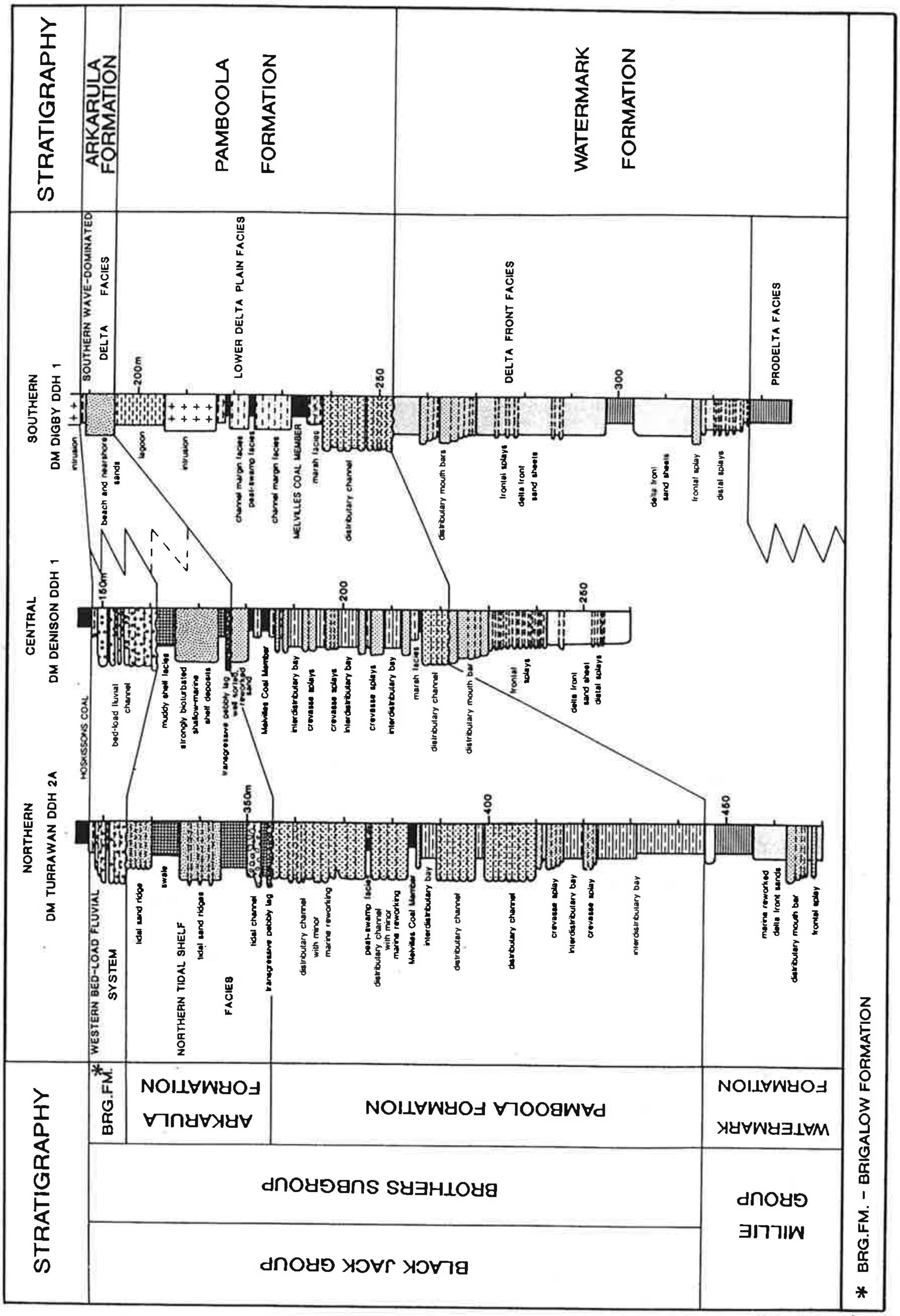


Figure 12. Typical vertical profiles showing stratigraphy of the upper part of the Millie Subgroup and the Brothers Subgroup superimposed on genetic facies interpretations for three boreholes located in the southern, central and northern parts of the Mullaley Sub-basin north of the Liverpool Range

The upper part of the Watermark Formation consists of two lithologically distinctive units forming a major upward-coarsening succession. The lower of those units, which is absent north of Boggabri (figure 12) consists of a finely laminated siltstone and claystone, with little or no bioturbation. In drill core the rocks have a homogeneous appearance and fissile mechanical state (Hamilton 1987). The rocks also contain sporadic ice-rafted "dropped pebbles", secondary calcite replacement zones, and glendonite crystals. The upper of those units consists of well-developed upward-coarsening sequences of grey laminated siltstone, silty sandstone and siltstone/sandstone laminite at the top, with strongly bioturbated horizons. The Watermark Formation sporadically includes a top layer of well-sorted clean fine- to coarse-grained sandstone.

Relationships and boundary criteria

The Watermark Formation has an upward-fining transitional contact zone with the underlying Porcupine Formation, passing from a bioturbated homogeneous mixture of siltstone and mudstone with sporadic silicic volcanic "dropped pebbles" and indistinct lamination to intensely bioturbated and burrowed (*Zoophycus*) sandy siltstone and mudstone, with bryozoans and shell fossils. It is distinguished from the underlying Porcupine Formation by almost a total absence of "dropped pebbles". The upper boundary is commonly gradational but can be recognised by a change from well-sorted, clean, fine- to coarse-grained sandstone to a coal-bearing, organic matter-rich sequence of lithic sandstone, siltstone, claystone and conglomerate (Hamilton 1985; 1987).

Age and evidence

The Watermark Formation spans much of the Permian Lower Stage 5b to Lower Stage 5c palynological zone (McMinn 1993).

Correlation

The correlative of the Watermark Formation on the southern side of the Liverpool Range is the Mulbring Siltstone and its equivalents in the Sydney Basin. The Berry Siltstone (at least the lower part) is the correlative in the south-eastern corner of the Gunnedah Basin (the Ulan–Rylstone area) and the western part of the Sydney Basin (Beckett *et al* 1983) (table 3).

Palaeoenvironment

The lower part of the Watermark Formation represents the maximum extent of Late Permian marine transgression into the Gunnedah Basin (Hamilton 1991), whereas the upper part represents marine regression associated with deposition of the subaqueous part of the Black Jack delta system. The lower part of the overlying Black Jack Group represents the subaerial part of the delta system and the ultimate disappearance of marine influence. Hamilton (1991; 1993a) assigned the lower part of the Watermark Formation sequence to his "Porcupine–lower Watermark marine-shelf system", and the upper part to his "Upper Watermark–lower Black Jack delta systems".

BLACK JACK GROUP

(variation of rank and re-definition: Tadros 1993a; 1995)

Hanlon (1949a) named the sequence now described as the Black Jack Group (table 2) after Black Jack Mountain to the southwest of Gunnedah. He assigned formation status to the sequence and described it as a sequence of sandstone, shale, conglomerate, chert, thin layers of limestone and coal. Britten and Hanlon (1975) provided a brief description of the stratigraphy of the "Black Jack Coal Measures" in the Gunnedah–Curlewis area, but gave no clear definition for the lower boundary. Beckett *et al* (1983) reviewed the original definition of the formation and divided the sequence into a number of widespread sedimentary facies. Hamilton (1985) and Tadros (1986a, b; 1993f), on the basis of detailed sedimentological studies, further described the principal genetic sedimentary facies within the lower and upper parts of the formation, respectively.

The Black Jack "Formation" contains some very distinctive units which have been used as stratigraphic markers, such as the Arkarula Sandstone Member, the Hoskissons "Coal Member" and the Clare Sandstone "Member". Other named members are the Melvilles Coal Member, "Allara Shale Member" (Britten & Hanlon 1975) and "Goran Conglomerate Member" (Beckett *et al* 1983). Some names are now abandoned. The lithological characteristics of many of the units are so persistent over large areas of the Mullaley Sub-basin that they can qualify for a separate formation status. Tadros (1993a) varied some of these units to formation status and elevated the Black Jack Formation to a group level to encompass the new formations (cf table 2).

Outcrop of the Black Jack Group is limited to a narrow north-northwesterly trending zone of discontinuous hills extending from Breeza in the southeast to Boggabri in the north. In the subsurface, sedimentary rocks of the Black Jack Group are present over much of the area of the Mullaley Sub-basin (figure 13). To the east and north of the outcrop zone, the Black Jack Group is mostly eroded or covered by Quaternary alluvium.

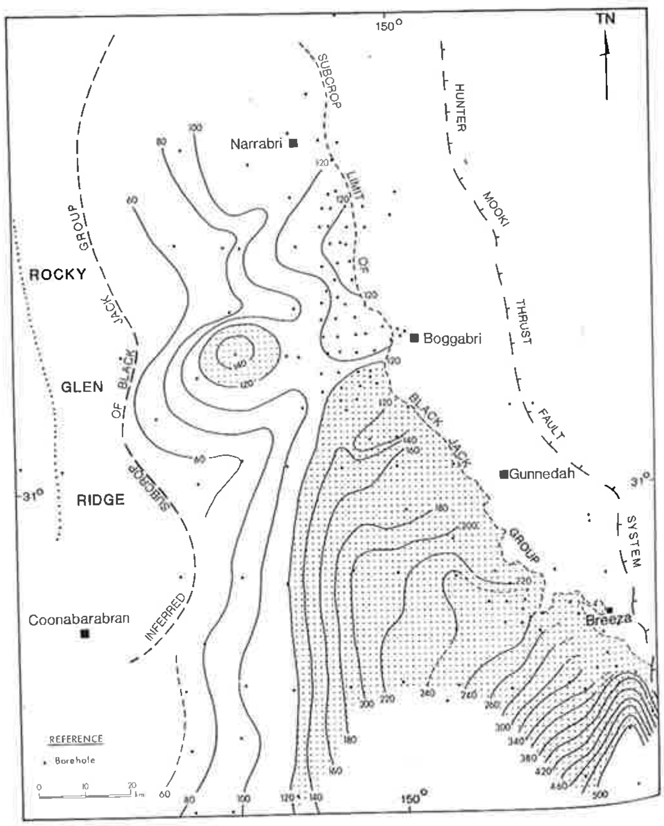


Figure 13. Isopachs (m), Black Jack Group in the Mullaley Sub-basin

Type section

The core interval from 348.7 m to 614.3 m in DM Springfield DDH 1 (228904 mE, 1524844 mN) is taken as the type section for the Black Jack Group.

Thickness

The Black Jack Group averages approximately 200 m in thickness over a large area of the Mullaley Sub-basin north of the Liverpool Range, but thickens from less than 50 m in the west to in excess of 470 m in the southeast (figure 13). The Group is 265.6 m thick in the type section. The Black Jack Group has been partially eroded in various parts of the basin, particularly in the north and northeast. The eastern subcrop is determined by the erosional surfaces of the Permo-Triassic and Quaternary unconformity surfaces.

Lithology

The Black Jack Group is divided lithologically into three subgroups (described below): the Brothers Subgroup at the base; the Coogal Subgroup; and the Nea Subgroup at the top (table 2).

The basal Brothers Subgroup consists of three lithological units;

1) basal lithic coal-bearing unit (Pamboola Formation),
2) a dominantly lithic sandstone, claystone and conglomerate unit (Arkarula Formation); and
3) a quartz-rich sandstone unit (Brigalow Formation).

The Coogal Subgroup of the Black Jack Group consists of three units:

1) a major coal unit (Hoskissons Coal) at the base; overlain in the east by
2) an organic-rich mudstone-dominated unit (Benelabri Formation); overlain by
3) a quartz-rich sandstone sequence (Clare Sandstone).

The Nea Subgroup at the top of the Black Jack Group comprises two units:

1) a dominantly lithic conglomeratic unit (Wallala Formation) at the base; and
2) a tuffaceous coaly unit (Trinkey Formation) at the top.

Several igneous intrusions, some more than 80 m thick, are also present within the Black Jack Group, particularly in the Breeza–Gunnedah region and southeast towards Quirindi. Detailed discussion of igneous intrusions in the sedimentary sequence of the Gunnedah Basin, including the Black Jack Group, has been given in Martin (1993).

Relationships and boundary criteria

Sedimentary rocks of the Black Jack Group are conformable with the underlying Millie Group. That boundary is characterised by upward change from well-sorted clean sandstone to either erosively and pebbly-based thick interbeds of fine- to coarse-grained lithic sandstone, or carbonaceous siltstone and claystone with abundant plant debris. The Late Permian Black Jack Group is unconformably and erosively overlain by the Triassic Digby Formation (table 2). The boundary is recognised by contrast in lithologies and geophysical characteristics of the two units. The boundary is easily recognised where the basal conglomerates of the Digby Formation are in contact with coal, tuff, tuffaceous sedimentary or pyroclastic units of the Black Jack Group. It is possible to recognise the boundary even where Black Jack Group conglomerates are in contact with those of the Digby Formation. Close examination of the rocks in drill core indicates that, although framework clasts may in some cases look similar, matrix is predominantly argillaceous and rich in tuff and pyroclastic detritus in Black Jack Group conglomerates, but sandy lithic in Digby Formation conglomerate. This contrast in matrix composition is clearly reflected in the geophysical log patterns of the Permian and Triassic conglomerates.

Age and evidence

Palynological assemblages indicate a Late Permian age for the Black Jack Group, extending from Lower Stage 5c to Upper Stage 5. *Microreticulatisporites bitriangularis* first appears in the upper zone above the Hoskissons Coal (McMinn 1993).

Correlation

The Black Jack Group has been correlated with the Wittingham and Wollombi Coal Measures of the Hunter Coalfield and the Illawarra Coal Measures of the Western and Southern Coalfields of the Sydney Basin (table 3).

Palaeoenvironment

The Black Jack Group is characterised by upward-diminishing marine influence (Tadros 1986b; 1993f) and by abundant coal in deltaic units in its lower part (Hamilton 1985; 1987; 1993b) and fluvial-lacustrine deposits in the upper part (Tadros 1986a, b; 1993f).

BROTHERS SUBGROUP

(Tadros 1993a; 1995)

The Brothers Subgroup is named after the Parish of Brothers west of Breeza. There are three formations (Pamboola, Arkarula and Brigalow Formations, table 2) in the subgroup, with outcrops mainly near Gunnedah.

Type section

The type section for the Brothers Subgroup is a composite of the type sections for the contained formations.

Lithology

The Brothers Subgroup consists predominantly of lithic sandstones and siltstones with coal seams in the lower part (Pamboola Formation), and burrowed silty sandstone (Arkarula Formation) in the upper part in the eastern part of the Mullaley Sub-basin north of the Liverpool Range, and quartz-rich sandstone (Brigalow Formation) in the western and northwestern parts of the sub-basin.

Relationships and boundary criteria

The Brothers Subgroup conformably overlies marine rocks of the Watermark Formation (Millie Group), and underlies the Hoskissons Coal (figure 12).

Age and evidence

The Brothers Subgroup is Late Permian in age, spanning Lower Stage 5c to Upper Stage 5 (McMinn 1993).

Palaeoenvironment

Rocks of the Brothers Subgroup are either marine or influenced by marine conditions — except along the western and northwestern margins of the Mullaley Sub-basin.

Pamboola Formation

(Tadros 1993a; 1995)

The Pamboola Formation is a named after Pamboola Creek near the type section. The formation occurs mainly in the subsurface of the Mullaley Sub-basin and is absent only in the west (figure 14). This unit forms a significant and characteristic part of the Black Jack sequence.

Type section

A section, 46.5 m thick from 176.5 m to 223.0 m in DM Denison DDH 1 (385054 mE, 1585274 mN) is taken as the type section for the Pamboola Formation (figure 12).

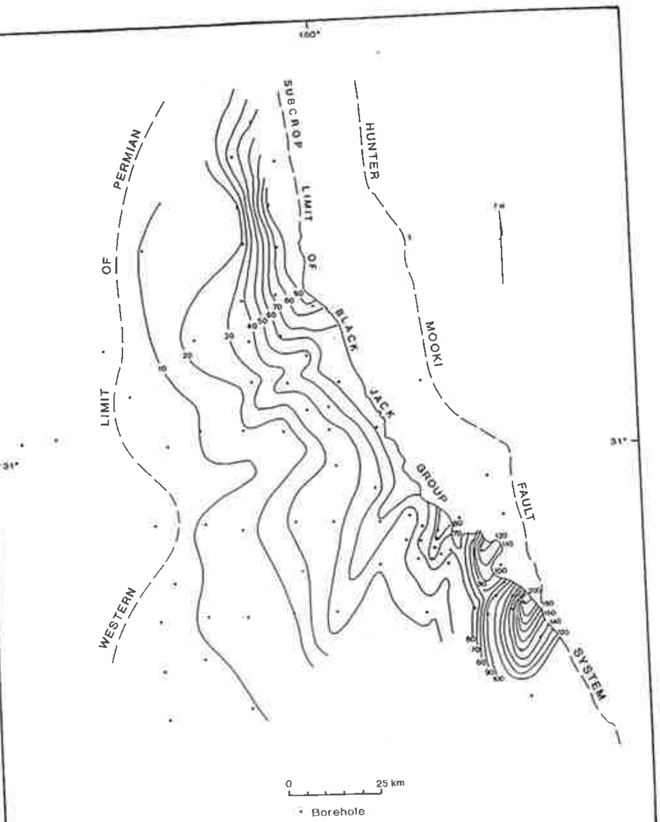


Figure 14. Isopachs (m), Pamboola Formation

Thickness

The Pamboola Formation ranges in thickness from 0 m in the far west along the western margin of the Mullaley Sub-basin, to 89 m in the north, and to more than 206 m in the southeast (figure 14).

Lithology

This formation consists mainly of lithic sandstone, siltstone, claystone, conglomerate and intercalated coals in generally upward-coarsening and sporadic upward-fining sequences. Interbeds, 3 m to 15 m thick, of fine- to coarse-grained sandstone with finely macerated organic matter and coaly fragments and erosive pebbly bases, form an important part of the Pamboola Formation. Lenticular-bedded, fine-grained sandstone and siltstone intercalated with parallel-laminated sandstone and claystone containing abundant burrows form a large part of the Pamboola Formation. Also intercalated are minor sequences of ripple-, parallel- and wavy-laminated sandstone, siltstone and claystone, upward-fining to carbonaceous claystone and capped by coal seams (Hamilton 1987). The Melvilles Coal Member is an important and regionally extensive coal present in the lower part of the Pamboola Formation.

Relationships and boundary criteria

The Pamboola Formation overlies the Watermark Formation with a boundary characterised by a change from well-sorted clean sandstone to either erosively and pebbly-based thick interbeds of fine- to coarse-grained lithic sandstone, or to carbonaceous siltstone and claystone with abundant plant debris. The boundary with the overlying Arkarula Formation in the south is characterised by a change from a coal-bearing sequence of sandstone, siltstone and claystone to the overlying very distinctive sequence of fine- to medium-grained sandstone with sporadic zones of very coarse detritus and abundance of subvertical mud-lined worm burrows. In the north, the boundary with the Arkarula Formation is characterised by a change to a succession containing well-sorted medium-grained sandstone, poorly sorted strongly bioturbated silty sandstone and a distinctive bioturbated silty sandstone with silicic volcanic pebbles.

Age and evidence

The Pamboola Formation is of Late Permian age, spanning the palynological range of Lower Stage 5c (McMinn 1993).

Correlation

The Pamboola Formation can be loosely correlated with similar units in the Sydney Basin: the lower Tomago Coal Measures in the north; the lower Nile Subgroup in the west; and the Pheasants Nest Formation of the Cumberland Subgroup in the south (table 3).

Palaeoenvironment

Sediments of the Pamboola Formation were deposited as the subaerial component of a major delta system (figure 12), mainly from distributary channels and crevasse splays and in interdistributary bay, lagoon and marsh areas of the lower delta plain environment (Hamilton 1987). Deposition was accompanied by favourable peat-forming conditions.

Melvilles Coal Member

(re-definition: Tadros 1993a; 1995)

Hanlon (1949a, pp 245, 246) proposed the name "Melville's Seam" for a seam which "had been prospected at Gladston's adit, in a shaft adjacent to the Gunnedah Colliery Main Adit, in an inclined shaft near the old Preston Colliery Adit, and in Melville's Well" after which, it appears, the seam was named. The seam was described as "lower in grade (than the Hoskisson's seam above) and has a maximum thickness of about 8 feet [2.44 m] including bands" (Hanlon 1949a, p 246). Britten and Hanlon (1975) named the seam the Melvilles Coal Member, but provided very little additional information.

The Melvilles Coal Member crops out in the central Gunnedah area sub-parallel to the Hoskissons Coal outcrop between Gunnedah and Preston Extended Collieries. In the subsurface, the Melvilles Coal Member is widely distributed over much of the eastern half of the Mullaley Sub-basin north of the Liverpool Range (figure 15). In the south-easternmost part of the sub-basin the coal member splits into several seams separated by sandy deposits.

Type section

Seam No 8 in DM Clift DDH 4 (235518 mE, 1536744 mN) is 3.11 m thick between 111.47 m and 114.58 m (figure 16) and is taken as the type section for the Melvilles Coal Member.

Thickness

The Melvilles Coal Member is generally 2.5 m to 3.2 m thick in the eastern part of the Mullaley Sub-basin and thins towards the west. Locally in the area southwest of Boggabri the coal member is up to 5.31 m thick (in DME Narrabri DDH 31).

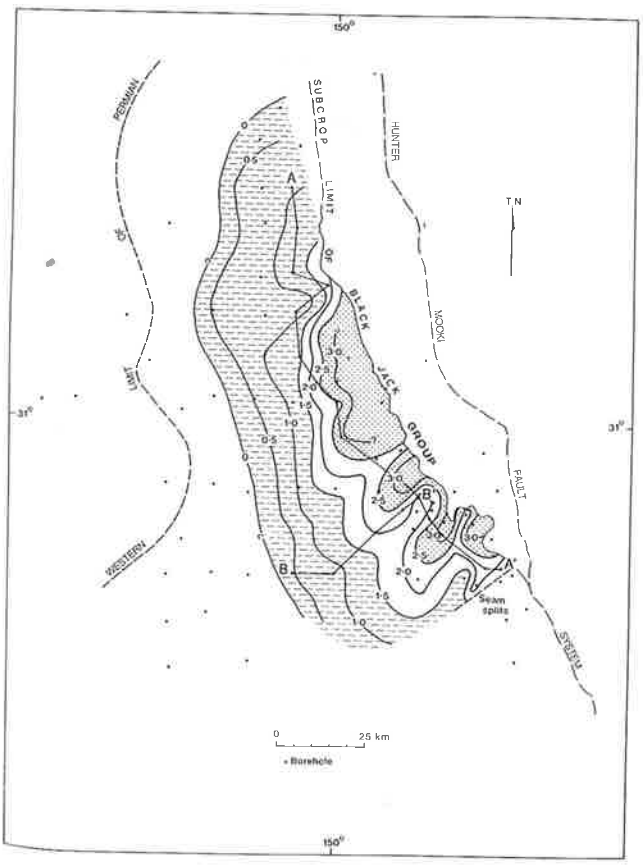


Figure 15. Isopachs (m), Melvilles Coal Member

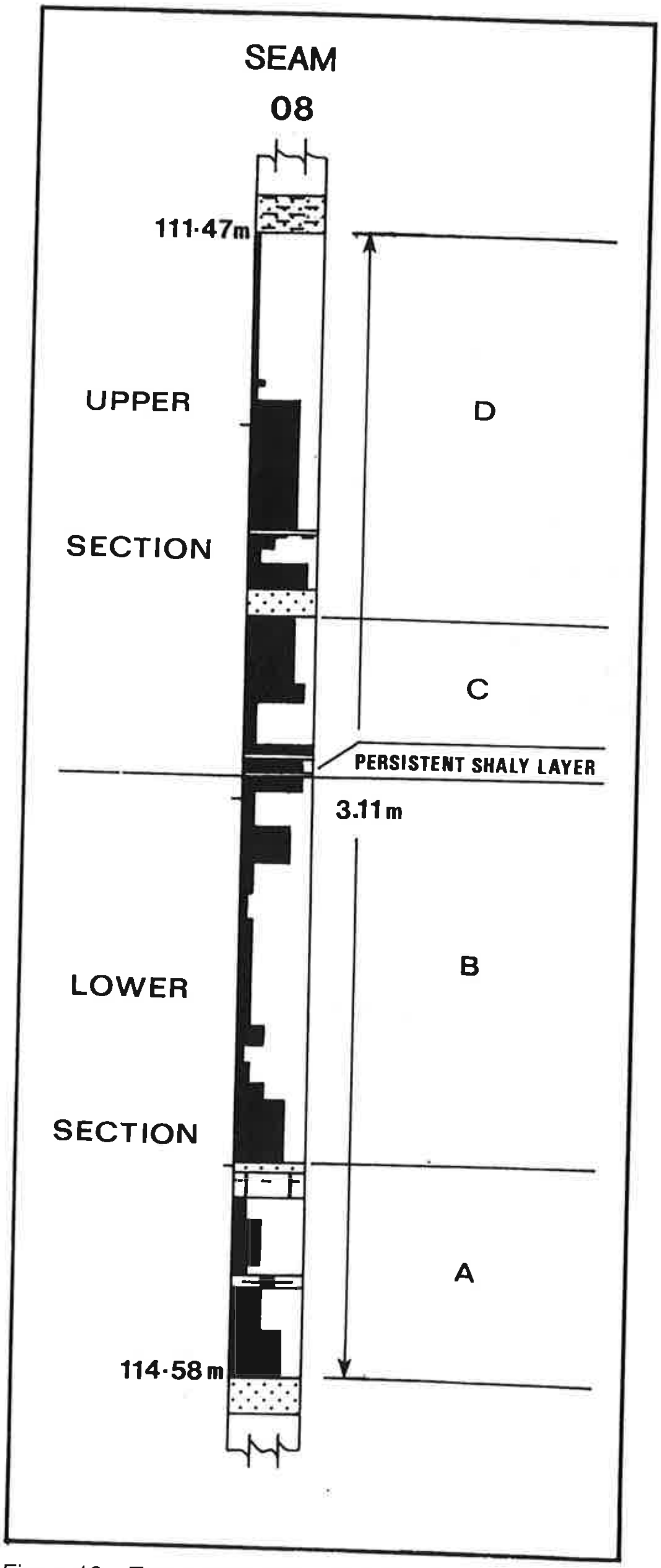


Figure 16. Type section of the Melvilles Coal Member in DM Clift DDH 4

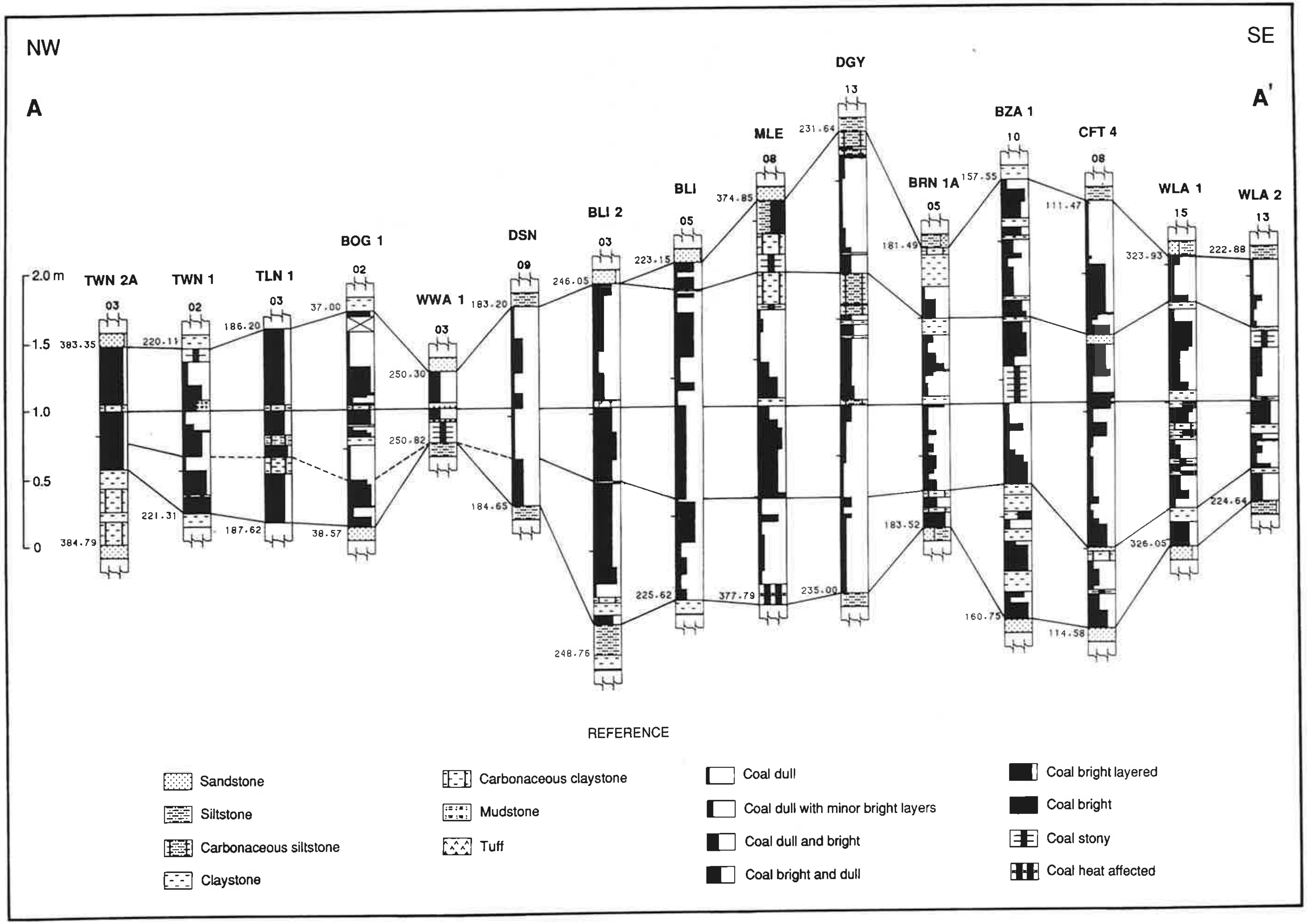


Figure 17. Lithotype (brightness profiles), Melvilles Coal Member. The cross-section runs north-west–south-east, parallel to the depositional strike (For borehole information, see figure 2. The number at the top of each profile indicates seam numbers.)

Lithotype profile (lithology)

The Melvilles Coal Member consists predominantly of moderate to high vitrinite coal with subordinate thin layers of fine-grained sandstone, carbonaceous siltstone/claystone and tuff. It is characterised by a consistent and correlatable coal lithotype profile (figure 16), except where the coal has deteriorated locally to carbonaceous siltstone and claystone (figures 17, 18). Pyrite in the form of lenses, nodules and framboids is irregularly distributed throughout the coal member and sometimes concentrated towards the top (Tadros *et al* 1987).

The coal lithotype profile of the Melvilles Coal Member consists of two sections separated by a persistent shaly layer (figure 16). The lower section consists of two main plies. A basal ply (A) is generally characterised by moderately bright coal, disrupted by thin clastic layers. A top ply (B), although generally variable in character ranging from dull to bright, has a tendency to show an upward-dulling profile in some places. The upper section also consists of two main plies: a lower ply (C) containing moderately bright coal with no apparent vertical change in coal character; and a top ply (D), variable in character and with both bright and dull coal layers as well as carbonaceous horizons. Ply (D) is separated from the underlying ply (C) by a zone of carbonaceous shale layers, but is apparently not developed in the northern part of the Mullaley Sub-basin (figure 17). The lithotype profile of the Melvilles Coal Member has been described in detail by Tadros *et al* (1987) and Hamilton *et al* (1993).

Relationships and boundary criteria

The Melvilles Coal Member is present roughly in the middle of the Pamboola Formation. The coal member, therefore, is underlain and overlain by a variety of sedimentary rocks characteristic of the formation — mainly fine-grained sandstone, carbonaceous siltstone and claystone, and to a lesser extent thick beds of medium- to coarse-grained lithic sandstone.

Age and evidence

The Melvilles Coal Member lies within the Late Permian Lower Stage 5c palynological zone (McMinn 1993).

Palaeoenvironment

The Melvilles Coal Member formed in a lower delta plain environment (figure 12) as a blanket peat which covered a slowly subsiding platform of abandoned deltaic sediment. The coal member overlies a variety of deltaic facies (the encompassing Pamboola Formation), including distributary channel, crevasse splay and interdistributary bay deposits (Hamilton 1987).

Arkarula Formation

(variation to published name and re-definition: Tadros 1993a; 1995)

The name of the Arkarula Formation was derived from Arkarula homestead, west of Gunnedah. Britten and Hanlon (1975) introduced the name Arkarula Sandstone Member for a 22 m thick massive medium-grained even-textured sandstone distinguished by abundant subvertical tubular impressions "likely to be worm burrows". Tadros (1993a) elevated this unit to formation status (cf table 2) and extended its usage to cover much of the Mullaley Sub-basin south of Narrabri (except where the unit is absent in the west and northwest).

The Arkarula Formation is present in the subsurface over the central and south central parts of the Mullaley Sub-basin. The abundance of prominent subvertical mud-lined worm burrows throughout the Arkarula Formation provides a distinctive marker horizon below the Hoskissons Coal,

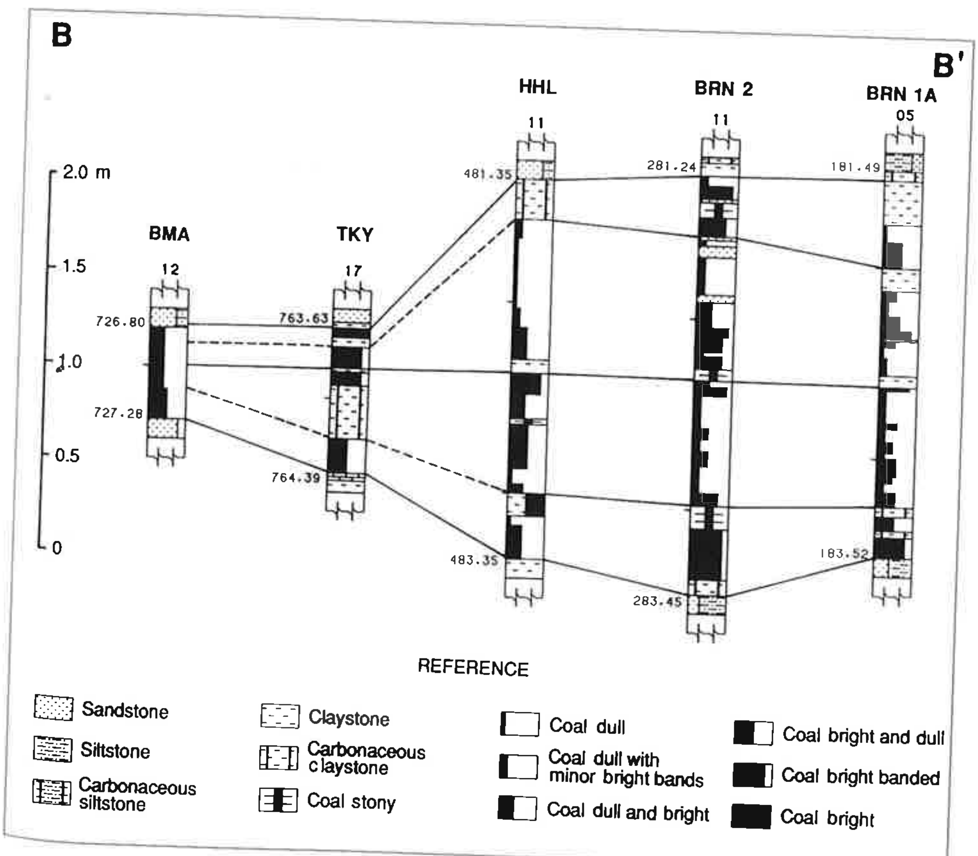


Figure 18. Lithotype (brightness profiles), Melvilles Coal Member. The cross-section runs south-west–north-east, approximately parallel to the depositional dip (For borehole information, see figure 2. The number at the top of each profile indicates seam numbers.)

and has long been used by mine workers in the central Gunnedah area for seam correlation.

Type sections

The assigned type section for the Arkarula Formation is 23 m thick in DM Millie DDH 1 (206200 mE, 1563016 mN), from 340.0 m to 363.0 m (Tadros 1993a).

Reference section

The reference section for the Arkarula Formation has a thickness of 31 m in DM Turrawan DDH 2A (189881 mE, 1632521 mN) between 324 m and 355 m (Tadros 1993a) (figure 12).

Thickness

The Arkarula Formation reaches a maximum recorded thickness of 22 m to 24 m in the Gunnedah Colliery area, and up to 51 m in the north of the Mullaley Sub-basin.

Lithology

The Arkarula Formation consists of an overall fining-upwards sequence of fine- to medium-grained lithic sandstone characterised by very distinctive subvertical mud-lined worm burrows and sporadic zones of very coarse detritus. The unit may grade upward into alternating sequences of poorly sorted silty sandstone and siltstone. Locally the upper few metres of the unit become quartz–lithic, particularly towards the north and west. At its top, the Arkarula Formation contains finely interbedded sandstone and siltstone, upward fining to laminated organic-rich siltstone and fine-grained sandstone, with lenticular bedding, oscillation ripples, load casts, mud cracks and mud drapes.

Locally, the top of the Arkarula Formation may contain up to 3 m of organic-rich black mudstone, which grades into the basal part of the overlying Hoskissons Coal.

From about 25 km southwest of Boggabri northwest to Narrabri the Arkarula Formation consists principally of well-sorted medium-grained sandstone with a thin pebbly base. That sandstone may coarsen up and locally become conglomeratic, or it may change into poorly sorted strongly bioturbated silty sandstone and mud-dominated sequences. A distinctive unit of a poorly sorted pebbly sandstone, crudely upward-fining and erosively based, may develop in the mud-dominated sequence. This unit contains silicic volcanic clasts up to pebble grade in size in a bioturbated medium-grained silty sandstone matrix. In the northernmost part of the Mullaley Sub-basin the unit may contain mud-dominated sequences with abundant disarticulated brachiopod shells (Hamilton 1987).

Relationships and boundary criteria

The Arkarula Formation overlies the Pamboola Formation and underlies the Hoskissons Coal (table 2, figure 12). The lower boundary is characterised by the appearance of the very distinctive burrowed sandstone above the coal-bearing sequence of the Pamboola Formation. The Arkarula Formation grades laterally to the west and southwest and locally in the north into the quartz-rich Brigalow Formation. The upper boundary is marked by a change from finely interbedded sandstone and siltstone to the overlying Hoskissons Coal, except in the west and north where the Arkarula Formation is overlain by the Brigalow Formation.

Age and evidence

A Late Permian age, spanning the palynological boundary between Lower Stage 5c and Upper Stage 5, and containing spinose acritarchs, has been assigned to the Arkarula Formation (McMinn 1993).

Correlation

The Arkarula Formation is a correlative of the Kulnura Marine Tongue in the Sydney Basin (table 3).

Palaeoenvironment

Hamilton (1985; 1987) interpreted the sediments of the Arkarula Formation to have been laid down in a wave-dominated delta system, a southern component of the basin-wide Arkarula shallow marine system, and consisting of barrier-beach, nearshore sands and lagoonal deposits. Lithostratigraphically, the lagoonal deposits are represented by the upper section of the Arkarula Formation. In the north, Hamilton (1985; 1987) interpreted the sedimentarys environment as a tidal shelf system.

Brigalow Formation

(Tadros 1993a; 1995)

Named after the Parish of Brigalow, the Brigalow Formation (Tadros 1993a) (table 2) is present in the subsurface in the western and northern areas of the Mullaley Sub-basin.

Type section

The formation is represented by a 7.5 m type section in DM Brigalow DDH 2 (361568 mE, 1574703 mN) between 508.5 m and 516.0 m.

Thickness

Generally, the thickness of the Brigalow Formation ranges from 0 m to 28 m.

Lithology

The Brigalow Formation consists dominantly of medium- and coarse-grained to pebbly, medium-bedded quartzose sandstone. It has a sharp base, commonly erosively overlying the Arkarula Formation. Medium-scale tabular and trough cross-stratification are dominant. Subordinate fine-grained sandstone finely interbedded with siltstone and carbonaceous siltstone also occur (Hamilton 1987).

Relationships and boundary criteria

In the northwest of the Mullaley Sub-basin the Brigalow Formation overlies, and grades laterally in a southeasterly direction into, the northern conglomeratic sandstone facies of the Arkarula Formation (table 2, figure 12). Locally, in the west, where the Arkarula Formation is absent, the Brigalow Formation overlies the Pamboola Formation. The Brigalow Formation has an overall fining-upward character and is overlain by the Hoskissons Coal (Tadros 1993a, f).

Age and evidence

The Brigalow Formation contains the first appearance of *Dulhuntyispora parvithola*, which marks the boundary between Late Permian Lower and Upper Stage 5 palynological zones (McMinn 1993) (table 2).

Correlation

The Brigalow Formation is a lithological correlative of the Marrangaroo Conglomerate in the western area of the Sydney Basin and the Rylstone–Ulan area in the southwesternmost part of the Gunnedah Basin (table 3).

Palaeoenvironment

The Brigalow Formation represents deposition of fluvial sediments along the western margin of the Mullaley Sub-basin. The sediments were deposited mainly by an easterly and southeasterly flowing bed-load channel system which emanated from the Lachlan Fold Belt in the west.

COOGAL SUBGROUP

(Tadros 1993a; 1995)

Named after the Parish of Coogal, west of Gunnedah, the Coogal Subgroup (table 2) has limited outcrop in the Gunnedah–Curlewis area, but extends in the subsurface over much of the Mullaley Sub-basin from a few kilometres north of Narrabri, south to Quirindi and westward to the western margin of the Mullaley Sub-basin.

Type section

The type section for the Coogal Subgroup is a composite of the type sections for the contained formations.

Lithology

Thick coal (Hoskissons Coal) at the base of the Coogal Subgroup is overlain by an organic-rich mudstone-dominated unit (Benelabri Formation) in the east and middle of the Mullaley Sub-basin and quartz-rich sandstone (Clare Sandstone) in the west.

Relationships and boundary criteria

The lower boundary of the Coogal Subgroup is the contact between the base of the Hoskissons Coal and the underlying burrowed sandstone and siltstone of the Arkarula Formation and the quartz-rich sandstones of the Brigalow Formation. The upper boundary with the Wallala Formation, the basal unit of the Nea Subgroup, is marked by a change in lithology from quartz-rich to lithic sediments, with the Breeza Coal Member at the interface.

Age and evidence

The age of the Coogal subgroup is Late Permian Upper Stage 5 associated with the *Microreticulatisporites bitriangularis* palynological zone (McMinn 1993).

Hoskissons Coal

(variation of rank and re-definition: Tadros 1993a; 1995)

Hanlon (1949a) briefly described the Hoskissons seam, which has been mined consistently in the central Gunnedah area at Gunnedah Colliery and at Preston and Preston Extended Collieries. Britten and Hanlon (1975) defined the Hoskissons "Coal Member" as being in the order of 30 m thick, with a worked subsection or seam at its base ranging from 2 m to 3 m. This basal subsection comprises bright vitrinite-rich coal and grades upwards through hard splintery dull coal to carbonaceous shale, or becomes canneloid in appearance. Tadros (1988b) carried out detailed petrographic studies on the Hoskissons "Coal Member", and provided information on vertical and lateral variations in its composition and character (Tadros 1993g). Tadros (1993a) assigned formation status to this unit and named it the Hoskissons Coal (table 2).

The Hoskissons Coal extends over much of the area of the Mullaley Sub-basin from just north of Narrabri to the limit of borehole information near Quirindi in the southeast and Coonabarabran in the southwest (figure 19). Subcrop and obscure outcrop of the Hoskissons Coal follow a line trending south-southeast from east of Narrabri to north of Quirindi.

Type section

The "type section" is presented here as being in two boreholes.

(a) North: DM Narrabri DDH 1B (180937 mE, 1646036 mN) between 596.32 m and 608.41 m, consisting of plies A-F.

(b) Southeast: DM Caroona DDH 3 (250025 mE, 1531555 mN) between 93.92 m and 105.12 m, consisting of plies B-G.

The relationship between the two sections is shown in (figure 20).

Lithotype profile (lithology)

The Hoskissons Coal maintains a consistent lithotype profile over large areas of the Mullaley Sub-basin (figure 21). Figure 20 compares two sections from northern and southern parts of the basin to show the remarkable similarity in their character.

The Hoskissons Coal consists predominantly of vitrinite-poor, inertinite-rich (dull) coal with subordinate layers of fine-grained sandstone, carbonaceous siltstone/claystone and tuff. The formation is characterised by an upward-dulling coal lithotype profile consisting of two sections separated by a persistent tuffaceous marker layer (figure 20). The

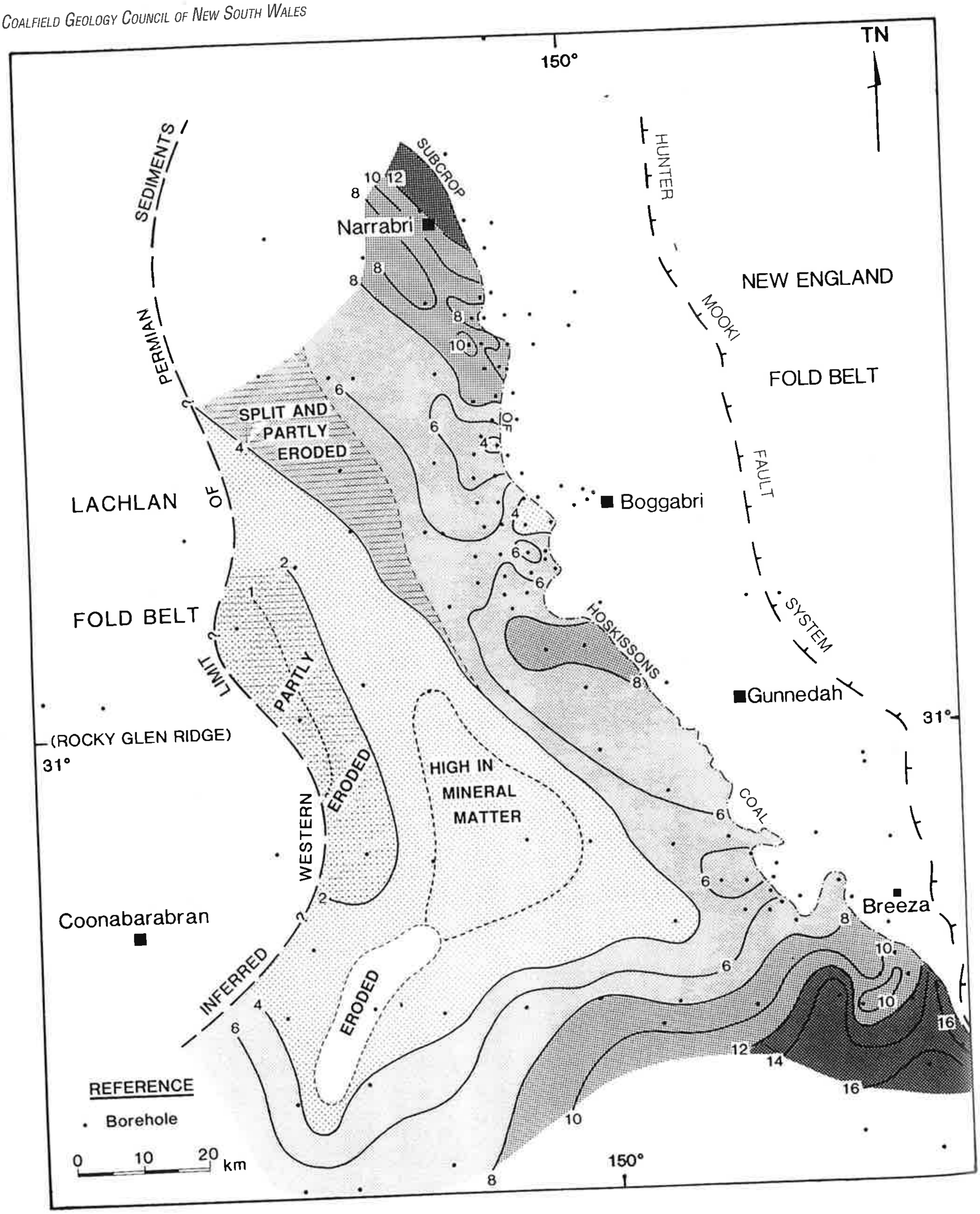


Figure 19. Isopachs (m), Hoskissons Coal

lower section consists of interlayered dull and bright coal at the base and dull coal with a few thin bright layers at the top. The upper section consists of a dull coal ply at the base, interlayered carbonaceous claystone, tuff and dull and bright coal in the middle and inter-layered dull and bright coal and carbonaceous layers at the top.

The Hoskissons Coal increases in thickness to the north and to the southeast by repetition of the topmost and lowermost plies, respectively (Tadros 1988b). However, the content of the bright coal layers tend to be marginally higher in the additional top plies than in those immediately below.

Thickness

The thickness of the Hoskissons Coal ranges from less than 1 m in the west, to more than 12 m in the north and to approximately 18 m in the southeast

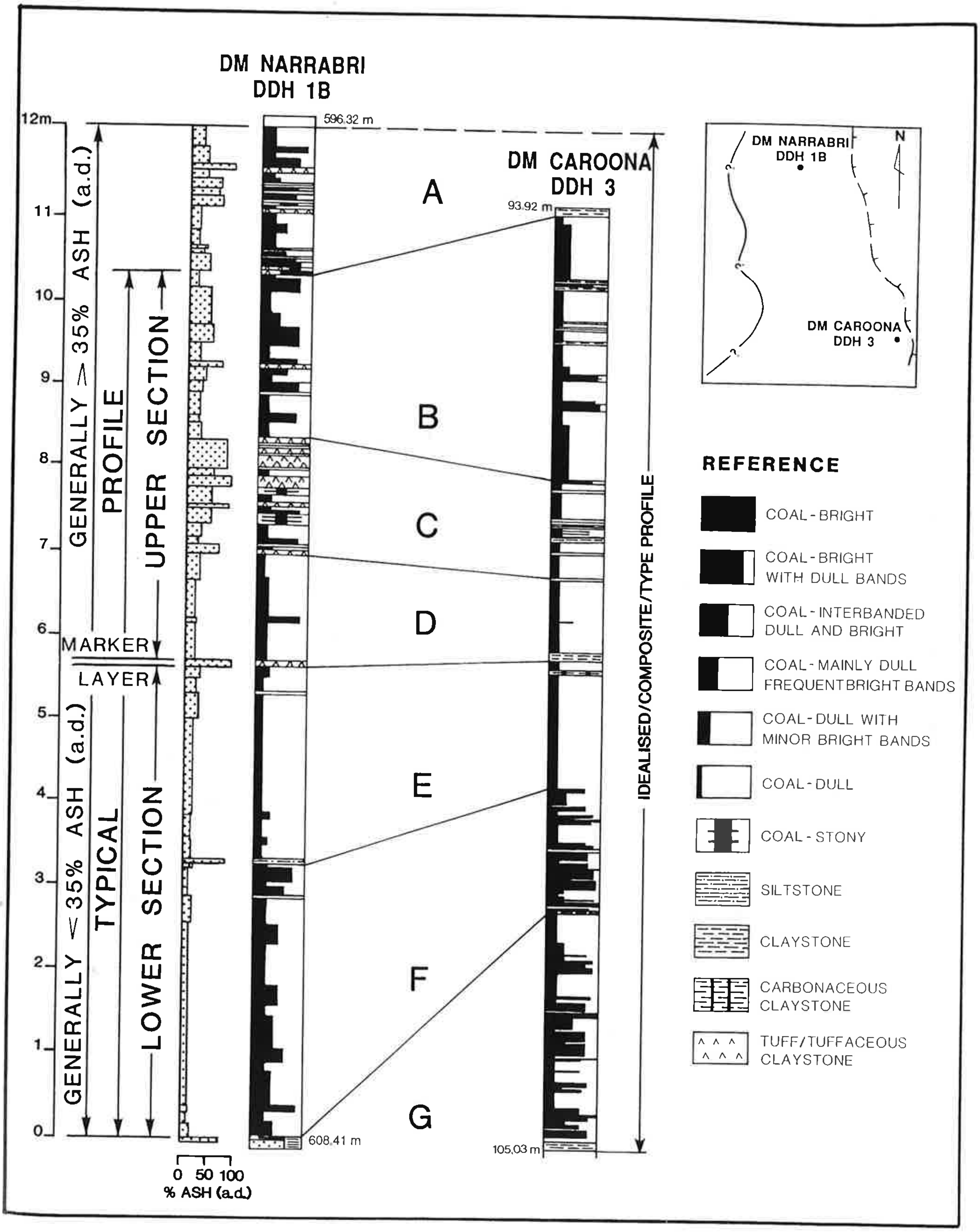


Figure 20. Two Hoskissons Coal lithotype profiles illustrating typical profile and an idealised profile (modified from Tadros 1988b, figure 9) (the drillholes are 150 km apart)

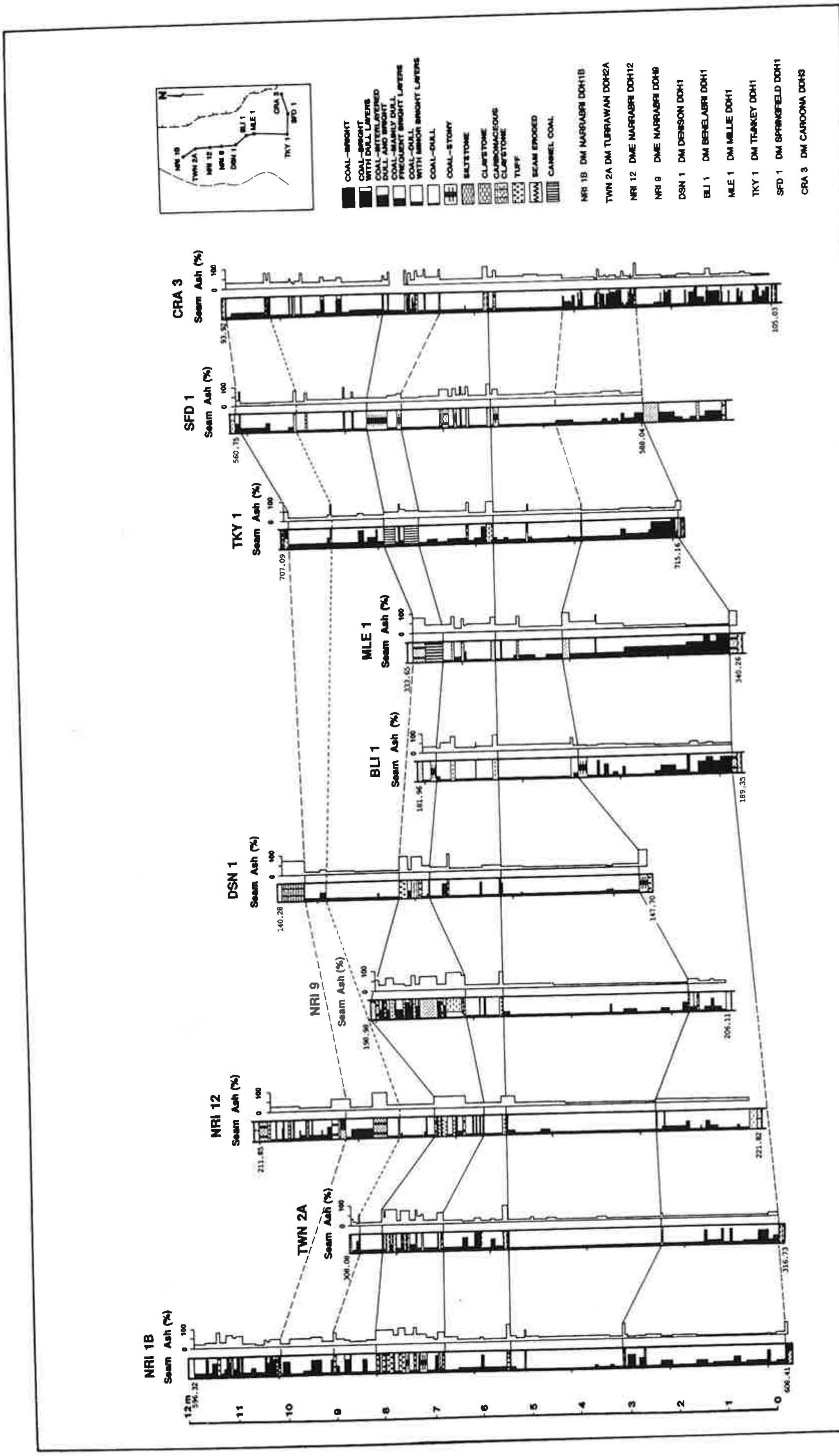


Figure 21. Hoskissons Coal lithotype and ash profiles, north–south(–east) section

(figure 19). In the two boreholes representing the type section (figure 20) the coal formation in the northern section is 12.09 m thick whereas the southern section is 11.1 m thick.

Relationships and boundary criteria

The Hoskissons Coal overlies the Arkarula Formation in an area extending from some 25 km southwest Boggabri to the central Gunnedah–Curlewis area and further southwards to Breeza, and the Brigalow Formation unit in the west and north (table 2). The coal interfingers with and is overlain by the Clare Sandstone in the west, in part this contact being erosional. In the east, the top of the Hoskissons Coal is marked by a gradational transition from coal to massive dark grey to black organic-rich mudstone of the Benelabri Formation (Tadros 1986a, b; 1993f, g).

Age and evidence

The Hoskissons Coal closely overlies the Arkarula Sandstone, which spans the palynological zone boundary between the Lower and Upper Stage 5, as indicated by the first appearance of *Dulhuntyispora parvithola* (McMinn 1993).

Correlation

Several widespread coals in the Sydney Basin, including the Bayswater seam in the Hunter Valley, the Ulan seam in the Western Coalfield and the Woonona Coal Member in the Southern Coalfield are correlatives of, and occupy a similar stratigraphic position to, the Hoskissons Coal (Beckett *et al* 1983; Hunt *et al* 1986).

Palaeoenvironment

The Hoskissons Coal represents a significant period of negligible deposition of terrigenous clastic sediments over all but the Mullaley Sub-basin periphery. Peat accumulated in vast swamps which developed on the extensive plain formed by marine regression. Initially the swamps formed behind coastal barriers and lagoons (Hamilton 1985), but quickly developed as basin-wide fluvially influenced peat swamps. Westerly sourced quartzose channel fills disrupted peat accumulation along the sub-basin's western margin (Tadros 1986b; 1988a; 1993g).

Benelabri Formation

(variation of published name and rank: Tadros 1993a; 1995)

Tadros (1986a, b) first described a distinctive mudstone-dominated unit above the Hoskissons Coal in the eastern part of the Mullaley Sub-basin, and recently (Tadros 1993a) assigned a member status to the mudstone unit. Two coal seams within this unit (informal seams in Tadros 1993a, e) are now given member status (table 2). It is therefore considered appropriate to elevate the Benelabri Mudstone Member to a formation to accommodate the two new coal members.

The Benelabri Formation is present over much of the eastern half of the Mullaley Sub-basin from Turrawan (25 km south of Narrabri) to west of Caroona in the southeast. The formation is absent in the western parts of the sub-basin and in a southeasterly trending zone, 10 km to 15 km wide, between Gunnedah and Quirindi. The distribution of the Benelabri Formation is best represented by the 60% contour on the percent sandstone map of the lacustrine system of Tadros (1986a, b; 1993f), shown here as figure 22.

Type section

The type section for the Benelabri Formation is 32.92 m thick in DM Narrabri DDH 41 (387662 mE, 1587493 mN) between 83.08 m and 116.0 m (figure 23).

Reference section

The reference section for the formation has a thickness of 27.28 m in DM Benelabri DDH 3 (395758 mE, 1579103 mN) between 56.35 m and 83.63 m.

Thickness

The Benelabri Formation averages 20 m to 30 m in thickness. It reaches 35 m in the north and is up to 68.35 m thick in the southeast in the east Caroona area (of that thickness, 13 m is coal).

Lithology

The formation has a characteristic overall upward-coarsening sequence of interbedded organic-rich mudstone, siltstone, coal seams and medium- to fine-grained quartzose sandstone. The sequence is distinctly cyclical. Each cycle is represented by an

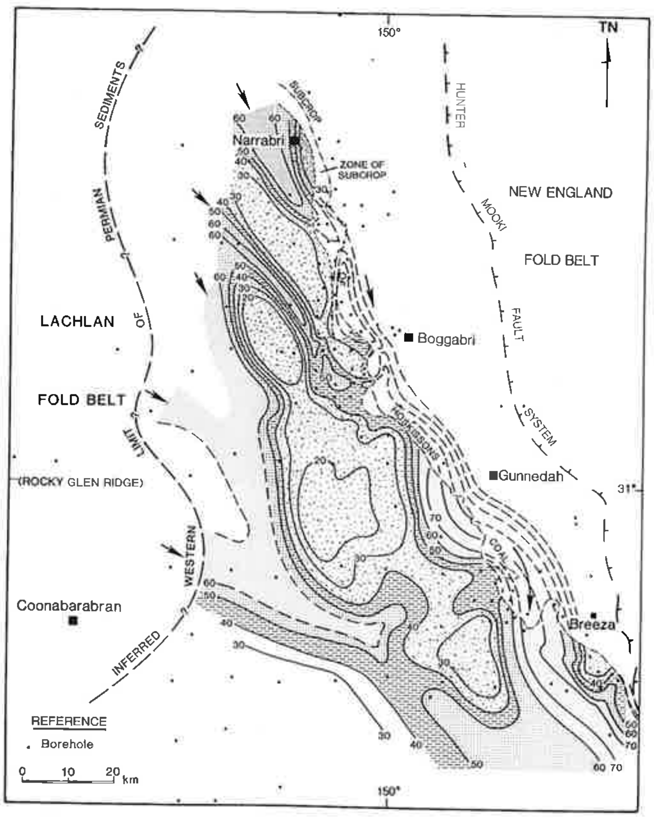


Figure 22. Percentage sandstone, Lacustrine System, upper Black Jack Group

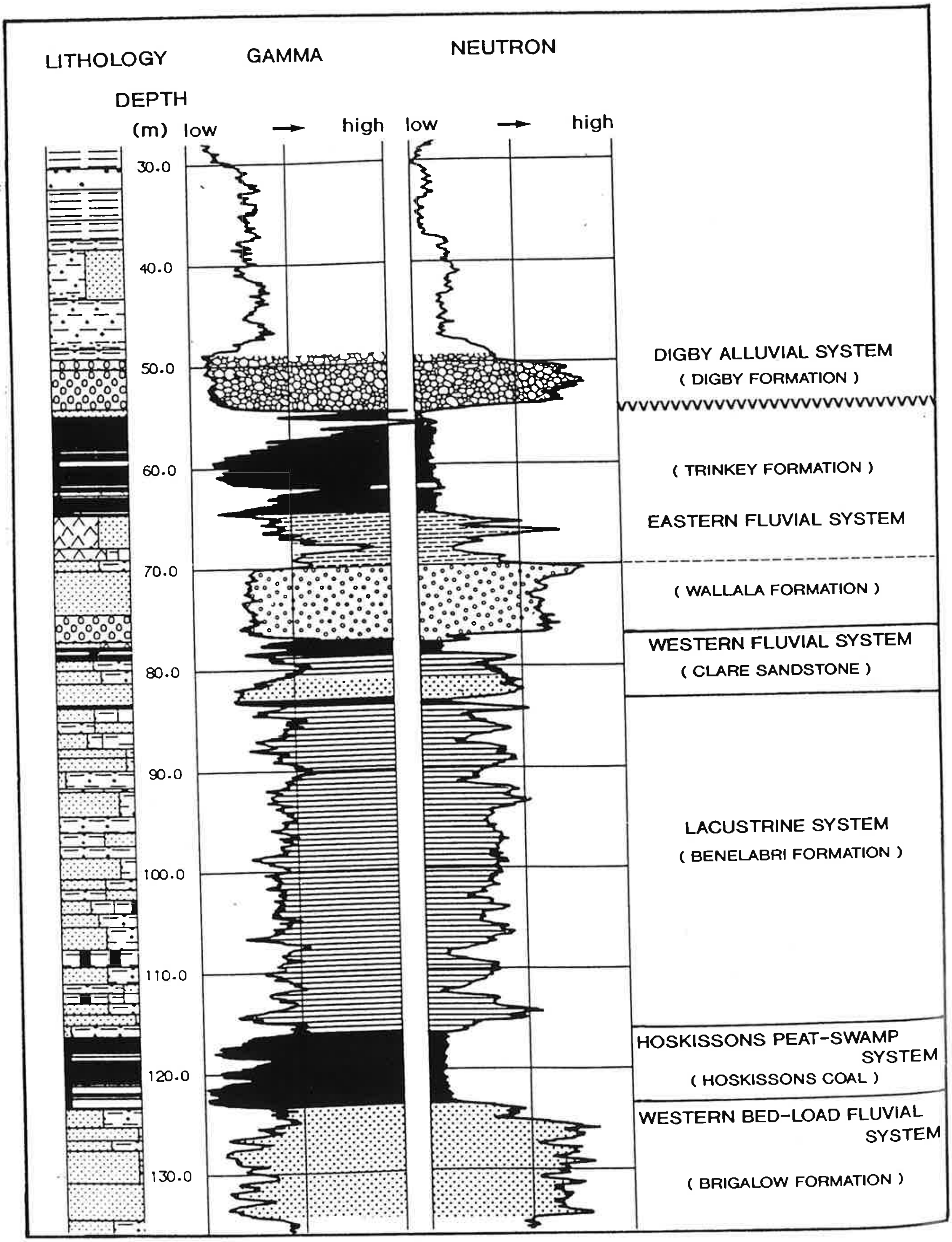


Figure 23. Type section of the Benelabri Formation in DM Narrabri DDH 41

upward-coarsening sequence, 3 m to 5 m thick, of organic-rich mudstone at the base, grading to mudstone/siltstone and graded siltstone/sandstone laminite with common burrows, which in turn passes into mainly sandstone at the top. Coal may develop in some cycles and the Howes Hill Coal Member is present at the top in the southeastern area. Sandstone layers increase towards the upper cycles (figure 22 shows sand distribution in the Benelabri Formation). Lenticular and flaser bedding, ripple lamination and desiccation cracks are common (Tadros 1986a, b; 1993a, e, f).

Relationships and boundary criteria

The Benelabri Formation overlies the Hoskissons Coal, often with a gradational boundary, and interfingers with, and underlies, the quartz-rich Clare Sandstone. Locally, where the Clare Sandstone is absent or removed by erosion, the Benelabri Formation may also be partly eroded and directly overlain by the lithic conglomerates and sandstones of the Wallala Formation.

Age and evidence

McMinn (1993) assigned a Late Permian Upper Stage 5 age (associated with the appearance of *Microreticulatisporites bitriangularis*) to the interval containing the Benelabri Formation (table 2).

Correlation

Based on the palynological assemblage, particularly *Microreticulatisporites bitriangularis*, McMinn (1982) correlated this sequence in DM Doona DDH 1 with the Denman and Dempsey Formations in the northern Sydney Basin. The Benelabri Formation is also an equivalent of the Baal Bone Formation in the western Sydney Basin (table 3).

Palaeoenvironment

The Benelabri Formation is of lacustrine origin (Tadros 1986a, b; 1993a, e, f), and formed in a large lake system that extended over the eastern half of the Mullaley Sub-basin. Westerly sourced (from the Lachlan Fold Belt) quartzose fluvial sediments were deposited around the margins of the lake, passing lakeward and upwards into organic-rich fine-grained sediments (figure 22). Cyclic fluctuation of lake level caused marginal sediments to interfinger with lake basin sediments, and ultimately the sands (now Clare Sandstone) infilled the lake (Tadros 1986a, b; 1993e, f).

Caroona Coal Member
(Tadros 1995)

The Caroona Coal Member (table 2) is the lowermost of the Black Jack Group coals above the Hoskissons Coal and is confined to the southeastern corner of the Mullaley Sub-basin north of the Liverpool range (figure 24).

Type section

Seam 2 in DM Caroona DDH 3 (250025.6 mE and 1531555.1 mN), which is 2.9 m thick (88.92 m to 91.82 m), is the type section for the Caroona Coal Member (figure 25).

Thickness

The Caroona Coal Member ranges in thickness from 2.3 m to 3.4 m in its central area, but has a tendency to split, attaining greater aggregate thickness, towards the southeast (figure 24).

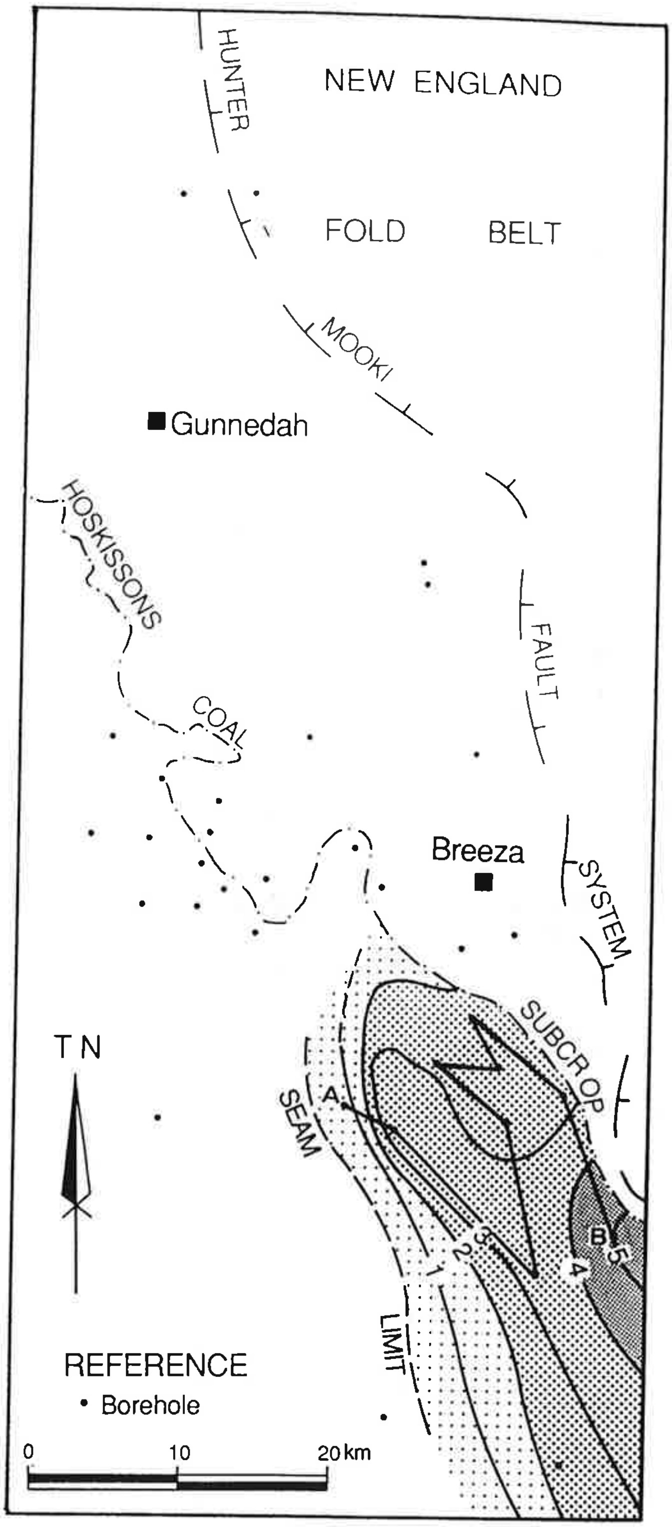


Figure 24. Isopachs (m), Caroona Coal Member

Lithotype profile (lithology)

The Caroona Coal Member maintains a characteristic lithotype profile (figure 25) consisting of a bright layered basal section (up to 1 m), a dull and minor bright layered middle section (up to 1.3 m) and a bright layered upper section (averaging 0.5 m). Thin carbonaceous claystone layers separate the three sections and thicken in a southeasterly direction, splitting the coal member into three discrete seams. Although generally brighter, the seam splits maintain an overall bright–dull–bright lithotype profile (figure 25).

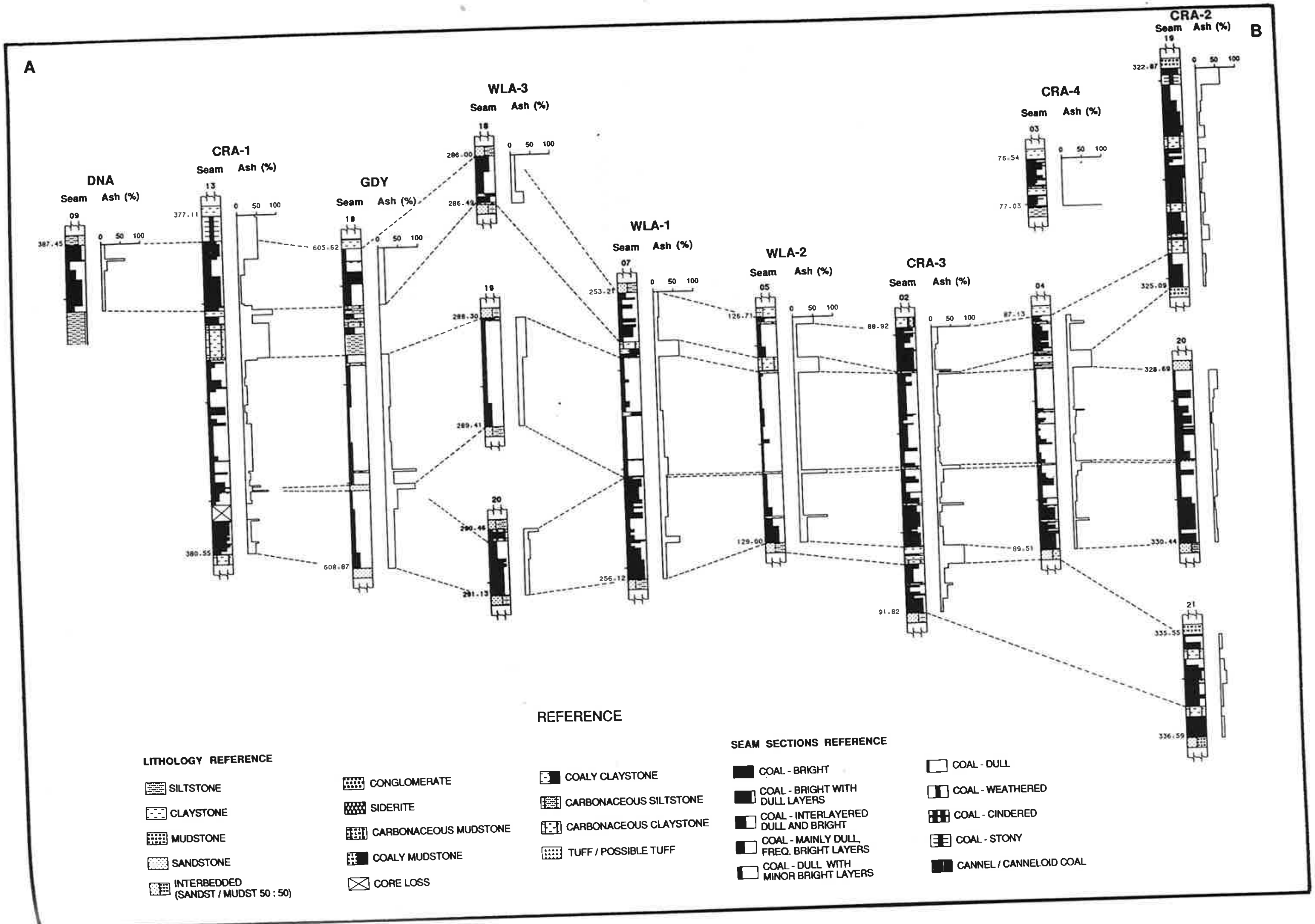


Figure 25. Typical lithotype and ash profiles, Caroona *Coal Member*

Relationships and boundary criteria

The Caroona Coal Member is close to the base of the Benelabri Formation. A thin sedimentary wedge (fine-grained) separates the Caroona Coal Member from the underlying Hoskissons Coal. The thickness of the wedge varies from a few centimetres in the west to 15 m in the east and southeast. The overlying rocks are mostly fine-grained mudstones characteristic of the Benelabri Formation.

Age and evidence

McMinn (1993) assigned a Late Permian Upper Stage 5 age (associated with the appearance of *Microreticulatisporites bitriangularis*) to the interval containing the Caroona Coal Member (table 2).

Palaeoenvironment

The Caroona peats formed on the margin of a southeasterly trending channel that carried quartz-rich sediments of the "western fluvial system" from the west and northwest (Tadros 1993f). The peats also occupied the basal part of the lacustrine system, which extended over much of the eastern half of the Mullaley Sub-basin above the Hoskissons Coal. The position of the axial channel immediately before the deposition of the Caroona peats is shown on the percentage sandstone map of the Hoskissons to Caroona interseam interval (figure 26) as a narrow southwesterly to southerly trending high-sand zone consisting of quartz channel fill (Tadros 1993f). The Caroona Coal Member is split and coal quality is at its lowest in boreholes in and around that zone. Coal quality generally improves westwards away from the main axial channel but the coal member thins abruptly and loses character in the west where it changes to organic-rich mudstone of the lake basin sequence above the Hoskissons Coal.

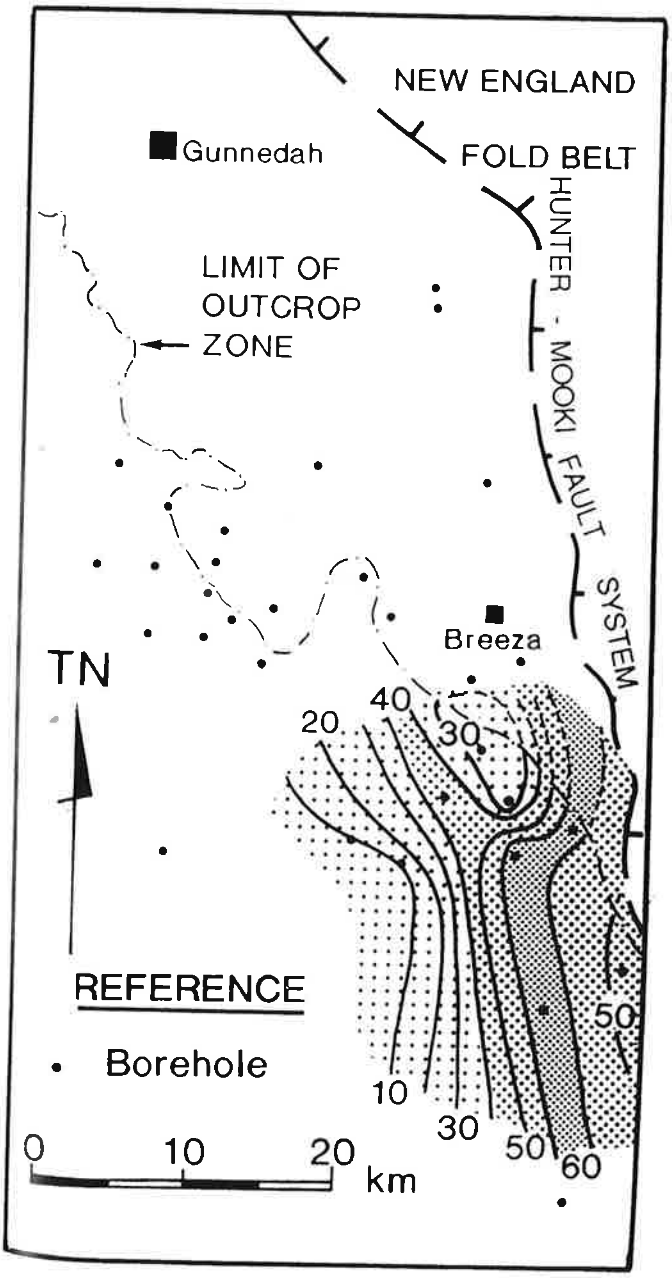


Figure 26. Percentage sandstone, Hoskissons–Caroona interseam interval

Howes Hill Coal Member
(Tadros 1995)

Britten and Hanlon (1975) introduced the term "Wondoba Coal Member" for a coaly interval (15 m thick as shown on their generalised stratigraphy figure 4) above the Hoskissons Coal, from the Gunnedah–Curlewis district, with bright coal towards the base. The term was not extensively used and has been abandoned. Extensive correlations of the coal seams in the upper part of the Black Jack Group have clearly indicated that within the interval named "Wondoba Coal Member" there are two distinctly different coal seams with interseam sedimentary rocks up to 52.76 m thick. The coal seams and the interseam rocks have been mapped in detail by Tadros (1993f) and given separate new names and granted coal member status. The lower seam, the Howes Hill Coal Member (table 2), covers the southeastern quarter of the Mullaley Sub-basin north of the Liverpool Range (figure 27) and has correlatives in the north. The upper seam, the Breeza Coal Member, covers the southern half of the Mullaley Sub-basin north of the Liverpool Range and also has correlatives in the north (defined and described below).

Type section

The type section for the Howes Hill Coal Member is assigned to seam 8 in DM Howes Hill DDH 1 (216971 mE and 1537034 mN), which is 2.77 m thick between 425.45 m and 428.22 m in depth (figure 28).

Thickness

The Howes Hill Coal Member ranges in thickness from 1 m to 4.95 m (figure 27). The coal member is absent in the east along a south-southeasterly trending zone up to 5 km wide.

Lithotype profile (lithology)

The Howes Hill Coal Member has a characteristic upward-dulling lithotype profile of interlayered dull and bright coal plies at the base, dull coal with frequent bright layers in the middle, and mainly dull

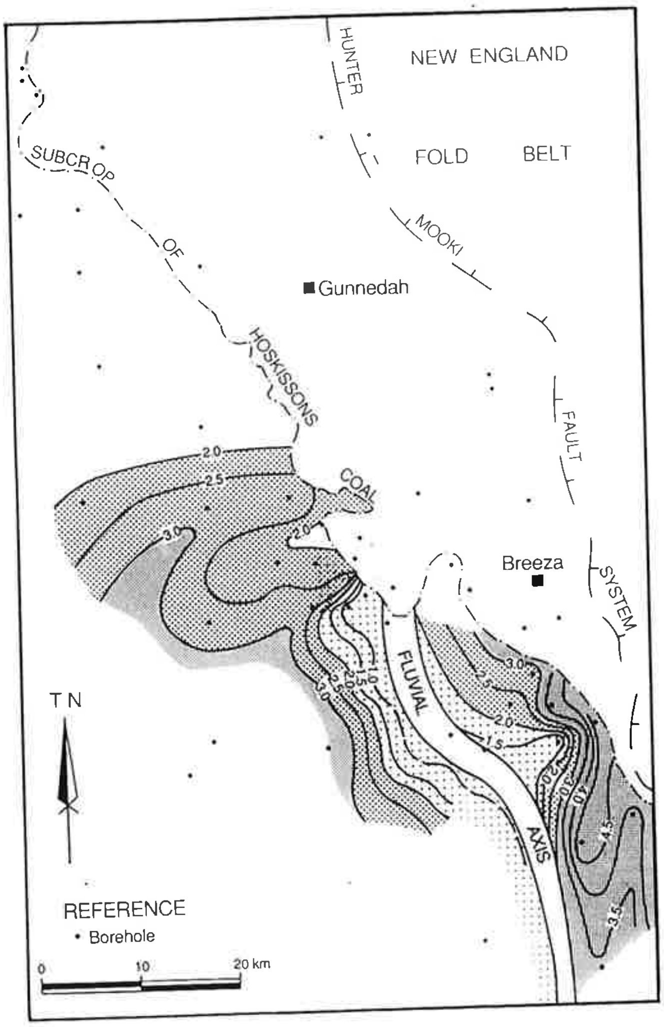


Figure 27. Isopachs (m), Howes Hill Coal Member

coal at the top (figure 28). Very persistent thin carbonaceous claystone and tuff layers separate the coal plies. Like to the Caroona Coal Member, coal plies of the Howes Hill Coal Member tend to be brighter in the southeast (figure 28).

Relationships and boundary criteria

The Howes Hill Coal Member is at the top of the Benelabri Formation. The coal member underlies the quartz-rich Clare Sandstone and overlies fine-grained sedimentary rocks of the Benelabri Formation.

Age and evidence

McMinn (1993) assigned a Late Permian Upper Stage 5 age (associated with *Microreticulatisporites bitriangularis*) to the interval containing the Howes Hill Coal Member (table 2).

Palaeoenvironment

The Howes Hill Coal Member is absent along a narrow zone occupied by the main axial channel which separates the coal member into eastern and western areas (figure 27). The coal, particularly in the western area, is underlain by channel margin, floodplain and lacustrine deposits. Disruption and seam splitting occur mainly along the margins of the axial channel complex. Coal quality improves away from the immediate margin of the channel but deteriorates in the area underlain by the lake basin units to the west and northwest.

Clare Sandstone

(variation published name and rank: Tadros 1993a; 1995)

The Clare Sandstone (table 2) represents one of the few Permian stratigraphic units which has a reasonable outcrop in the Gunnedah Basin. The best known outcrop is in the central Breeza–Curlewis area, particularly near the top of Mount Watermark, where very distinctive quartz-rich sandstone beds form near-vertical cliffs up to 12 m high.

This unit was first named "Clare Sandstone Member" after "Clare" homestead near Gunnedah by Waters (1971) to describe a 28.8 m section of sandstone containing quartz pebbles in Gunnedah Colliery Old Bore 2 and in outcrops. However, the name was never formalised. Britten and Hanlon (1975) confirmed its informal status, and since 1980 the name has been strongly associated, through field usage and in the literature (Beckett *et al* 1983; Hamilton and Beckett 1984; Hamilton 1985, 1987, 1991; Hamilton *et al* 1988) with quartz-rich sandstone encountered above the Hoskissons Coal in the regional drilling in the Mullaley Sub-basin. Those sandstones have been mapped in detail (Tadros 1993f) and have distinct lithological characteristics and mappable boundaries — which favours retaining the name. Consequently, Tadros (1993a) re-defined the Clare Sandstone Member, extended its usage to encompass the area from Narrabri to Quirindi and westward to east of Coonabarabran, and elevated its status to formation level (table 2).

Type section

The type section for the Clare Sandstone is in DM Wallala DDH 1 (247698 mE, 1527836 mN), between 195.5 m and 261.0 m (figure 29).

Thickness

In its type section the thickness of the Clare Sandstone is 65.5 m. The formation thickness ranges

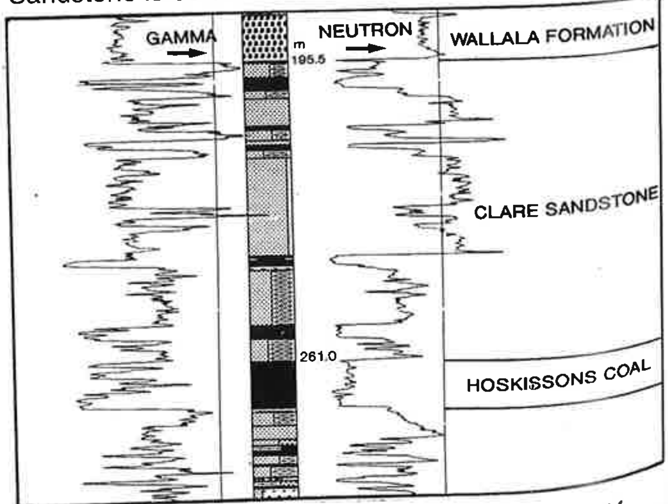


Figure 29. Type section for the Clare Sandstone in DM Wallala DDH 1

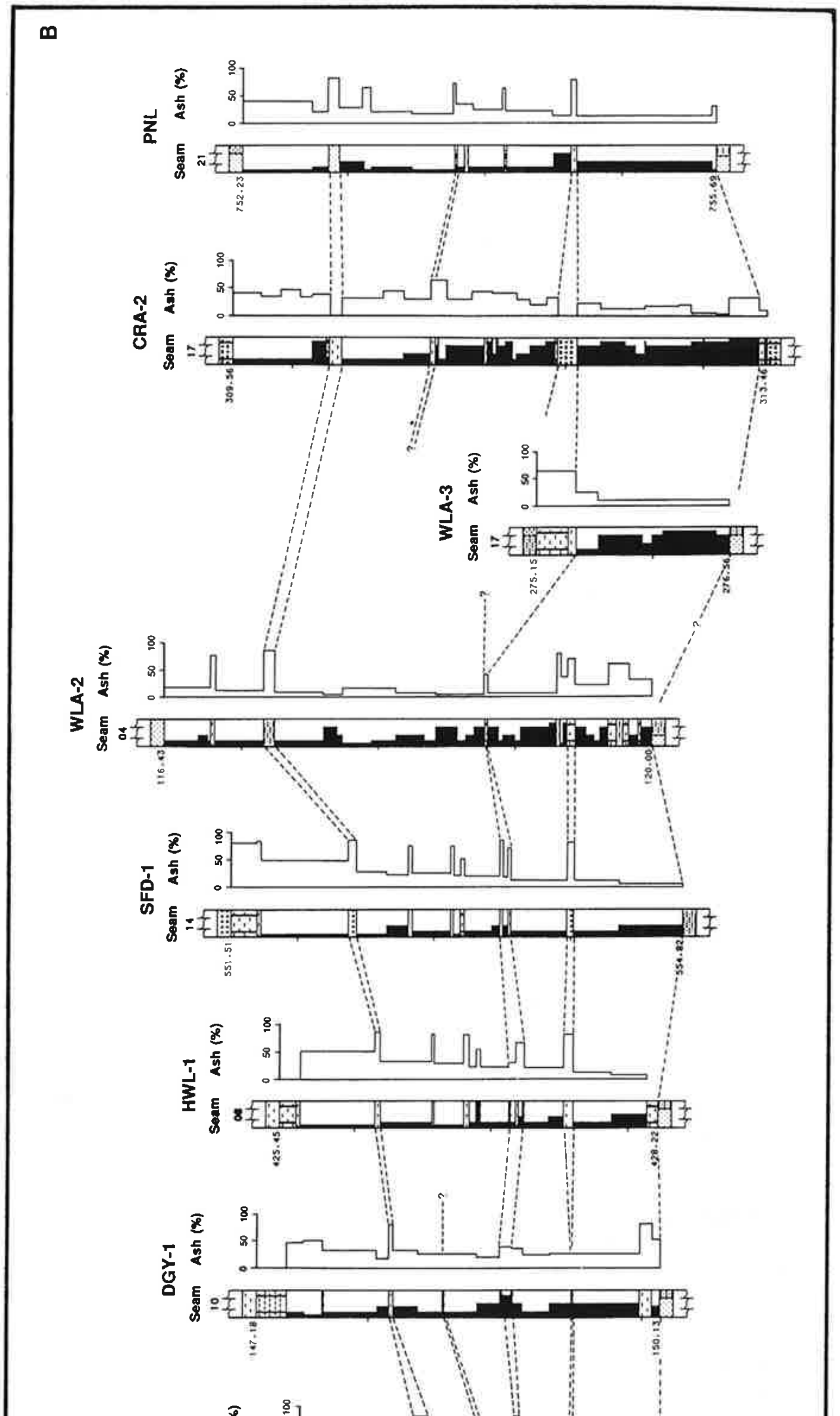


Figure 28. Typical lithotype and ash profiles, Howes Hill Coal Member (For reference, see figure 25.)

from a few metres in the western and northern parts of the Mullaley Sub-basin to more than 86 m in the southeast towards Quirindi.

Lithology

The Clare Sandstone consists predominantly of medium- and coarse-grained quartz-rich sandstone, with subordinate quartz conglomerate locally developed. Medium-bedded units with low-angle medium-scale tabular and trough cross-stratification generally form the main components in the unit. The unit sporadically changes to upward-fining thinner interbeds of sandstone/siltstone rich in plant debris and organic matter with small-scale trough cross-beds, fine ripples, ripple cross-lamination, climbing ripples, wavy and parallel laminations, clay drapes and laminated mud layers. The upper part of the unit comprises an upward-fining sequence of interlaminated thin siltstone and claystone, with the Breeza Coal Member at the top. Sporadic upward-coarsening sequences may also develop with internal erosional surfaces and palaeosols towards the top (Tadros 1986b; 1993f).

Relationships and boundary criteria

Over much of the Mullaley Sub-basin the Clare Sandstone overlies the Hoskissons Coal, but interfingers with and splits the coal into as many as three seams along the extreme western margin of the sub-basin. The unit also interfingers with the organic-rich mudstone unit over the eastern half of the sub-basin. The Clare Sandstone is overlain by the upper lithic sequence, with either an erosional or gradational contact. The upper boundary coincides with the top of the Breeza Coal Member (table 2) (Tadros 1986b; 1993f).

Age and evidence

The Clare Sandstone is of Late Permian Upper Stage 5 age. The Benelabri Formation, which interfingers with the Clare Sandstone in the east, is associated with the first appearance of *Microreticulatisporites bitriangularis* (McMinn 1993).

Correlation

The Blackmans Flat Conglomerate in the Western Coalfield of the Sydney Basin is a correlative of the Clare Sandstone (table 3).

Palaeoenvironment

Sediments of the Clare Sandstone were deposited mainly by an easterly and southeasterly flowing bed-load channel system which emanated from outcrops of the Lachlan Fold Belt in the west. Deposition was initially along the western margin of the Mullaley Sub-basin and ultimately over the entire sub-basin. The Breeza Coal Member, at the top of the formation, marks the change in deposition from the westerly sourced quartz-rich sediments to the easterly sourced volcanic–lithic sediments of the overlying Wallala and Trinkey Formations of the Nea Subgroup (Tadros 1986b; 1993f).

Breeza Coal Member
(Tadros 1995)

The Breeza Coal Member (table 2) extends over much of the southern area of the Mullaley Sub-basin north of the Liverpool Range and generally attains a thickness between 5 m and 7 m (figure 30). Like the Howes Hill Coal Member, the Breeza Coal Member had been included in the now-discarded term "Wondoba Coal Member" (Britten & Hanlon 1975).

Type section

Seam 4 in DM Breeza DDH 1 (231887.95 mE and 1541383.54 mN), which is 5.6 m thick (70.35 m to 75.95 m), has been assigned as the type section for the Breeza Coal Member (figure 31).

Thickness

The thickness of the Breeza Coal Member ranges from 2 m to 6 m in the southeast, 3 m to 5 m in the northeast, 5 m to 6 m in the central area and, where split in the west, the thickness can exceed 9 m (figure 30).

Lithotype profile (lithology)

The typical lithotype profile of the Breeza Coal Member can be divided into five coal sections separated by tuff or claystone layers, those layers ranging from 0.05 m to 0.35 m in thickness (figure 31). The two lowermost coal sections consist of dull coal with minor bright layers and there is a tendency for increased brightness towards the top. The middle section consists of a bright basal coal ply and a dull top ply. The lower of the two uppermost coal sections consists of dull coal with minor bright layers, and the topmost section consists of dull–bright coal. The coal member splits in the west, centre and southeast (cf figure 31) but can still be recognised because the coal sections maintain their character.

Relationships and boundary criteria

The Breeza Coal Member is at the top of the quartz-rich Clare Sandstone. Lithic sandstone and conglomerate of the Wallala Formation are directly over the coal member except along a zone — a few kilometres wide — in the east and southeast, where the overlying units are of intermixed quartz-rich and lithic composition.

Age and evidence

McMinn (1993) assigned a Late Permian Upper Stage 5 age to the Breeza Coal Member, based on *Microreticulatisporites bitriangularis* (table 2)..

Palaeoenvironment

The architecture of the sedimentary units splitting the Breeza Coal Member indicates contemporaneous deposition from lacustrine and bed-load fluvial systems. The percentage sandstone map of the Howes Hill Coal Member to Breeza Coal Member

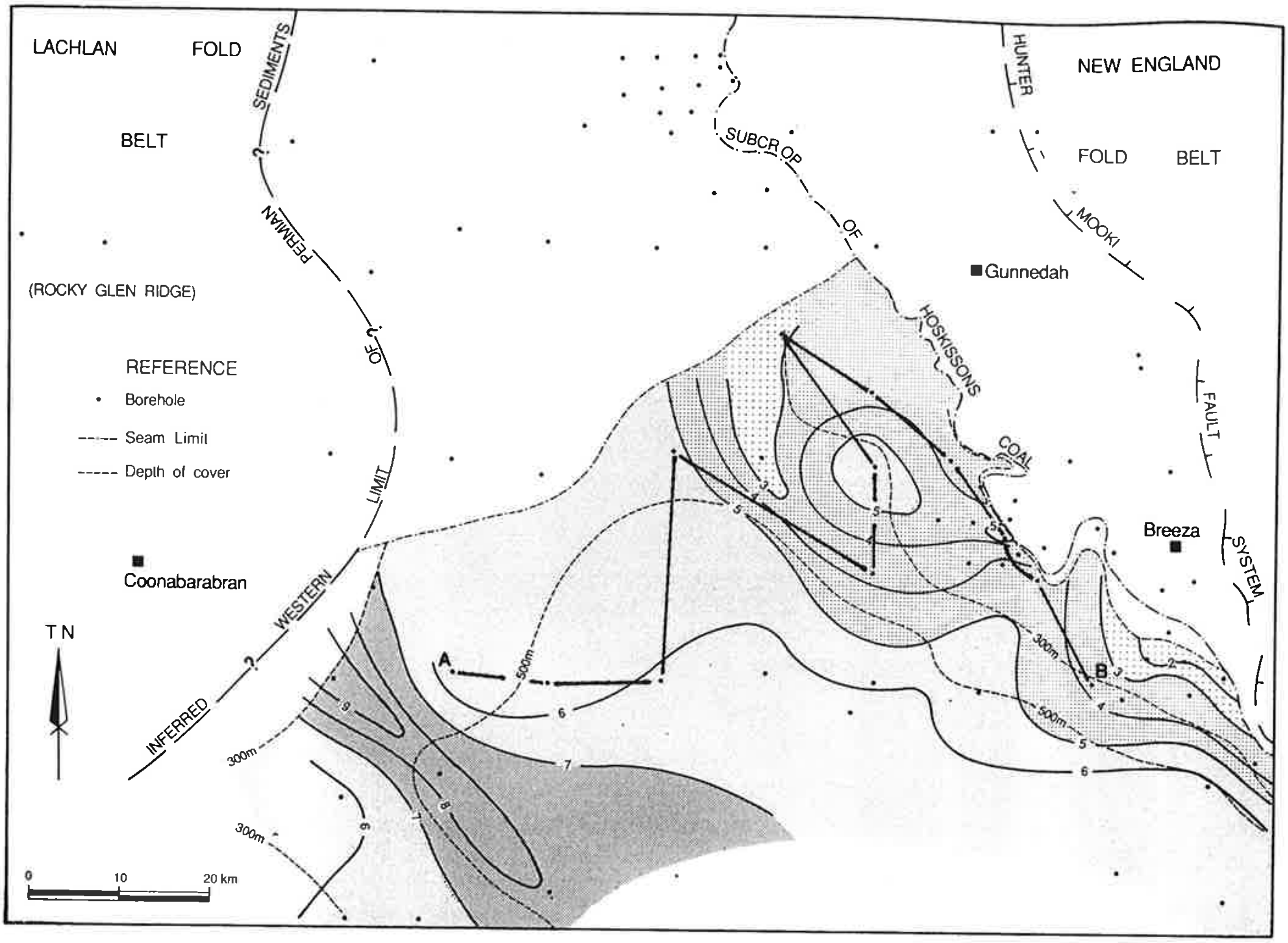


Figure 30. Isopachs (m), Breeza Coal Member

interseam interval (figure 32) defines a southeast-trending axial channel complex of the western fluvial system and small southeast-trending tributary streams along the western basin margin. Elsewhere, clastic deposition is insignificant except for crevasse-splay development off the axial channel complex west of Breeza (figure 32). This environment continued during accumulation of the Breeza Coal Member peats and greatly influenced seam distribution and coal quality. Splitting of the seam is most pronounced in the southeast where quartzose channel-fills of the axial complex were deposited. Minor splits, also by quartzose channel-fills, occur in the west from small southeasterly flowing tributary streams, and splitting in the central area is by fine-grained laminated lacustrine and marginal sandy crevasse-splay deposits (Tadros 1993f).

NEA SUBGROUP

(Tadros 1993a; 1995)

The Nea Subgroup (table 2) has been named after the Parish of Nea, northwest of Breeza. Outcrops of this subgroup are generally poor and are preserved only where they are capped by more resistant rocks of the Triassic formations or Tertiary basalt. In the subsurface the Nea Subgroup extends over much of the Mullaley Sub-basin, from a few kilometres north of Narrabri south to Quirindi and west to the western margin of the sub-basin.

Type section

The type section for the Nea Subgroup is a composite of the type sections for the contained formations.

Lithology

The Nea Subgroup is made up of two units (table 2).

1) Wallala Formation: a predominantly conglomeratic unit at the base, present mainly along the eastern sub-basin area south of Boggabri.
2) Trinkey Formation: a dominantly fine-grained tuffaceous coaly unit, which covers the entire sub-basin area south of Narrabri.

Relationships and boundary criteria

The Nea Subgroup overlies the Clare Sandstone and is separated from the overlying Triassic Digby Formation by the Permo-Triassic unconformity surface (table 2). The boundary with the Clare Sandstone is gradational along a narrow zone in the southeast, but is erosional in the north as it truncates the underlying beds down to the Benelabri Formation. A large part of the Nea Subgroup has been removed by erosion in the northeast (Tadros 1993f).

Age and evidence

McMinn (1993) assigned a Late Permian Upper Stage 5 age (within the *Microreticulatisporites bitriangularis* palynological zone) to the rocks of the Nea Subgroup.

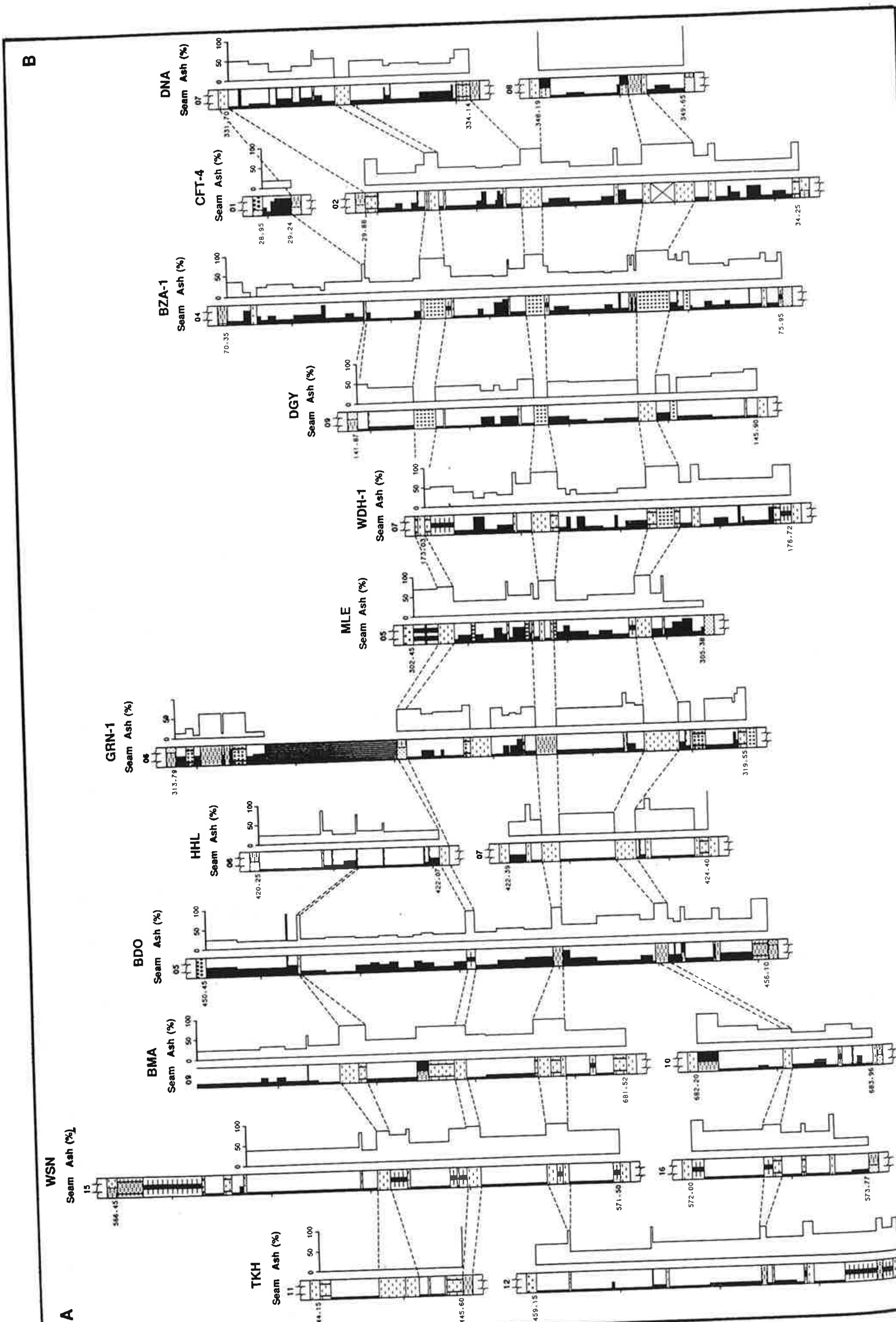


Figure 31. Typical lithotype and ash profiles, Breeza Coal Member (For reference, see figure 25.)

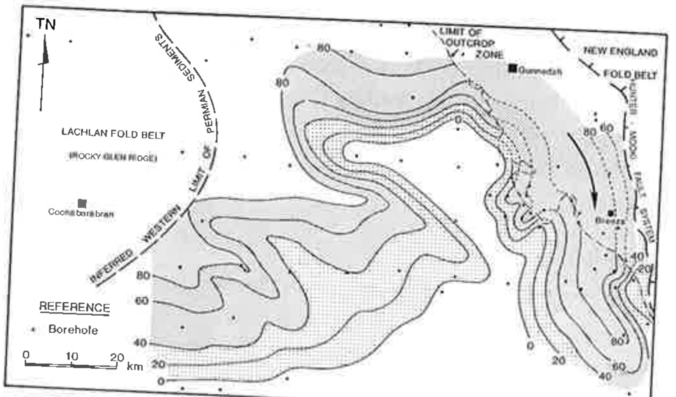


Figure 32. Percentage sandstone, Howes Hill (and/or Hoskissons)–Breeza interseam interval

Correlations

The Nea Subgroup is an equivalent of the Wallerawang Subgroup (The Gap Sandstone and Farmers Creek Formation) in the Western Coalfield of the Sydney Basin (table 3). It is also postulated that the Nea Subgroup is equivalent to the Wollombi and Newcastle Coal Measures.

Palaeoenvironment

Sedimentary rocks of the Nea Subgroup are dominantly fluvial, and were almost exclusively derived by streams emanating from alluvial fans farther to the east.

Wallala Formation

(Tadros 1993a; 1995)

The Wallala Formation (table 2) is named after the Parish of Wallala and is present along the eastern and central areas of the Mullaley Sub-basin, north of the Liverpool Range, between Boggabri in the north and the Caroona–Quirindi area in the southeast (figure 33).

A variably stratified granule to pebble conglomerate within the Wallala Formation has been named the "Goran Conglomerate Member" by Beckett *et al* (1983). They described the conglomerate as occurring near the base of their tuffaceous stony coal facies — ie, the now obsolete "Wondoba Coal Member" (Britten & Hanlon 1975), loosely equivalent to the Breeza Coal Member (Tadros 1993a, e, f). However, since its introduction by Beckett *et al* (1983), the name has been incorrectly applied to all Permian conglomerates above the "Wondoba Coal Member", despite their different lithological composition and stratigraphic position. To alleviate this problem, Tadros (1993a) proposed that the term "Goran Conglomerate Member" should be abandoned and the encompassing Wallala Formation be formalised and given formation status.

Type section

A 55.4 m drill core interval in DM Wallala DDH 3 (252539 mE, 1524344 mN), from 170.1 m to 225.5 m, has been selected as the type section for the Wallala Formation.

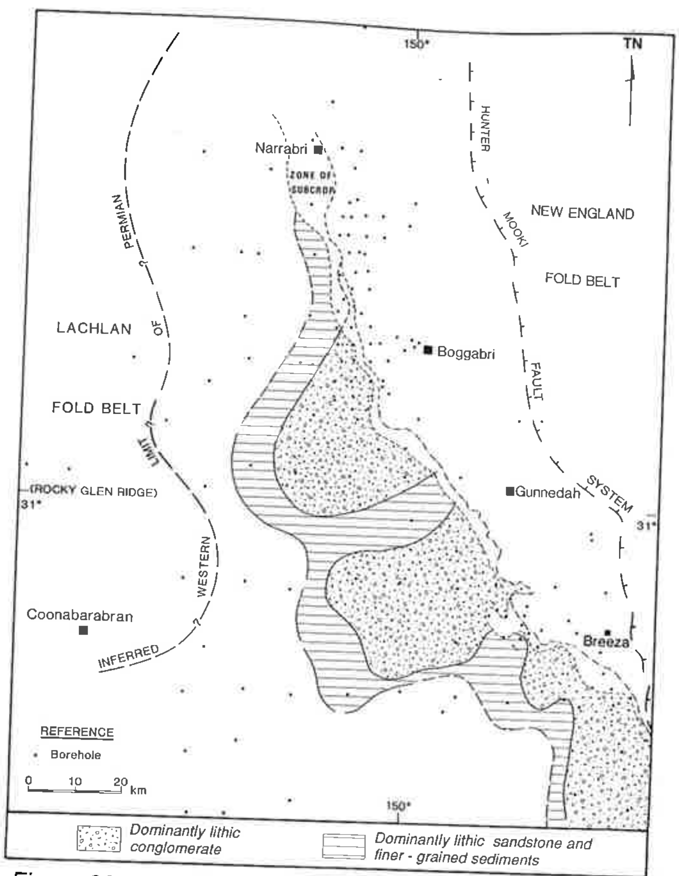


Figure 33. Distribution of the Wallala Formation of the Black Jack Group in the Mullaley Sub-basin

Thickness

The thickness of the Wallala Formation ranges from a few metres in the western and northern margins of the formation up to 54.4 m in its type section in the southeast. The formation is well developed in the Breeza area (DM Nea DDH 2) and west of Gunnedah to Mullaley (DM Goran DDH 1).

Lithology

The Wallala Formation is an upward-fining sequence of lithic conglomerate, sandstone, siltstone, claystone and coal, with only minor amounts of tuff and tuffaceous sedimentary rocks. The conglomerate forms horizontal, medium to massively bedded units, up to 5 m thick, interbedded with subordinate thin beds of sandstone, siltstone, claystone and coal. That conglomerate generally has good clast contact and medium to coarse-grained sandstone and claystone matrix. Pebbles are generally rounded, equant, and include red, green and grey chert, jasper and both silicic and mafic volcanic clasts. Locally, in some areas in the southeast, the basal part of the conglomerate units are quartz–lithic, but the quartz content rapidly decreases upwards (Tadros 1993f). Laterally, the conglomerate shows a gradual and progressive decrease in clast size towards the west.

The lithic conglomeratic unit is generally topped by a fining-upward sequence of thinly bedded, fine-grained sandstone, siltstone and claystone (Tadros 1986b; 1993f).

Relationships and boundary criteria

The Wallala Formation overlies the Clare Sandstone and underlies the Trinkey Formation (table 2). The lower boundary is marked by the top of the Breeza Coal Member and its equivalents in the north (Tadros 1993f). Where the Breeza Coal Member or its equivalents are absent, the lower boundary is marked by a change from quartz-rich rocks of the underlying unit to lithic conglomerates and sandstones. The upper boundary is marked by the base of the Clift Coal Member, which is present mainly in the south. Where the Clift Coal Member is absent, the boundary is marked by a rapid increase in tuff and tuffaceous components (Tadros 1993f). The Wallala Formation is also marked by its blocky homogeneous geophysical log patterns, with high neutron response, in contrast to the neutron signature of the underlying Breeza Coal Member and the highly serrated motif of the overlying tuffaceous coaly unit.

Age and evidence

Microfloras in the conglomeratic beds are rather restricted and core samples are often barren. However, finer grained rocks within the Wallala Formation indicate Late Permian Upper Stage 5 within the *Microreticulatisporites bitriangularis* palynological zone (McMinn 1993).

Correlation

The Wallala Formation can be loosely correlated with The Gap Sandstone in the upper part of the Illawarra Coal Measures of the Western Coalfield in the Sydney Basin (table 3).

Palaeoenvironment

Sediments of the Wallala Formation were derived from the New England Fold Belt region by westerly and southwesterly flowing streams which emanated from alluvial fans located farther to the east (Tadros 1986b; 1993f). The greater part of the alluvial fans has been eroded. However, thickly bedded coarse-grained conglomerate sequences present in the southeast (in the Caroona–Quirindi area) represent toes of the most extensive of these alluvial fans (Tadros 1986b; 1993f). Fine-grained units of this formation represent the distal products of the alluvial system in the form of overbank and flood plain deposits.

Trinkey Formation

(Tadros 1993a; 1995)

The Trinkey Formation (table 2) has been named after the Parish of Trinkey in the southwestern part of the Mullaley Sub-basin north of the Liverpool Range. The formation is represented on the surface by a few scattered small weathered outcrops along a north-northwest trending outcrop zone in the east. In the subsurface, the unit extends over much of the area of the Mullaley Sub-basin (figure 34). Tadros (1993a) established formation status for this unit because of its distinctive lithological characteristics and composition.

Type section and thickness

The type section of the Trinkey Formation is 141.7 m thick in DM Trinkey DDH 1 (205418 mE, 1525491 mN) from 531.3 m to 673.0 m. The formation reaches 258 m in thickness in the southeast towards Quirindi.

Lithology

The Trinkey Formation is dominated by finely bedded claystone, siltstone and fine-grained sandstone intercalated with tuff, tuffaceous sedimentary units and abundant carbonaceous coaly matter and tuffaceous stony coal seams. Tuffs range from thinly bedded to massive. Common sedimentary structures are thin, planar laminations, small-scale cross-bedding, distorted bedding, root traces and abundant plant debris. The formation contains minor upward-fining sequences of cross-bedded lithic sandstone with scour bases, and siltstone and claystone showing fine cross-lamination, climbing ripples and root traces. The Trinkey Formation also contains up to 40 m of medium to thickly bedded, lithic, granule to pebble conglomerate sequences consisting of chert and silicic volcanic clasts in a dominantly tuffaceous sandstone matrix. Conglomerate beds in the Trinkey Formation are confined mainly to the southeastern corner of the Mullaley Sub-basin north of the Liverpool Range, between Gunnedah, Mullaley and Quirindi (figure 34). Bed thickness and clast size increase towards the south-east where the conglomerate forms a significant part (up to 40%) of the sequence (Tadros 1993f). A lithic granule

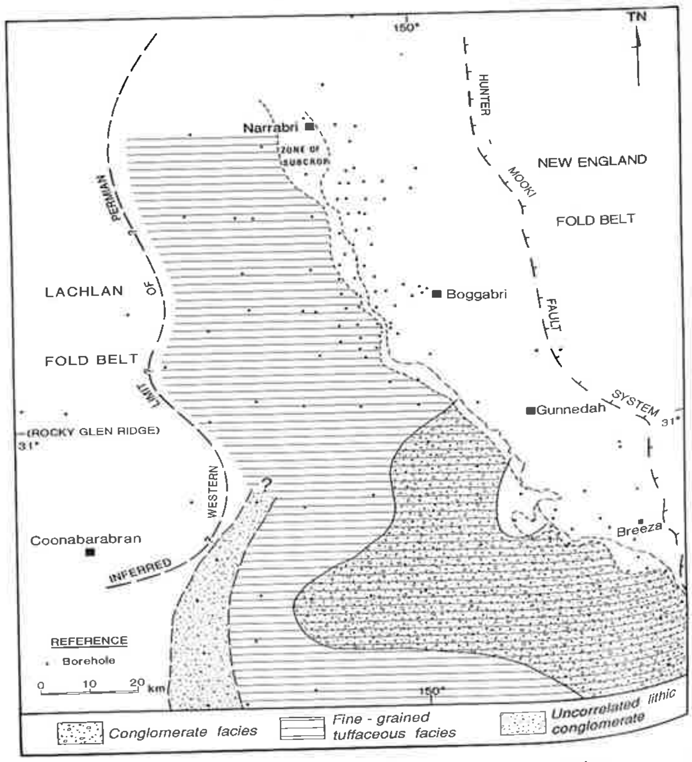


Figure 34. Distribution of the Trinkey Formation of the Black Jack Group in the Mullaley Sub-basin

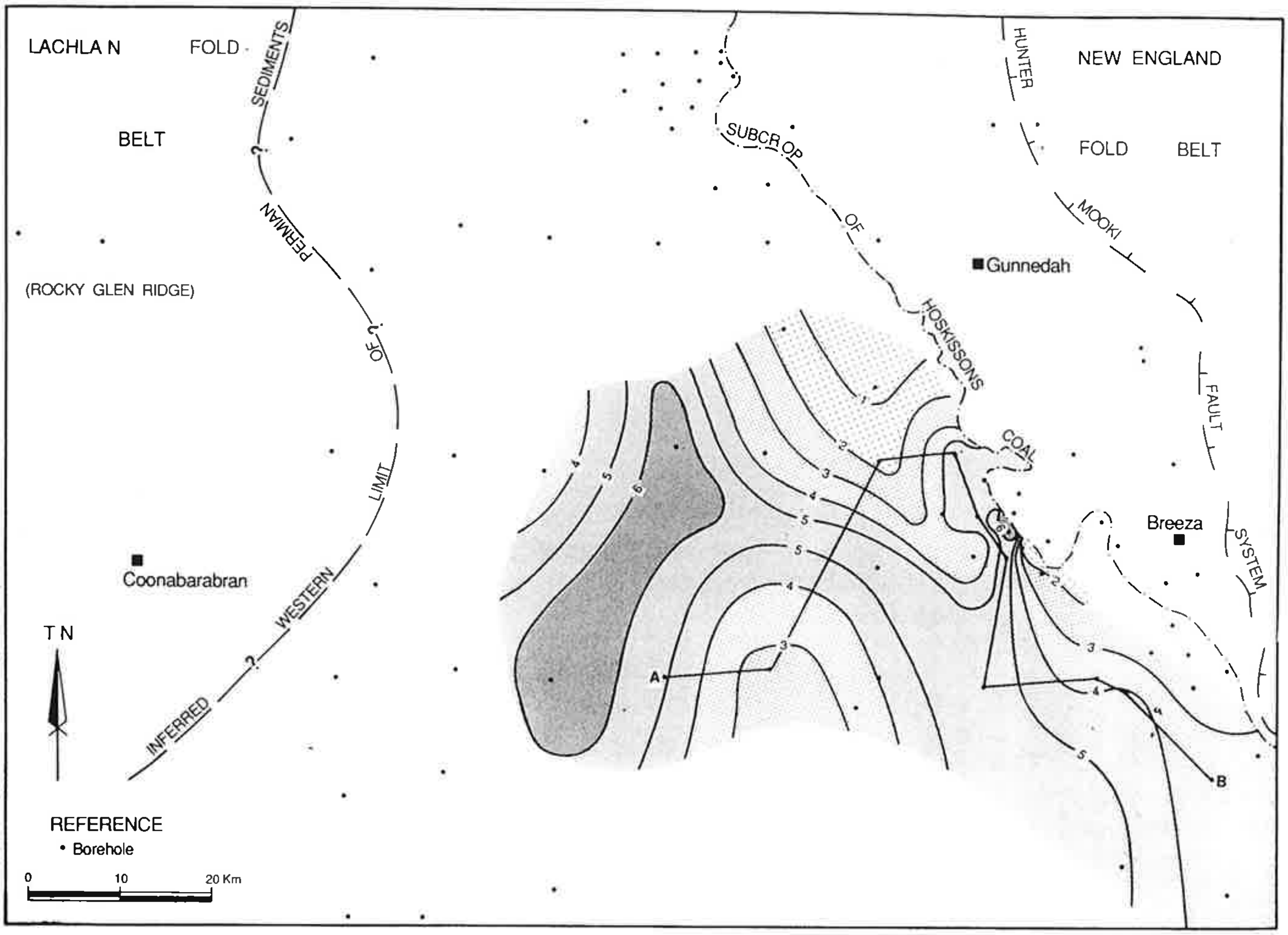


Figure 35. Isopachs (m), Clift Coal Member

conglomerate unit, up to 30 m thick, is present at the top of the Trinkey Formation in the southwest. This unit does not appear to be continuous with the conglomerate in the southeast (of the Mullaley Sub-basin).

Relationships and boundary criteria

The Trinkey Formation overlies the Wallala Formation and underlies Triassic rocks of the Digby Formation (table 2). The lower boundary is marked by the base of the Clift Coal Member in the south or, where the seam is absent, by a rapid increase of tuff and tuffaceous detritus, either as discrete beds or as matrix in the conglomerate. The upper boundary is the unconformity surface between the Permian and Triassic (Tadros 1993a, b, e, f; also see discussion for the Black Jack Group).

Age and evidence

A Late Permian age, within the *Microreticulatisporites bitriangularis* palynological zone (Upper Stage 5c), has been ascribed to the tuffaceous coaly unit in the Trinkey Formation (McMinn 1993).

Correlation

Broadly equivalent horizons to the Trinkey Formation include the Farmers Creek Formation near the top of the Illawarra Coal Measures in the Western Coalfield of the Sydney Basin.

Palaeoenvironment

Sediments of the Trinkey Formation were exclusively derived from the New England region and deposited over much of the Mullaley Sub-basin by mixed-load streams in point bars, levees, crevasse splays and as suspended-load in backswamp areas. The southeastern corner of the sub-basin was close to the New England source and received coarser sediments deposited from bed-load streams on toes of alluvial fans located farther to the east. Tuff and tuffaceous sediments were derived from tephra ejected contemporaneously from volcanoes in the New England region (Tadros 1993f).

Clift Coal Member

(Tadros 1995)

The Clift Coal Member (table 2) of the Trinkey Formation is present over much of the southern part of the Mullaley Sub-basin, north of the Liverpool Range, except in the west (figure 35).

Type section

The type section for the Clift Coal Member is assigned to a 9.41 m interval including seams 5 and 6 in DM Clift DDH 2 (231312 mE and 1538149 mN) (figure 36). The total thickness of the coal in the two seams is 5.34 m, in the section between 157.97 m and 167.38 m.

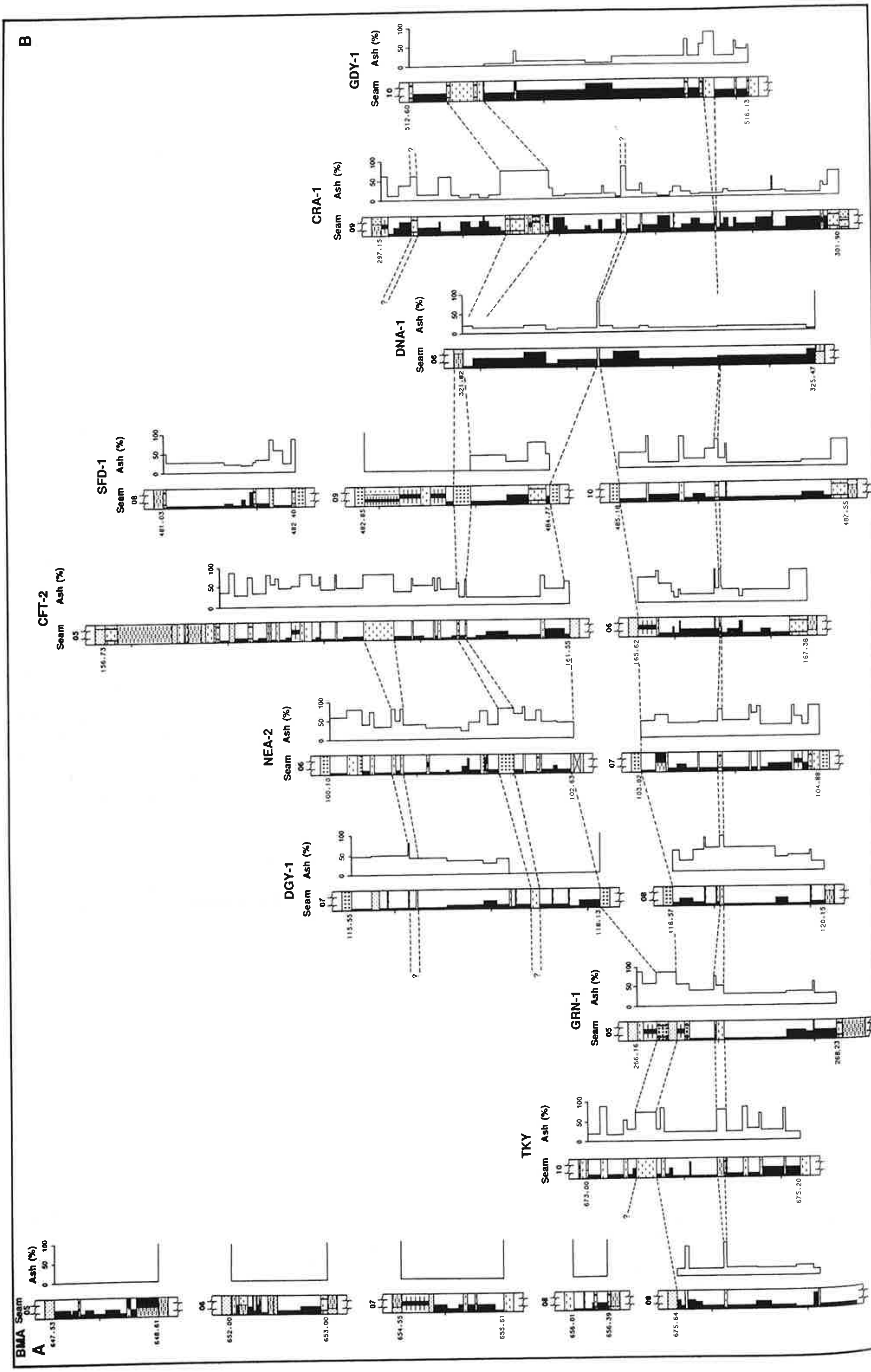


Figure 36. Typical lithotype and ash profiles, *Cliff Coal Member (For reference, see figure 25.)*

Thickness

The thickness of the Clift Coal Member ranges from 1.2 m in the northeast and 3 m to 4 m in the southeast to more than 5 m in the central west. Where split in the central east and in the west, the Clift Coal Member can exceed 10 m in thickness (figure 35).

Lithotype profile (lithology)

The Clift Coal Member generally has a characteristic upward-dulling profile consisting of five sections separated by persistent claystone or tuff layers, those layers ranging from 0.05 m to 0.3 m in thickness (figure 36). The lower two sections consist of interlayered dull and bright coal with increased frequency of bright layers towards the base of the coal member. In the upper three sections, the bright layers are less common and decrease progressively towards the top. In the southeast, the seam displays a similar trend but with generally brighter coal plies. The upper part of the Clift Coal Member loses character in the southwest due to excessive splitting and deterioration of coal quality, making correlation of all but the basal two sections speculative in that area (cf figure 36). Splitting of the coal member also occurs (locally) in the north by volcanic–lithic sandstone interpreted as channel-fills which range in thickness from 2.5 m to 8 m thick.

Relationships and boundary criteria

The Clift Coal Member is present at the base of the Trinkey Formation and overlies sandstones and conglomerates of the Wallala Formation.

Age and evidence

McMinn (1993) assigned a Late Permian age, within the *Microreticulatisporites bitriangularis* palynological zone (Upper Stage 5c) to rocks of the Trinkey Formation — which contains the Clift Coal Member (table 2).

Palaeoenvironment

The percentage sandstone map for the Breeza to Clift interseam interval (figure 37) reflects the palaeogeography prior to accumulation of the Clift Coal Member peats and demonstrates the major change in sedimentation following renewed tectonic activity in the New England Fold Belt. Large tributary streams emanated from the New England region and flowed southwesterly, pushing the axial channel complex basinward (compare figures 32 and 37). This was accompanied by a dramatic change in sediment composition as the New England tributaries carried volcanic–lithic detritus into the axial channel complex. A transition from quartzose, to mixed quartz/volcanic–lithic, and finally volcanic–lithic sandstones and conglomerates is documented in borehole intersections of the Breeza Coal Member to Clift Coal Member interseam interval (figure 38). Southwestward expansion of the tributary streams, including some lateral migration, continued throughout accumulation of the Clift Coal Member peats, accounting for seam splitting by volcanic–lithic channel-fills and deterioration of coal quality in the north and southeast. Seam splitting in the southwest is also attributed to the southwesterly expansion of the tributary facies. The percentage sandstone map for the sequence overlying the Clift Coal Member shows this area to be the focus of coarse clastic deposition (figure 39).

Springfield Coal Member

(Tadros 1995)

The Springfield Coal Member of the Trinkey Formation (table 2) is present over much of the southeastern part of the Mullaley Sub-basin, north of the Liverpool Range (figure 40).

Type section

The type section for the Springfield Coal Member is assigned to seam 9 in DM Trinkey DDH 1 (228904 mE and 1524844 mN), which is 4.77 m thick (between 649.23 m and 654.00 m) (figure 41).

Thickness

The Springfield Coal Member is 4.8 m thick in the central area (figure 40) of its occurrence. It has a tendency to split and thin (with an accompanying loss of seam character) away from the central area, and in the west, where splitting is excessive, correlation is speculative (figure 41).

Lithotype profile (lithology)

The lithotype profile for the Springfield Coal Member is characterised by several "dulling-upward" cycles ranging in thickness from 0.15 m to 2.2 m (figure 41). The basal section of the lowermost cycle consists of plies of up to 100% bright coal. Brightness decreases rapidly in the upper plies. This bright-dull arrangement is repeated in overlying cycles, but with a general tendency for a decreased overall brightness towards the top of the seam (figure 41). Discrete sedimentary layers separate the coal cycles. These layers vary in thickness from 0.1 m to greater than 0.3 m and in composition from tuff to tuffaceous sedimentary units in the central and eastern areas — to claystone and carbonaceous claystone elsewhere (figure 41).

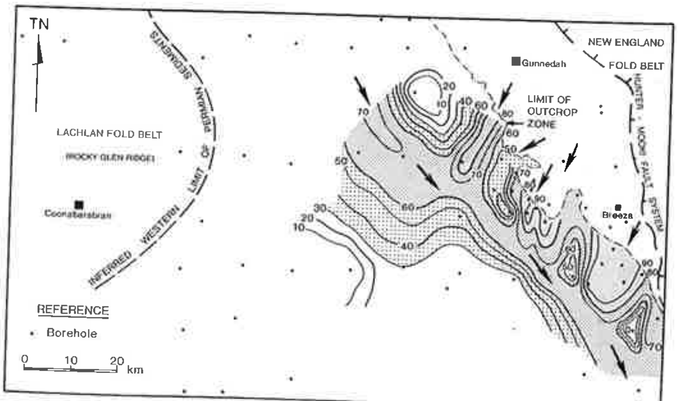


Figure 37. Percentage sandstone, Breeza–Clift interseam interval

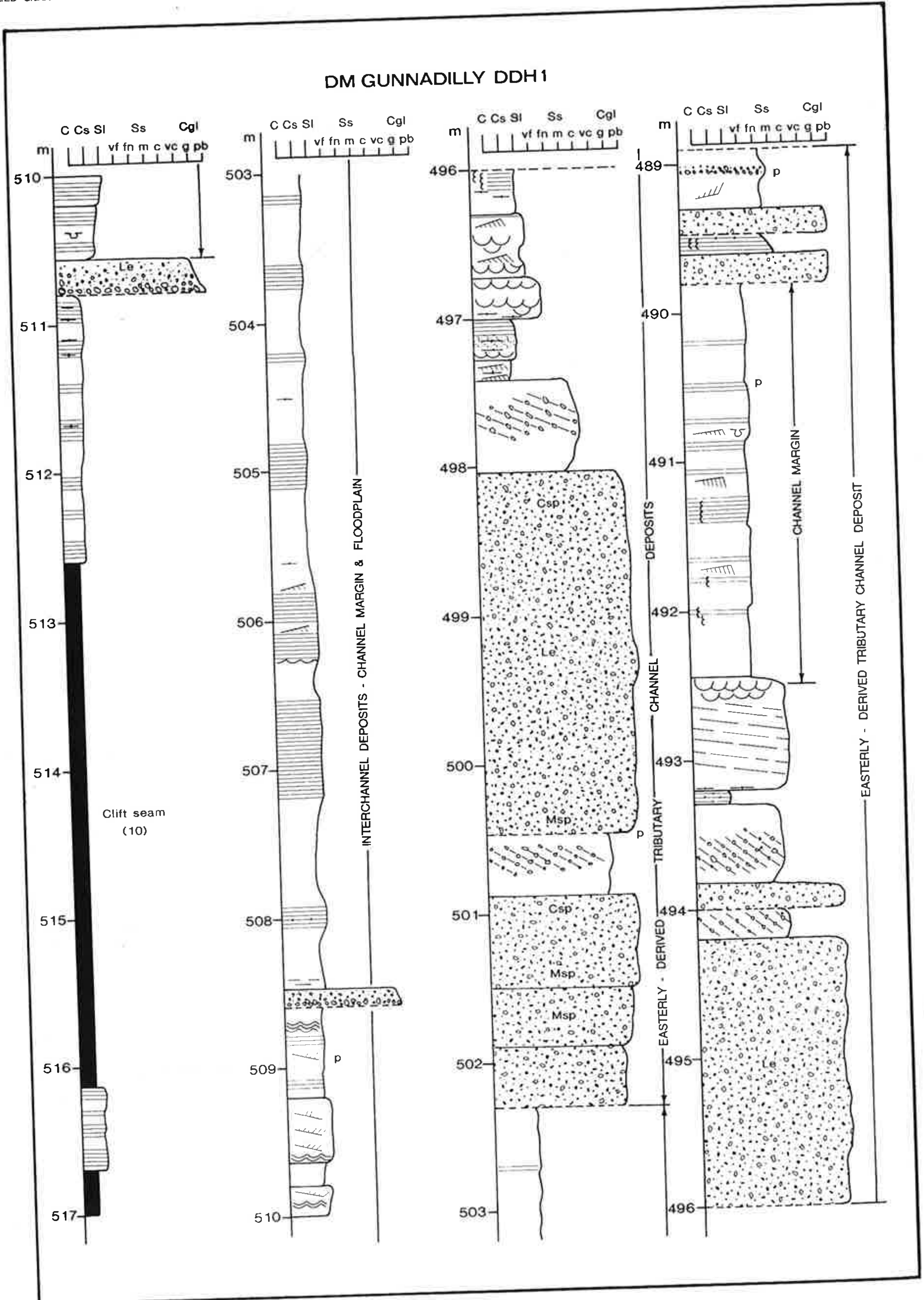


Figure 38. Vertical profile of floodplain, channel margin facies derived mixed-load and alluvial fan systems (derived from the New England) in DM Gunnadilly DDH 1

Relationships and boundary criteria

The Springfield Coal Member is part of the Trinkey Formation, which is characterised by fine-grained lithic sandstones, siltstones, claystones and tuff and tuffaceous sediments.

Age and evidence

McMinn (1993) assigned a Late Permian age, within the *Microreticulatisporites bitriangularis* palynological zone (Upper Stage 5c), to rocks of the Trinkey Formation, including the Springfield Coal Member (table 2).

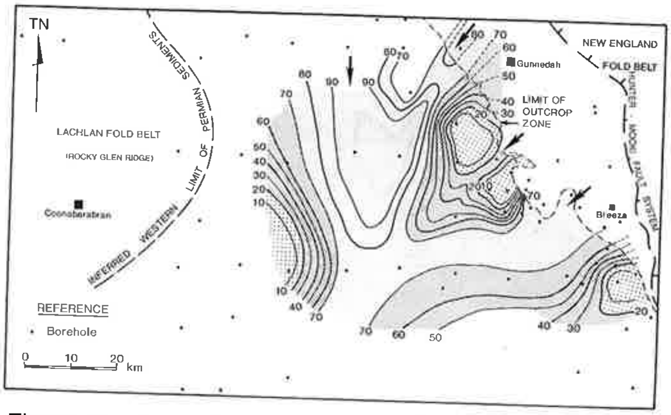


Figure 39. Percentage sandstone, Clift–Springfield interseam interval

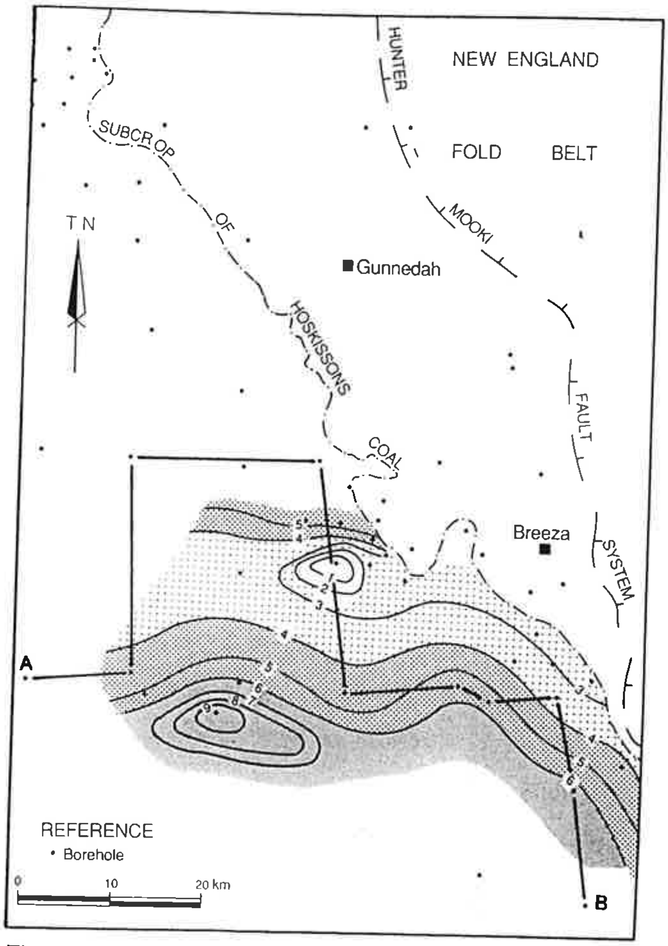


Figure 40. Isopachs (m), Springfield Coal Member

Palaeoenvironment

Peats of the Springfield Coal Member formed within an alluvial setting, as indicated by the percentage sandstone in rocks beneath the seam (figure 39). Contributory drainage patterns are recognised by the confluence of south and southwesterly sand-rich trends separating discrete interchannel areas.

Pyroclastic detritus derived from contemporaneous volcanic activity in the New England region disrupted peat accumulation in the uppermost part of the Trinkey Formation. Air-fall tuff frequently mantled the peat swamps, arrested peat growth and inhibited development of seam character and continuity.

LITHOLOGY CHARACTERISTICS AND BOUNDARY RELATIONSHIPS BETWEEN THE PERMIAN AND TRIASSIC STRATIGRAPHIC UNITS IN THE GUNNEDAH BASIN

The stratigraphic and structural relationships between the Permian and Triassic rocks in the Gunnedah Basin have been most uncertain and misunderstood. Kenny (1964) and Manser (1965a, b) considered that the Triassic Digby Beds are conformable upon the Black Jack sequence. Beckett *et al* (1983, p 11) believed that development of the Late Permian Black Jack "Formation" was terminated by the deposition of the terrestrial Digby Formation and that there is no unconformity between the two formations (with no apparent erosion of the Black Jack "Formation" prior to the deposition of the Digby Formation). Furthermore, Beckett *et al* (1983) believed that the lower part of the Digby Formation is Late Permian and commonly contains a coaly sequence up to 10 m thick, locally with one or two coal seams developed. They also suggested that deposition of the Digby conglomerate on the Black Jack "Formation" was time-transgressive and may have commenced in the north and east and prograded slowly across the region. Further, Beckett *et al* (1983) stated that in the north the Digby conglomerate rests conformably on top of the Hoskissons Coal, while in the south it was deposited on stratigraphically higher units of the Black Jack "Formation". Tadros (1993b, e) discussed these issues, some of which have already been discussed under the Permian stratigraphy in the previous section.

The Digby Formation is Early Triassic in age (Kenny 1928; 1929; 1964) as it covers the *Lunatisporites pellucidus* palynological zone (equivalent to the *Punctatisporis walkomii* Zone of McMinn 1993), *Protohaploxypinus samoilovichii* and *Aratrisporites tenuispinosus* zones (equivalent to the *Aratrisporites wollarensis* palynological zone of McMinn 1993).

Rocks of the Digby Formation differ lithologically from those of the Permian, and rest erosively and unconformably on the underlying Permian sequence (Tadros 1986b; Tadros *in* Tadros *et al* 1987; Tadros 1993f).

The Digby Formation consists mainly of two lithostratigraphic units, the Bomera Conglomerate Member at the base and the Ulinda Sandstone Member (table 2) (cf Tadros 1993a, e), with variable distribution over the basin.

The Bomera Conglomerate Member consists of persistent beds of predominantly lithic, clast-supported conglomerate with subordinate lithic sandstone. The conglomerate consists of clasts up to cobble size of varying composition, mainly red and green jasper, grey and darkgrey laminated chert, silicic and mafic volcanic rocks and white vein quartz pebbles in a sandstone matrix of similar composition. Volcanic clasts of different colours are observed

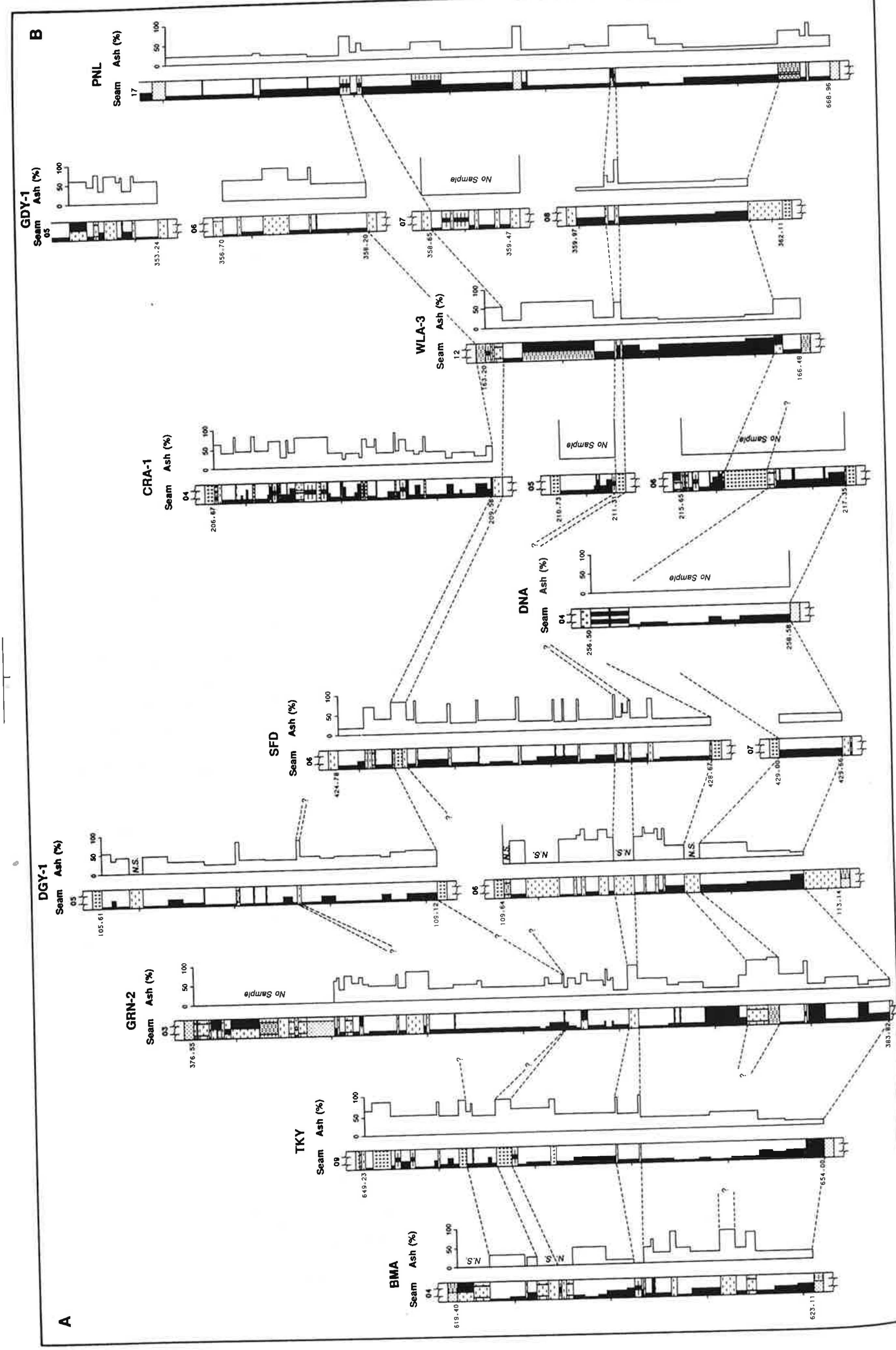


Figure 41. Typical lithotype and ash profiles, Springfield Coal Member (For reference, see figure 25.)

more in the basal part of the unit; jasper is relatively abundant in the middle; whereas light to dark grey chert and white vein quartz pebbles are common in the upper part (Jian 1991; Jian & Ward 1993).

Boundary criteria

In the northern part of the Gunnedah Basin, the Digby Formation unconformably and progressively truncates underlying rocks of the Black Jack Group and Watermark and Porcupine Formations in northerly, easterly and westerly directions (Tadros 1986b; Tadros *in* Tadros *et al* 1987; Tadros 1993b, d, f). Farther to the east and west, the Digby Formation rests, respectively, on basal volcanic units (Boggabri Volcanics), and on metamorphic rocks of the Lachlan Fold Belt. Over much of the basin south of Narrabri, the Digby Formation rests with a low angular unconformity on various horizons of the Black Jack Group.

Lithological criteria

Recognition of the boundary between basal conglomerates of the Digby Formation (the Bomera Conglomerate Member) and any of the underlying Permian rocks is simple, as there is enough contrast in lithology between the conglomerates and the underlying rocks (Tadros 1993e, f). Generally, the Digby Formation and its basal conglomerate are free of coal, carbonaceous material and tuff and tuffaceous sedimentary units, all of which are characteristic of the Black Jack Group. This contrast in lithology is clearly reflected on the geophysical log patterns of the Black Jack Group and Digby Formation (Tadros 1993f). Similarly, the lithology of the Digby Formation markedly contrasts with marine rocks of the Watermark and Porcupine Formations and with shallow marine facies (Arkarula Formation) within the Black Jack Group. Also, there is contrast in lithologies of these conglomerates and those of the basal volcanic rock types, metamorphic rocks of the Lachlan Fold Belt, and the coal-bearing sequences of the Black Jack Group (Tadros 1993e, f). Even in the few occurrences where the Bomera Conglomerate Member is in contact with conglomerate of the Black Jack Group, the conglomerates generally differ in composition allowing easy recognition of the boundary (Tadros 1993e, f). Hanlon (1949a) recognised the difference between the two conglomerates and stated (p 248):

"The basal beds [of the Digby Formation] consist of conglomerates and are characterised by the presence of abundant pebbles of red jasper. The conglomerates differ sufficiently from other conglomerates [i.e. Black Jack Group conglomerates] which outcrop in the district to make them readily recognisable and form a very valuable horizon for mapping purposes, enabling the upper limits of the Permian System to be delineated accurately. They are noteworthy for the presence in them of boulder beds, many of the boulders being more than a foot [0.3 m] in diameter."

Digby Formation conglomerates are mainly clast-supported, with the matrix and cement forming less than 30% of the total volume of the rock. Clasts of the Digby Formation are often larger in size than those of the Black Jack Group, ranging to cobble grade. Boulders up to 0.3 m to 0.4 m in diameter were reported from outcrops near Gunnedah (Hanlon 1949a; Waters 1971). The clasts are also richer in colour because of the abundance of red and green jasper and, to a lesser extent, volcanic rocks of different colours. Matrix is generally sandstone, similar to the clasts in composition. Cement is clayey but can be ferruginous (iron oxide replacement) close to the surface and in outcrops. Digby Formation conglomerates are free of tuffaceous rocks and pyroclastic detritus. In contrast, Black Jack Group conglomerates are rich in tuffaceous material and pyroclastic detritus, particularly those in the upper parts of the sequence (Tadros 1993a, e, f). Clasts are generally small, ranging from granule to pebble grade, matrix-supported and richer in green volcanic pebbles. Matrix is also rich in tuffaceous material and forms up to 70% of the rock by volume.

In the west, where the Bomera Conglomerate Member is absent, the upper unit of the Digby Formation (Ulinda Sandstone Member) rests, unconformably and erosively, on rocks of the Black Jack Group. This unit contrasts well with most Permian rocks in the Gunnedah Basin as it is characterised by coarse, white, quartzose sandstone interbedded with pebbly quartz sandstone and conglomerate with quartz sandstone matrix and by absence of coal and carbonaceous rocks. In the westernmost areas, where the Permian is also absent, the unit rests on metamorphosed basement rocks.

IGNEOUS INTRUSIONS AND EXTRUSIONS

Post-Permian intrusions occur in many parts of the Gunnedah Basin, particularly in the central and southern regions. Numerous alkali-olivine basalt and teschenite sills, dykes and plugs have intruded the Permian and Triassic strata. Some of the intrusions are exposed in the area between Breeza and Boggabri. Many authors considered the intrusions to be Tertiary in age (Jensen 1907a, b; Wilkinson 1956; 1957a, b; 1958; 1959; Wilshire & Standard 1963; Manser 1965a, b). However, Martin (1993) suggested that some are of Jurassic age, equivalent in age to the Garrawilla Volcanics, which cover large areas in the Coonabarabran–Tambar Springs–Mullaley region and in the northeast on the western side of the Nandewar Range (Dulhunty 1986).

Martin (1985; 1993) found that some stratigraphic control is evident in the emplacement of igneous intrusions. In the Gunnedah Basin, intrusions are preferentially emplaced in fissile rocks and in coal seams. She also suggested that bright (vitrinite-rich) coal allows preferential penetration by magma.

Softening of vitrinite by hot gases ahead of the advancing magma leads to the formation of weak, easily fractured coke which facilitates preferential intrusion. This mechanism may explain the high occurrence of igneous intrusions in the Hoskissons Coal, which has a well-developed vitrinite-rich lower section up to 3.5 m thick in the Breeza–Gunnedah area. The Hoskissons Coal has been affected by several igneous intrusions. The Sylvandale Sill (Wilkinson 1958; Britten & Hanlon 1975), which is at least 100 m thick, closely underlies the coal at Black Jack Mountain near Gunnedah and has carbonised the coal to a variable degree. An intrusion, probably in the form of a laccolith up to 90 m thick, has cindered the Hoskissons Coal and "domed-up" the overlying strata in an area to the south of Long Mountain (Tadros 1985). Farther to the southwest, a similar igneous intrusion, with an aggregate thickness of 110 m, has been emplaced 40 m above the coal and has had no effect on it. Tadros (1985) noticed that only limited cindering has taken place where the igneous intrusion is situated above the coal seam or even in its upper part.

Only a few thin igneous intrusions have been intersected in the Melvilles Coal Member. In the Breeza–Gunnedah area the Melvilles Coal Member is the least affected of all seams in the Black Jack Group (Tadros 1985).

A detailed discussion of igneous intrusions in the Gunnedah Basin, their distribution, composition and relationship to, and influence on, the coal seams was given in Martin (1993). Appendix 4 in the Gunnedah Basin Memoir (Tadros 1993h) contained extensive data tables listing igneous intrusions and extrusions intersected within the Gunnedah Basin and the overlying Surat Basin.

CORRELATION WITH THE SYDNEY BASIN

EARLY PERMIAN

The earliest Permian sedimentary rocks in the Sydney Basin consist of isolated occurrences of fluvial, coastal plain and marine units. These are represented in the south by the Talaterang Group, consisting of the Clyde Coal Measures, Pigeon House Creek Siltstone and the Wasp Head Formation (Fielding & Tye 1994; Tye & Fielding 1994) deposited on older Palaeozoic basement, and the fluvio-lacustrine Seaham Formation in the Newcastle and Hunter regions (table 3).

A major tectonic movement in the Early Permian caused the initial basin subsidence and initiated a widespread marine transgression throughout the Sydney Basin — forming the Shoalhaven Group (including the Yadbro and Tallong Conglomerates and the Pebbley Beach Formation) in the south and west and the Dalwood Group in the Newcastle region. The Yarrunga Coal Measures were deposited at this time in the southern Sydney Basin, in a paralic zone (Herbert 1980; coastal plain environment, cf Tye & Fielding 1994) that moved westwards as the transgression took place (Herbert 1980). Thick basaltic and rhyolitic sequences were also formed, such as the Lochinvar Formation and Gyarran Volcanics in the Sydney Basin, and the Boggabri Volcanics and Werrie Basalt in the Gunnedah Basin. A thick lacustrine sequence (Goonbri Formation), equivalent in age to the uppermost part of the Dalwood Group (table 3), was also deposited in the Maules Creek Sub-basin of the eastern Gunnedah Basin and in the Bohena and Bellata Troughs of the Mullaley Sub-basin (Tadros 1993b, d, e).

A temporary regression, which started late in the Early Permian, terminated the deposition of the Dalwood Group and allowed the accumulation of a thick fluvio-deltaic sediment wedge (Greta Coal Measures). This wedge prograded southwards from tectonically active areas in the New England region. It reached the Hunter Valley and Newcastle areas but did not prograde to the southern part of the Sydney Basin. Marine conditions continued uninterrupted in the south, forming the sequence from the Wasp Head Formation to the Snapper Point Formation and the Wandrawandian Siltstone (table 3). Deposition also commenced in the western part of the Sydney Basin at this time, with a thick transgressive shoreline and near-shore deposit (Snapper Point Formation) which was mainly derived from the Late Devonian quartzite of the Lachlan Fold Belt (Herbert 1980).

The equivalents of the Greta Coal Measures in the Gunnedah Basin, the Leard and Maules Creek Formations, were deposited over a sequence of weathered basal volcanic rocks (Boggabri Volcanics and Werrie Basalt).

MID-PERMIAN

Rapid subsidence in the mid-Permian followed the Early Permian deposition, and led to a transgressive marine inundation of the Greta Coal Measures and its equivalents. The transgression was developed first in the Sydney Basin, with deposition of the Branxton Formation of the Maitland Group in the Hunter Valley region. It subsequently spread northwards and resulted in deposition of the Porcupine Formation in the Gunnedah Basin. The presence of ice-rafted "dropped pebbles and boulders" in these formations are thought to indicate a cold climate, which persisted until at least the end of Maitland Group time (Brakel 1984).

A regressive–transgressive episode interrupted the open marine shelf deposition and formed near-shore sand sheets (the Muree Sandstone in the north and the Nowra Sandstone in the south). These beds were followed by the finer offshore sediments of the Mulbring Siltstone in the north, the Berry Siltstone in the south and west and the Watermark Formation in the Gunnedah Basin (table 3).

The upper part of the Porcupine Formation and the lower part of the conformably overlying Watermark Formation in the Gunnedah Basin represent deepening of the marine-shelf environment (Hamilton 1993a, b).

LATE PERMIAN

The main period of coal deposition (ie peat accumulation) in the Sydney–Gunnedah Basin commenced very early in the Late Permian, subsequent to the mid-Permian period of deformation (Leitch 1974). Rapid subsidence associated with continuing uplift and volcanism in the New England region resulted in increased erosion and transport of sediment westwards and southwestwards into the basins. Sedimentation was by prograding fluvio-deltaic systems which formed the Tomago Coal Measures, the Wittingham Coal Measures and the Black Jack Group (table 3). The Sydney–Gunnedah Basin also received sediments from the Lachlan Fold Belt (from the south and west) by progradation of alluvial systems — northwards and eastwards in the Sydney Basin and southeastwards in the Gunnedah Basin. Those sediments formed the lower part of the Illawarra Coal Measures and the Brigalow Formation and Clare Sandstone within the Black Jack Group (table 3).

Two marine incursions interrupted terrestrial sedimentation for short periods during this main coal-forming interval. The first incursion, caused by tectonic subsidence (Brakel 1986), deposited the Kulnura Marine Tongue and its lateral equivalents in the Sydney Basin, the Bulga Formation and Archerfield Sandstone in the north, the Erins Vale Formation in the south. In the Gunnedah Basin (Mullaley Sub-basin north of the Liverpool Range) the marine incursion is represented by the Arkarula Formation. This marine incursion did not reach the west, where sedimentation was dominated by the westerly sourced braided fluvial wedge of the Marrangaroo Conglomerate in the Sydney Basin and its equivalent, the Brigalow Formation of the Black Jack Group in the Gunnedah Basin (table 3).

The return to terrestrial sedimentation marked a very important event, the establishment of basin-wide swamps in which peat accumulated as a nearly continuous blanket over the emergent, subdued-relief surface resulting from the infilling of the preceding marine embayment (Brakel 1984). That peat formed the Bayswater seam (in the Hunter region)and the Woonona Coal Member (of the Wilton Formation) in the Sydney Basin and the Hoskissons Coal and (in the southwest) the Ulan seam in the Gunnedah Basin. Widespread peat formation was followed by continued southward progradation of the Tomago and Wittingham Coal Measures in the northern Sydney Basin and the southeastward progradation of the upper quartz-rich unit (Clare Sandstone) of the upper part of the Black Jack Group in the Gunnedah Basin (table 3).

The deposits of the second marine incursion, which was probably eustatically controlled (Brakel 1986), are very extensive in the Sydney Basin and comprise the Watts Sandstone/Denman Formation and the Waratah Sandstone/Dempsey Formation sequences in the north, the Baal Bone Formation in the west and the Darkes Forest Sandstone/Bargo Claystone sequence in the south (see elsewhere in this volume). The Dempsey/Denman incursion did not reach the Gunnedah Basin, but its lateral equivalents are represented by freshwater lacustrine rocks (the organic-rich mudstone-dominated Benelabri Formation) in the upper part of the Black Jack Group in the eastern half of the Mullaley Sub-basin (Tadros 1986a, b, f).

Coal measure sedimentation resumed after those incursions, with the southward progradation of major fluvial/deltaic systems from the north of the Sydney Basin. This regression resulted in deposition of the Wollombi and Newcastle Coal Measures in the north, the upper part of the Illawarra Coal Measures in the south and west, and the uppermost part of the Black Jack Group (the Nea Subgroup) in the Gunnedah Basin (table 3). Sedimentation during that interval, particularly in the northern Sydney Basin and in the Gunnedah Basin, was influenced by the encroachment of conglomeratic braided fluvial systems and an abundance of tuff and pyroclastic detritus. The tuff and conglomerate were mainly derived from the tectonically active New England (Fold Belt) region, except for those of the Newcastle Coal Measures, which were apparently derived from the "Northumberland Ridge" to the east of the present coastline (Brakel 1984).

In the Late Permian, a major depositional break and a period of structural readjustment, uplift and erosion are evident in the northern Gunnedah Basin and the Hunter Valley in the Sydney Basin. An angular unconformity is present in the northern Gunnedah Basin between the Triassic Digby Formation and the Permian Millie and Black Jack Groups (Tadros 1986b; Tadros *in* Tadros *et al* 1987). In the Hunter Valley Dome Belt, a significant depositional break occurred between the Late Permian coal measures and the overlying basal Narrabeen Group. An unconformity is also present over the Lochinvar Anticline, where the Newcastle–Tomago Coal Measures sequence has been completely eroded and the Triassic Munmorah Conglomerate (Narrabeen Group) rests directly on the underlying marine Maitland Group (Herbert 1980).

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STRATIGRAPHY OF THE GRETA COAL MEASURES — MUSWELLBROOK ANTICLINE AREA — HUNTER COALFIELD

J. Beckett; H. Binnekamp; J. Rogis & G. Salter

INTRODUCTION

The stratigraphic nomenclature and subdivision published by the Standing Committee on Coalfield Geology of New South Wales (1975) has been considered and revised by the Greta Working Party of the Hunter Coalfield Subcommittee. The revision was undertaken in an attempt to resolve correlation difficulties between two geographically separate mining areas, namely:

- the Savoy Trig area, located to the south and west of Muswellbrook township (Bayswater and Drayton Collieries), and
- the Muswellbrook or Skeletar Trig area, located to the north and east of Muswellbrook township (Muswellbrook Coal Company).

The area involved is shown in figure 1.

Numerous fully cored boreholes intersecting the entire coal-bearing sequence have been sunk since 1978, enabling detailed correlation studies to be undertaken.

WORKING PARTY CONCLUSIONS AND AMENDMENTS

The Greta Working Party found that direct coal seam correlation between the Savoy and Skeletar areas was not possible. Rapid changes in depositional environment brought about by variable tectonic settings and underlying geology led to the development of localised stratigraphic sequences. Additionally, extensive sill-type igneous intrusions have destroyed seam profiles over large areas between the geographic locations, further inhibiting direct correlation.

Amendments resulting from the studies of the Greta Working Party are as follows:

1. Formal redefinition of the top and base of the Greta Coal Measures.
2. Formal redefinition of the stratigraphic limits of the Rowan and Skeletar Formations within the Greta Coal Measures.
3. Formal recognition and naming of a persistent, transitional sandstone member at the base of the Maitland Group.
4. Reclassification of formal 'Coal Members' to informal 'seams' for the Savoy and Skeletar areas. New reference sections based on cored borehole intersections for the seam nomenclatures are presented, and the Thiess seam in the Savoy area has been introduced.
5. The Ayrdale Sandstone Member has been retained as a formal stratigraphic unit in the Savoy area. This unit is not recognised in the Skeletar area.

REVISED STRATIGRAPHY AND TERMINOLOGY FOR THE GRETA COAL MEASURES, MUSWELLBROOK ANTICLINE AREA

Definitions for formal stratigraphic units are included as appendix.

A comparison of previous, current and proposed stratigraphy is presented in tables 1 and 2, and coal seam associations between the Savoy and Skeletar areas are shown in figure 2.

Amendments have been based on the following criteria:

A pelletoidal, kaolinitic clayrock sequence with intercalated dull coal seams (pelletoidal clayrock facies of Hamilton 1986) has been identified at the base of all Greta equivalent sections in the Muswellbrook Anticline area. Its disposition is similar to the Maules Creek/Leard Formation association for Greta equivalent occurrences east of Boggabri, NSW (Brownlow 1981). The pelletal clayrock unit appears to overlie, and be sourced from, the early Permian Gyarran Volcanics, indicating at least a disconformable relationship between these units.

Additionally, some borehole intersections to the north-east of the Skeletar area passed conformably through the kaolinitic clayrock sequence into a dark grey (marine) siltstone, whereas some to the south-west of the Savoy area passed conformably into coarse, immature volcanolithic sediments. A Dalwood-equivalent age has been assigned to these underlying units after palynological analysis (McMinn 1981, 1984). No coal seams have been intersected in strata underlying the pelletoidal clayrock unit.

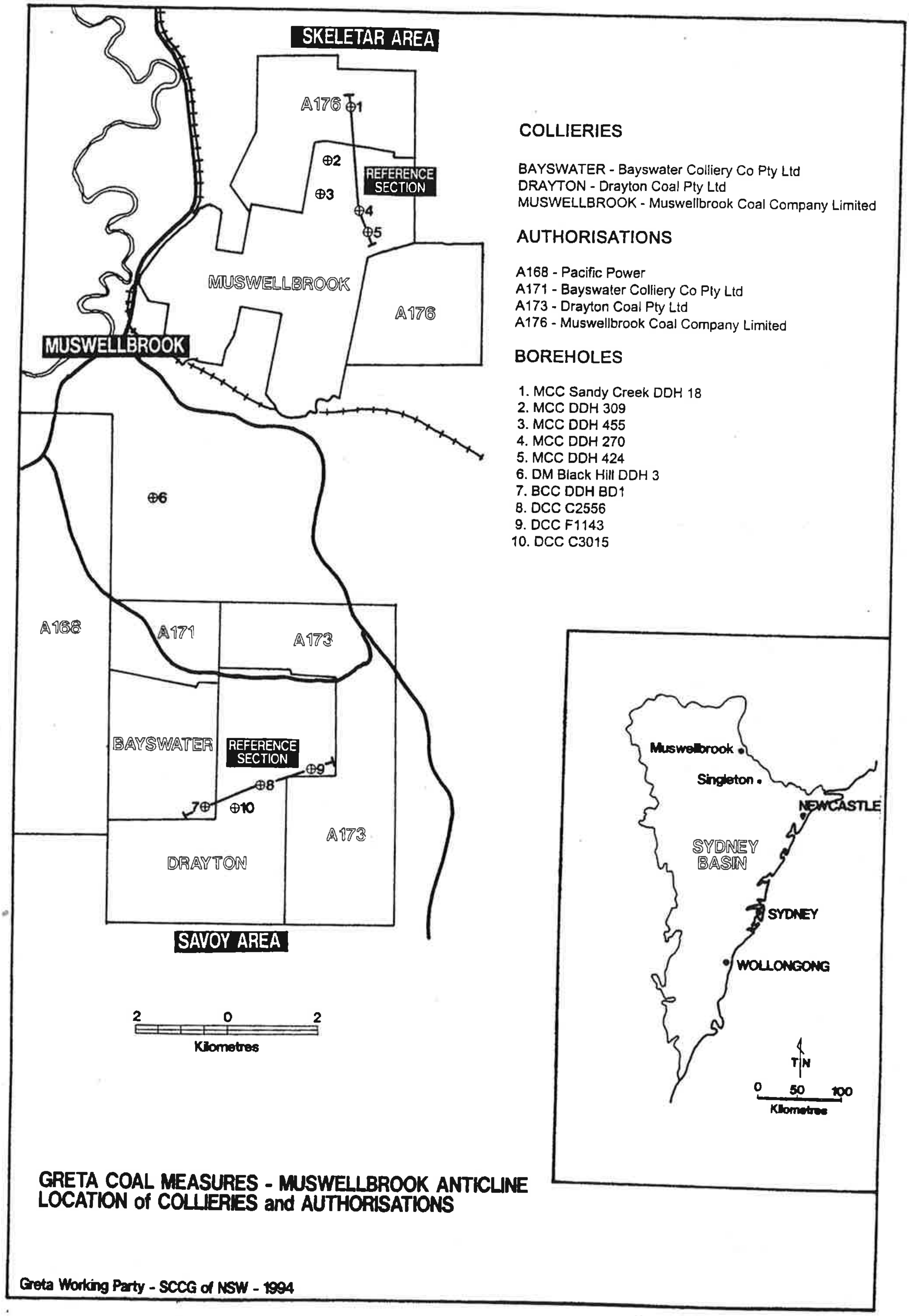

Figure 1. Location of collieries and authorisations, Greta Coal Measures — Muswellbrook Anticline (Greta Working Party, Standing Committee on Coalfield Geology of New South Wales 1994)

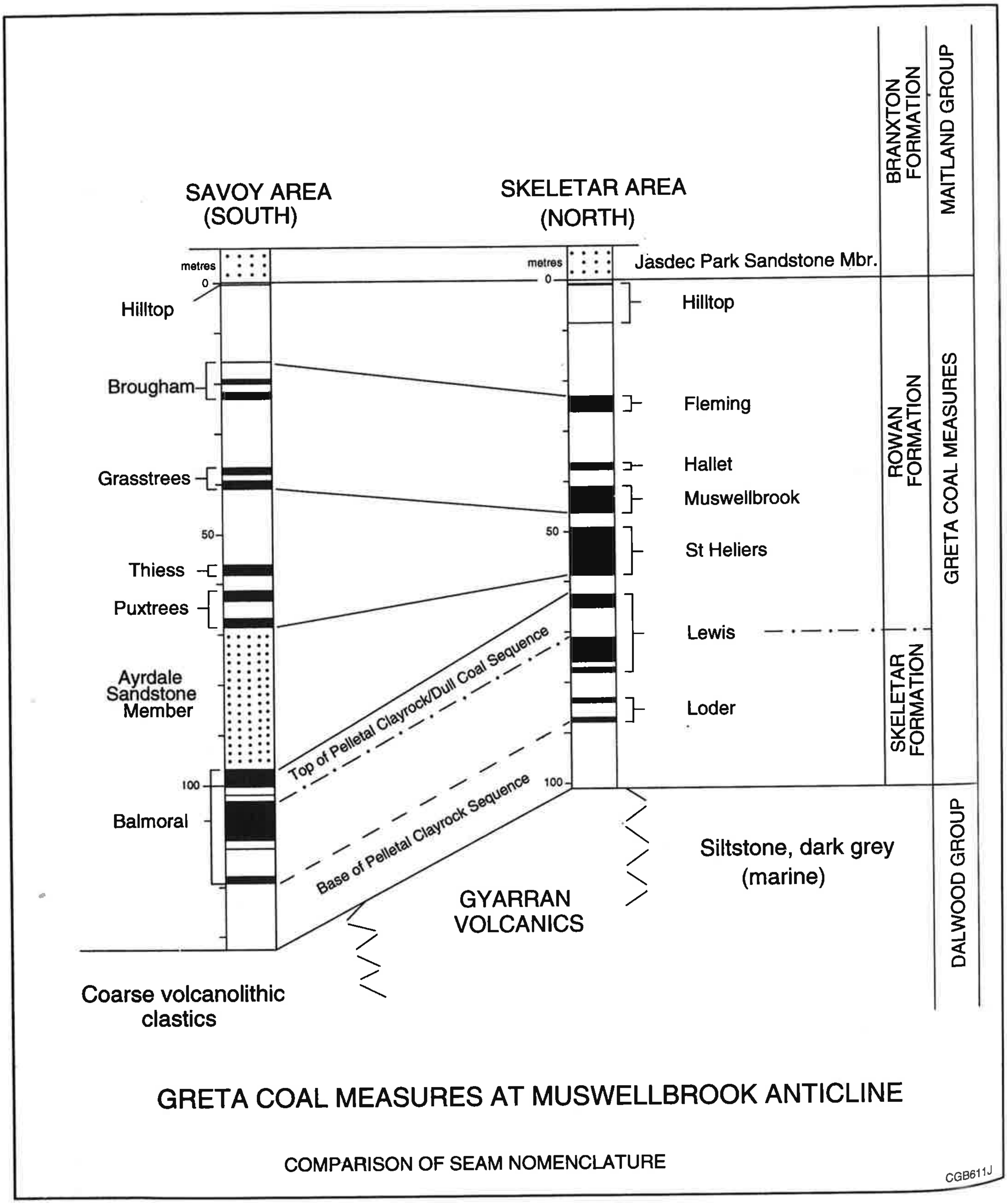

Figure 2. Comparison of seam nomenclature, Greta Coal Measures — Muswellbrook Anticline (Greta Working Party, Standing Committee on Coalfield Geology of New South Wales 1994)

TABLE 1 STRATIGRAPHIC REVISION — GREETA COAL MEASURES (MUSWELLBROOK ANTICLINE) — EXCLUDING COAL
(Greta Working Party, Standing Committee on Coalfield Geology of New South Wales 1994)

Metres		Previous Usage				Current Usage		Proposed Usage	
		Raggatt 1938		Booker 1953		Standing Committee 1975		Standing Committee 1994	
-50 to 0	(Basal Section) Sandy shale and mudstone with erratic	Upper Marine	Branxton Lower	Maitland Group	(Branxton) (Subgroup)	Maitland Group	Branxton Formation	Maitland Group	Branxton Formation Jasdec Park Sandstone Member
0 to 100	Coal and sediments	Greta Coal Measures	Muswellbrook Stage	Greta Coal Measures	Muswellbrook Formation	Greta Coal Measures	Rowan Formation Ayrdale Sandstone Member	Greta Coal Measures	Rowan Formation Ayrdale Sandstone Member
100 to 200	- Rhyolite - Rhyolite breccia - Interbedded white shales with *Glossopteris*		Skeletar Stage		Skeletar Formation		Skeletar Formation		Skeletar Formation
200	- Rhyolite - Rhyolite breccia	Lower Marine	Gyarran Volcanics			Dalwood Group	Gyarran Volcanics	Dalwood Group	Gyarran Volcanics + others (redefinition required)
300 to 400	- Amygdaloidal basalt - Felsite			Dalwood Group	Gyarran Volcanics				

TABLE 2 STRATIGRAPHIC REVISION GRETA COAL MEASURES (MUSWELLBROOK ANTICLINE) COAL SEAM NOMENCLATURE (Greta Working Party, Standing Committee on Coalfield Geology of New South Wales 1994)

	Current Usage Standing Committee 1975		Proposed Usage Standing Committee 1994	
	Savoy Area	Skeletar Area	Savoy Area	Skeletar Area
Rowan Formation	Hilltop Coal Member		Hilltop seams	Hilltop seams
	Brougham Coal Member	Fleming Coal Member	Brougham seams	Fleming seams
		Hallett Coal Member		Hallett seams
	Grasstrees Coal Member	Muswellbrook Coal Member	Grasstrees seams	Muswellbrook seams
			Thiss seams	
	Puxtrees Coal Member	St Heliers Coal Member	Puxtrees seams	St Heliers seams
	Ayrdale Sandstone Member		Ayrdale Sandstone Member	
	Balmoral Coal Member	Lewis Coal Member	part Balmoral seams	part Lewis seams
		Loder Coal Member		
Skeletar Formation			part Balmoral seams	part Lewis seams Loder seams

The stratigraphic relationship between the three early Permian units below the Greta Coal Measures is not known, and an examination of this question was beyond the scope of this study. Their presence, however, has allowed the recognition of a consistent base for the Greta Coal Measure sequence, namely, the base of the pelletoidal, kaolinitic clayrock sequence.

Therefore, the following stratigraphic revisions are made:

- The Dalwood Group to variously include:
  - dark grey (marine) siltstone (north-east)
  - Gyarran Volcanics
  - coarse, immature volcanolithic clastic unit (south-west).
- The section of rhyolite, rhyolite breccia, chert and white tuffaceous shale previously assigned to the Skeletar Formation is reassigned to the Dalwood Group.
- The Greta Coal Measures to consist of the Skeletar Formation and the overlying Rowan Formation.
- The Skeletar Formation stratigraphic limits to be as follows:

  Variously overlies the units assigned to the Dalwood Group. Includes colluvial/alluvial kaolinitic pelletoidal clayrocks and intercalated, generally dull, coal seams. Includes strata to the top of the dull coal section of the seam directly overlying the topmost pelletal clayrock sequence (generally the Lower Lewis seam in the Muswellbrook area and the Balmoral middle splits in the Savoy area).
- The Rowan Formation stratigraphic limits to be as follows:

  Generally conformably overlying the Skeletar Formation and includes the sequence to the base of the Maitland Group (Branxton Formation).
- Branxton Formation

  A laterally persistent, mappable unit herein named the Jasdec Park Sandstone Member has been recognised at the base of the Branxton Formation. It ranges from 1 in to 20 m thickness, and separates paraconglomerates or diamictites assigned to the Branxton Formation from the Greta Coal Measures strata.

RECLASSIFICATION OF COAL MEMBERS TO INFORMAL LITHOSTRATIGRAPHIC UNITS

The Greta Coal Measures in the Muswellbrook Anticline area are classed as a Type 2 deposit, as defined by the Warren Centre Study on Advanced Surface Mining Technology (1985), where three or more coal seams occur as multiples, and seam thickness and interburden lithology are not laterally consistent or persistent. Seam splitting is common.

Mining operations in these deposits require increased drilling densities and detailed computer generated stratigraphic models to support high volume extraction. There is also an increased trend towards the recovery of thinner seams previously considered uneconomic by open cut methods, and selective mining of coal plies. This trend has resulted in the need for detailed subdivision of economic units on a local scale.

A computer-generated stratigraphic model contains many coal plies/seams that are uniquely identified by a mnemonic code, generally related to an original formal Coal Member or Seam. This is especially the case in an established mining area such as the Muswellbrook Anticline where local coal seam relationships are understood. The original formal nomenclature (Standing Committee on Coalfield Geology of New South Wales 1975) has served its purpose in standardising the naming of groups of coal seams/plies in each geographic location. Subsequent workers have informally expanded the existing definitions, and cooperated in the establishment of uniform mnemonic identifiers for computer modelling.

When considering the revision of the existing formal Coal Member nomenclature, the Greta Working Party

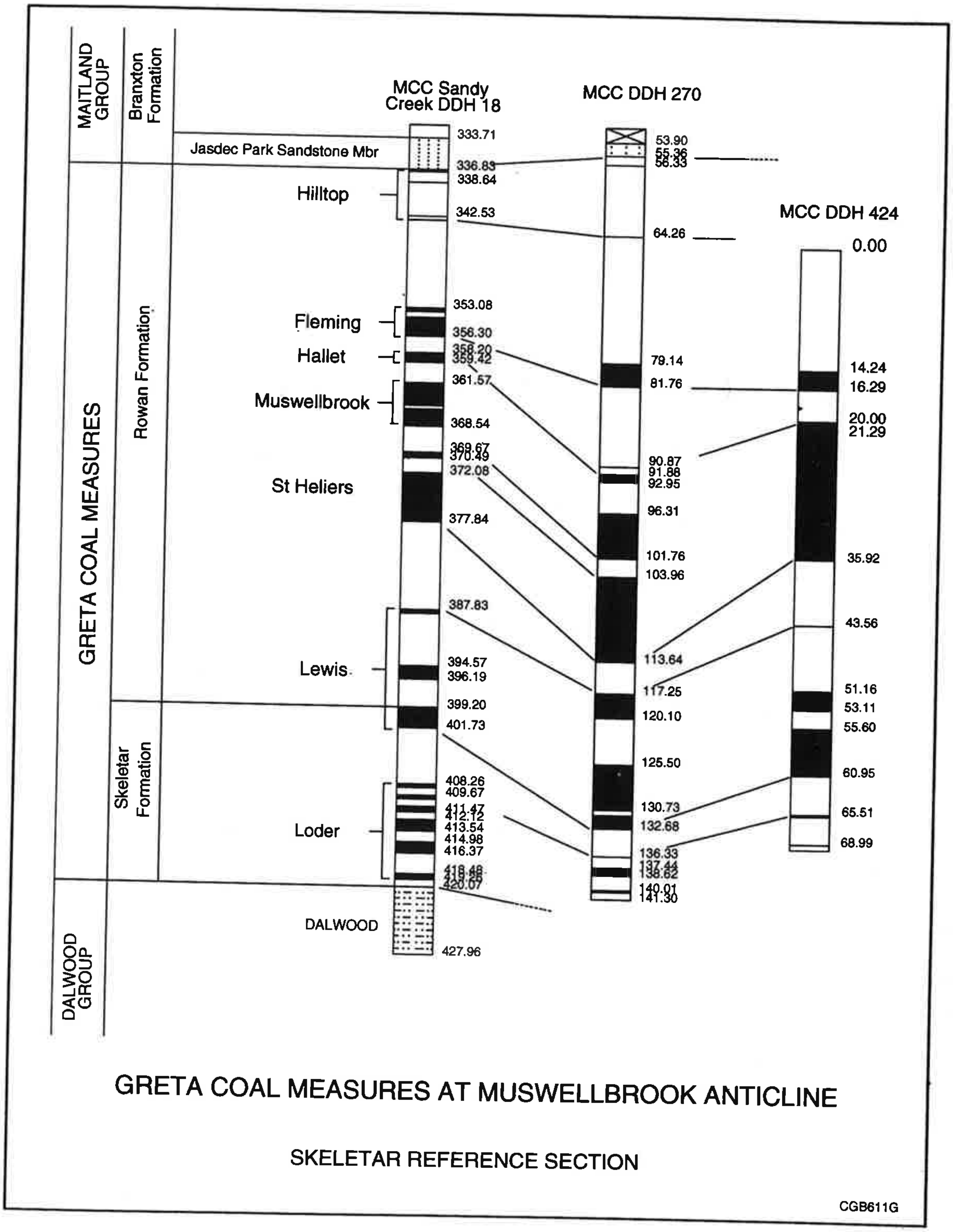

Figure 3. Skeletar reference section, Greta Coal Measures — Muswellbrook Anticline (Greta Working Party, Standing Committee on Coalfield Geology of New South Wales 1994)

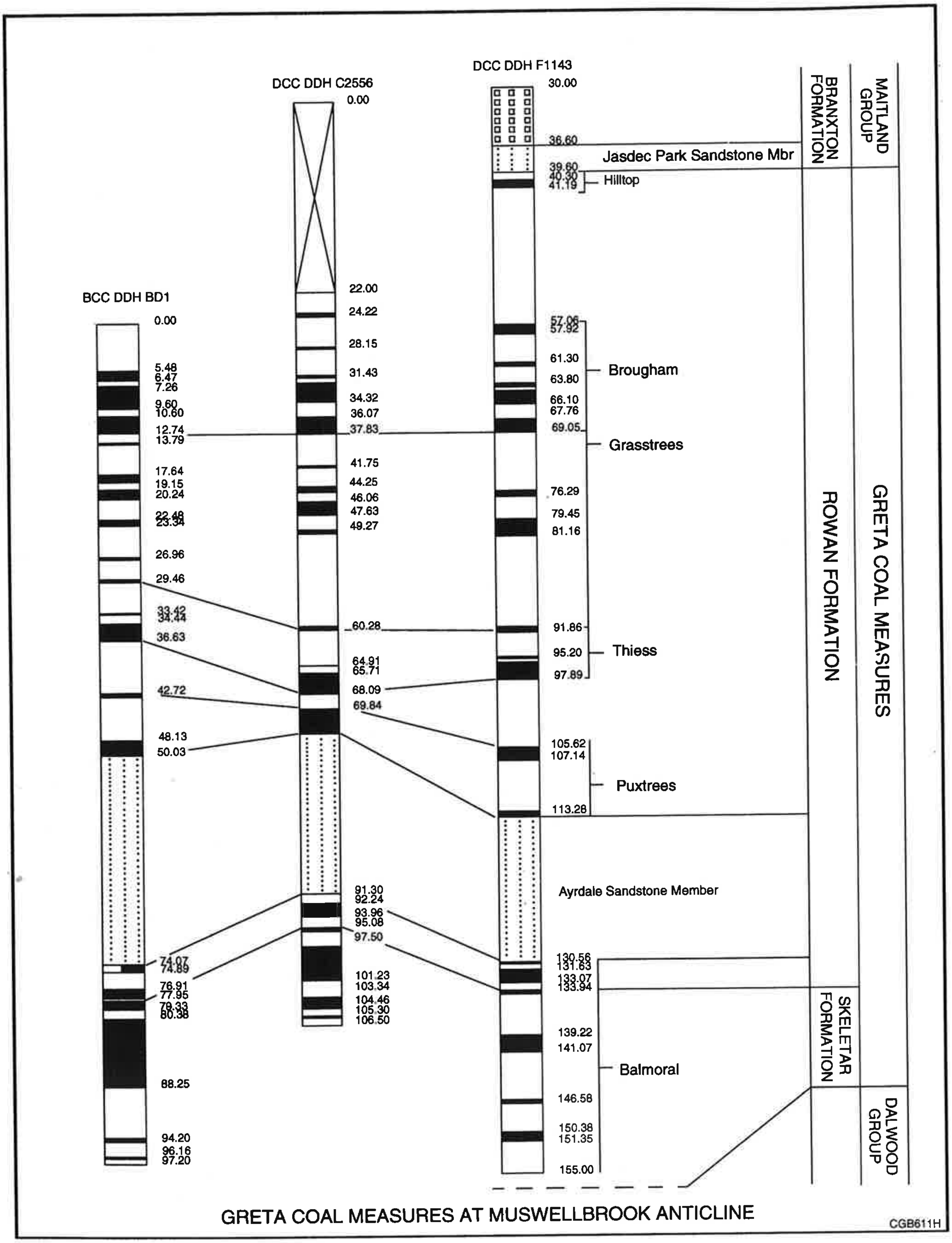

Figure 4. Savoy reference section, Greta Coal Measures — Muswellbrook Anticline (Greta Working Party, Standing Committee on Coalfield Geology of New South Wales 1994)

concluded that the formal stratigraphic recognition of mnemonic units was unnecessarily complicated, whereas expansion of existing formal Coal Members to include all generic mnemonic units would contain inappropriate amounts of non-coal strata. However, the reclassification of the existing formal nomenclature to informal lithostratigraphic or economic units (seams), with identification presented on reference borehole cross sections for each geographic area, allows for the dissemination of information and the flexible addition of new seams/plies as necessary.

Reference sections for the Skeletar area (figure 3) and Savoy area (figure 4) are presented. Section locations are shown on figure 1.

WORKING PARTY MEMBERSHIP

J. Beckett	Coal and Petroleum Branch, NSW Department of Mineral Resources
J. G. Binnekamp	Drayton Coal Pty Ltd
J. Rogis	Muswellbrook Coal Company Limited
G. Salter	Bayswater Colliery Co Pty Ltd

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APPENDIX
DEFINITIONS OF STRATIGRAPHIC UNITS

JASDEC PARK SANDSTONE MEMBER

***Derivation*:** After homestead located within Muswellbrook 1:25 000 (9033-II-N) sheet boundaries

***Previous Usage*:** New name

***Type Section*:** Location: MCC DDH 455 (ISG coordinates 293321 mE, 1431641 mN) from 59.57 to 74.24 m

Repository: Muswellbrook Coal Company Limited core store, Muswellbrook NSW

***Reference Section*:** MCC DDH 309 (ISG coordinates 293512 mE, 1432378 mN) from 177.03 to 183.33 m

***Lithology*:** Generally sandstone, coarse, lithic, interbedded with and often grading to conglomerate, granule and pebble.

***Thickness*:** General range 1 to 20 m

***Distribution*:** General vicinity of Muswellbrook Anticline

***Relationships and Boundary Criteria*:** Basal unit of the Branxton Formation. Overlies the coal-bearing lower delta plain sediments (Hamilton, 1986) of the Rowan Formation. Basal channelling suggests disconformity. Top of unit commonly marked by a 1 to 2 m bioturbated, thinly interbedded fine sandstone/siltstone unit. Conformably overlain by paraconglomerates or diamictites.

***References*:** HAMILTON D.S. 1986. Depositional systems and coal seam correlation in the Greta Coal Measures of the Muswellbrook region. *Australian Coal Geology (Coal Geology Group of the Geological Society of Australia, Journal)* **6,** 1-18.

ROWAN FORMATION

***Derivation*:** Parish in County Durham, New South Wales

***Previous Usage*:** Standing Committee on Coalfield Geology of New South Wales (1975)

***Type Section*:** Location: MCC DDH 270 (ISG coordinates 294249 mE, 1431299 mN) from 55.36 to 125.56 m

Repository: Muswellbrook Coal Company Limited core store, Muswellbrook NSW

***Reference Section*:** Drayton Coal DDH F1143 (ISG coordinates 293400 mE, 1419160 mN) from 39.60 to 133.94 m

***Lithology*:** Sandstone, siltstone, shale and mudstone with intercalated coal seams and subordinate conglomerate.

***Thickness*:** Skeletar (northern) area 40 to 78 m and Savoy (southern) area 70 to 100 m

***Distribution*:** General vicinity of Muswellbrook Anticline

***Relationships and Boundary Criteria*:** Upper unit of the Greta Coal Measures. Named coal seams in the Skeletar (northern) area are the Lewis (upper split), St Heliers, Muswellbrook, Hallett, Fleming and Hilltop, and in the Savoy (southern) area, Balmoral (upper splits), Puxtrees, Thiess, Grasstrees, Brougham and Hilltop.

Overlies distinctive, coal-bearing pelletoidal clayrock sequences (Hamilton, 1986) now assigned to the Skeletar Formation. The lower boundary is taken at the base of lithic sediments above the pelletoidal claystone. Definition of this

CONTINUED APPENDIX DEFINITIONS OF STRATIGRAPHIC UNITS

boundary may sometimes be difficult due to the common presence of a coal seam between the markedly differing sediment types. In these cases, the coal is excluded from the Rowan Formation.

The top of the Rowan Formation has been slightly eroded by the Jasdec Park Sandstone Member, the lowest unit of the Branxton Formation. This member represents the transition between coal-bearing sediments and overlying marine strata. The upper contact is generally sharp, often directly overlying the Hilltop seam.

References: HAMILTON D.S. 1986. Depositional systems and coal seam correlation in the Greta Coal Measures of the Muswellbrook region. *Australian Coal Geology (Coal Geology Group of the Geological Society of Australia, Journal)* **6**, 1-18.

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Notes: Upper boundary unchanged. Lower boundaries revised to conform with similar early Permian stratigraphic relationships for the Maules Creek/Leard Formation (Gunnedah Basin).

SKELETAR FORMATION

Derivation: Skeletar Trig station (Parish Rowan, County Durham, New South Wales

Previous Usage: Standing Committee on Coalfield Geology of New South Wales (1975)

Type Section: Location: MCC DDH 455 (ISG coordinates 293321 mE, 1431641 mN) from 134.10 to 156.06 m

Repository: Muswellbrook Coal Company Limited core store, Muswellbrook NSW

Reference Sections: MCC DDH 309 (ISG coordinates 293512 mE, 1432378 mN) from 242.16 to 266.53 m

DM Black Hill DDH 3 (ISG coordinates 290068 mE, 1435529 mN) from 104.09 to 125.45 m

Lithology: Carbonaceous shale, buff coloured pelletoidal clayrock sandstone, siltstone and conglomerate with intercalated, generally dull coal seams. Lithic fragments within clastic units are invariably kaolinitic (flint) clay.

Thickness: Skeletar (northern) area 5 to 33 m and Savoy (southern) area 10 to 25 m. Not fully penetrated in most Savoy area boreholes.

Distribution: General vicinity of Muswellbrook Anticline

Relationships and Boundary Criteria: Lower unit of the Greta Coal Measures. Named coal seams in the Skeletar (northern) area are the Lewis (lower split) and Loder, and in the Savoy (southern) area the Balmoral (lower splits).

Equates to distinctive, coal-bearing pelletoidal clayrock sequences described by Hamilton, 1986. The lower boundary is taken at the base of the pelletoidal clayrock sequence, and the unit disconformably/unconformably overlies weathered ?early Permian volcanics (MCC DDH 455), from which it appears to have been sourced. Also conformably overlies early Permian marine siltstones (MCC DDH 309) and volcanolithic clastics (DM Black Hill DDH 3).

The Skeletar Formation includes strata to the first occurrence of lithic sediments, which constitute the overlying Rowan Formation. A coal seam commonly separates the two lithotypes. This coal is generally dull, and is included in the Skeletar Formation .

References: HAMILTON D.S. 1986. Depositional systems and coal seam correlation in the Greta Coal Measures of the Muswellbrook region. *Australian Coal Geology (Coal Geology Group of the Geological Society of Australia, Journal)* **6**, 1-18.

STANDING COMMITTEE ON COALFIELD GEOLOGY OF NEW SOUTH WALES 1975. Stratigraphy of the Greta Coal Measures — Singleton–Muswellbrook coalfield. *Geological Survey of New South Wales, Records* **16**, 21-29.

Notes: Upper and lower boundaries revised to conform with similar early Permian stratigraphic relationships for the Maules Creek/Leard Formation (Gunnedah Basin), and varying lithologies of underlying units intersected by recent drilling.

AYRDALE SANDSTONE MEMBER

Derivation: After homestead located within Muswellbrook 1:25 000 (9033-II-N) sheet boundaries

Previous Usage: Standing Committee on Coalfield Geology of New South Wales (1975)

Type Section: Location: Drayton Coal DDH C3015 (ISG coordinates 292181.49 mE, 1418834.90 mN) from 31.02 to 52.53 m

Repository: Drayton Coal core store, Muswellbrook, NSW

Reference Section: Bayswater Colliery BD 1 (ISG coordinates 291099 mE, 1418323 mN) from 50.03 to 74.07 m

Lithology: Generally sandstone, lithic, medium to coarse grained with occasional pebbly bands grading to pebble conglomerate. Usually massively bedded. Basal unit (up to 4 m thick) commonly consists of a fine grained sandstone laminated with siltstone.

Thickness: General range 5 to 25 m

Distribution: Savoy area to the south and west of Muswellbrook. Unit not present in the Skeletar (northern) area.

Relationships and Boundary Criteria: Underlies Puxtrees seam and overlies Balmoral seams.

References: HAMILTON D.S. 1986. Depositional systems and coal seam correlation in the Greta Coal Measures of the Muswellbrook region. *Australian Coal Geology (Coal Geology Group of the Geological Society of Australia, Journal)* **6**, 1-18.

STANDING COMMITTEE ON COALFIELD GEOLOGY OF NEW SOUTH WALES 1975. Stratigraphy of the Greta Coal Measures — Singleton–Muswellbrook coalfield. *Geological Survey of New South Wales, Records* **16**, 21-29.

COAL SEAM NOMENCLATURE APPLICATION IN THE HUNTER COALFIELD

J. Beckett

INTRODUCTION

The application of coal seam nomenclature in the Hunter Coalfield (figure 1) is complicated by the large number of seams.

Correlation of the seams is complicated by local and regional variation in seam development. The coalescence and splitting of seams and ply sections of seams also increases the difficulty of seam identification.

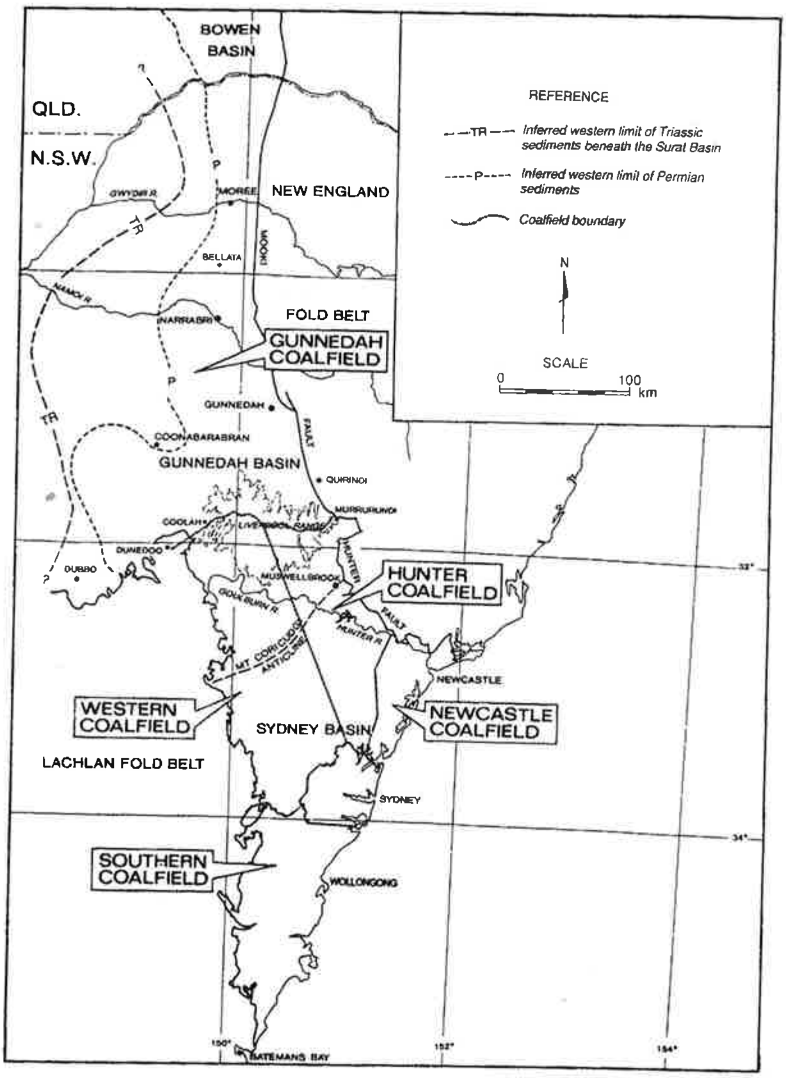

Figure 1. Location of the Hunter Coalfield in the Sydney Basin

The continued application of 'local' nomenclature to coal seams, which was initially applied when they were explored in areas where the stratigraphy was not readily correlateable with standard or type sections, and the mistaken identification of seams or marker horizons has further compounded the difficulty of seam nomenclature application.

REVIEW OF STRATIGRAPHY

The stratigraphy and nomenclature of the Wollombi and Wittingham Coal Measures in the Hunter Coalfield were formalised by the NSW Standing Committee on Coalfield Geology of New South Wales (1975). The stratigraphy of the Greta Coal Measures in the Hunter Coalfield was formalised by the Standing Committee in 1975 from an original report by Robinson (1963).

Subsequent workers for this committee, P. Wooton et al (Standing Committee's 1986 report) and Rogis et al (1992) have modified the stratigraphy for specific parts of the sequence as described below.

R.A. Britten (Standing Committee's 1975 report) formalised the coal measure stratigraphy in the Hunter Coalfield by dividing the 'Singleton Super Group' into the Wollombi and Wittingham Coal Measures, with each group further subdivided into subgoup, formation and member (figure 2). Coal seam names were formalised by member status, but even at this stage there were two recognised regional nomenclatures for the Foybrook Formation of the Wittingham Coal Measures (figure 3).

The redefinition of the stratigraphy of the Jerrys Plains Subgroup by Wooton in 1986 (Standing Committee's 1986 report) included the elevation of three tuffaceous claystone marker horizons to formation status and modification of the boundaries of existing formations. New coal seam names were introduced to rectify anomalies caused by previous mistaken correlations (figure 4). The status of each coal seam was reduced to an

Coal Measures	Subgroup	Formation	Member
WOLLOMBI COAL MEASURES	GLEN GALLIC SUBGROUP	GREIGS CREEK COAL	
		REDMANVALE CREEK FORMATION	
		DIGHTS CREEK COAL	HILLSDALE COAL Mbr
			NALLEEN TUFF Mbr
			HOBDEN GULLY COAL Mbr
	DOYLES CREEK SUBGROUP	WATERFALL GULLY FORMATION	
		PINEGROVE FORMATION	HAMBLEDON HILL SANDSTONE Mbr
			WYLIES FLAT COAL Mbr
			GLENGOWAN SHALE
	HORSESHOE CREEK SUBGROUP	LUCERNIA COAL	EYRIEBOWER COAL Mbr.
			LONGFORD CREEK SILTSTONE Mbr
			ROMBO COAL Mbr
			HILLSDALE CLAYSTONE
			CARRAMERE COAL Mbr
		STRATHMORE FORMATION	
		ALCHERINGA COAL	
		CLIFFORD FORMATION	
	APPLE TREE FLAT SUBGROUP	CHARLTON FORMATION	STAFFORD COAL Mbr
			MONKEY PLACE CREEK TUFF Mbr
		ABBEY GREEN COAL	
	WATTS SANDSTONE		
WITTINGHAM COAL MEASURES	JERRYS PLAINS SUBGROUP	DENMAN FORMATION	
		MALABAR FORMATION	WHYBROW COAL Mbr
			ALTHORPE CLAYSTONE Mbr
			REDBANK CREEK COAL Mbr
			WAMBO COAL Mbr
			WHYNOT COAL Mbr.
		MOUNT OGILVIE FORMATION	BLAKEFIELD COAL Mbr
			GLEN MUNRO COAL Mbr
			WOODLANDS HILL COAL Mbr
		BURNAMWOOD FORMATION	FAIRFORD CLAYSTONE Mbr
			MOUNT ARTHUR COAL Mbr
			PIERCEFIELD COAL Mbr
			VAUX COAL Mbr
			BROONIE COAL Mbr
			BAYSWATER COAL Mbr
	ARCHERFIELD SANDSTONE		
	VANE SUBGROUP	BULGA FORMATION	
		FOYBROOK FORMATION	LEMINGTON COAL Mbr
			PIKES GULLY COAL Mbr
			ARTIES COAL Mbr
			LIDDELL COAL Mbr
			BARRETT COAL Mbr
			HEBDEN COAL Mbr
	SALTWATER CREEK FORMATION		

Figure 2. Stratigraphy of the Wollombi and Wittingham Coal Measures, after Britten (Standing Committee on Coalfield Geology of New South Wales 1975)

Foybrook Area	Muswellbrook Area
Lemington	Wynn
Pikes Gully	Edderton
Arties	Clanricard
Liddell	Bengalla
Barrett	Edinglassie
Hebden	Ramrod Creek

Figure 3. Coal seam nomenclatures for the Foybrook Formation

informal name in recognition of the fact that seams associated with the tuffaceous lithology formations could be developed in more than one formation.

Unpublished correlation of the coal seam nomenclature of the Foybrook Formation by Hall, Salter and Bembrick for the Standing Committee in 1987 established the relationship between the two seam nomenclatures for the sequence in the Ravensworth, Howick and Mt Arthur areas (figure 5).

In 1992 the Standing Committee ratified a redefinition of the stratigraphy of the Greta Coal Measures (Rogis, 1992), (figure 6), which redefined the boundaries of the two formations in the sequence and demonstrated the limits of regional correlation of the coal seams.

CURRENT NOMENCLATURE APPLICATION

Figure 7 shows the coal seams that are mined or proposed to be mined in each of the operating coal mines and major development proposal areas of the Hunter Coalfield.

The coal seam nomenclature applied in this diagram is in accordance with the current stratigraphy ratified by the Standing Committee which is not necessarily the same as the stratigraphy used by the company.

The variations to the current stratigraphy and/or other features related to the seam nomenclature for individual mines and exploration areas (figure 8) are explained in the following notes which refer to the circled numbers shown at the tops of the columns in figure 7.

Note 1. Warkworth Mining

Warkworth Mining apply a numbering system to the seams of the Jerrys Plains Subgroup. Their internal nomenclature is therefore unaffected by changes to the coal seam nomenclature or to the correlation of particular ply sections.

Coal seam development at Warkworth mine also provides an excellent example of the multiple seam splits or ply sections that can develop in the Jerrys Plains Subgroup. Here there are 44 recognisable seam sections comprising the 15 named seams (figure 9).

	NSW STANDING COMMITTEE ON COALFIELD GEOLOGY (1975)		NSW STANDING COMMITTEE ON COALFIELD GEOLOGY (1986)		
	WATTS SANDSTONE		WATTS SANDSTONE		
	DENMAN FORMATION		DENMAN FORMATION		
JERRYS PLAINS SUBGROUP	MALABAR FORMATION	Whybrow Coal Mbr	MOUNT LEONARD FM	Whybrow seam	JERRYS PLAINS SUBGROUP
		Althorpe Claystone Mbr	ALTHORPE FORMATION		
		Redbank Creek Coal Mbr	MALABAR FORMATION	Redbank Creek seam	
		Wambo Coal Mbr		Wambo seam	
		Whynot Coal Mbr		Whynot seam	
	MOUNT OGILVIE FORMATION	Blakefield Coal Mbr		Blakefield seam	
		Glen Munro Coal Mbr	Mt. OGILVIE FORMATION	Saxonvale Member	
				Glen Munro seam	
		Woodlands Hill Coal Mbr		Woodlands Hill seam	
	BURNAMWOOD FORMATION	* Fairford Claystone Mbr	MILBRODALE FORMATION		
		* Mount Arthur coal Mbr	MOUNT THORLEY FM	Arrowfield seam	
				Bowfield seam	
		* Piercefield Coal Mbr		Warkworth seam	
		+ Fairford Claystone Mbr	FAIRFORD FORMATION		
		+ Mount Arthur Coal Mbr	BURNAMWOOD FORMATION	Mt Arthur seam	
		+ Piercefield Coal Mbr		Piercefield seam	
		Vaux Coal Mbr		Vaux seam	
		Broonie Coal Mbr		Broonie seam	
		Bayswater Coal Mbr		Bayswater seam	

* Position in DM Doyles Creek DDH 11

\+ Position in JEM Mount Arthur DDH 1

Figure 4. Stratigraphy of the Jerrys Plains Subgroup

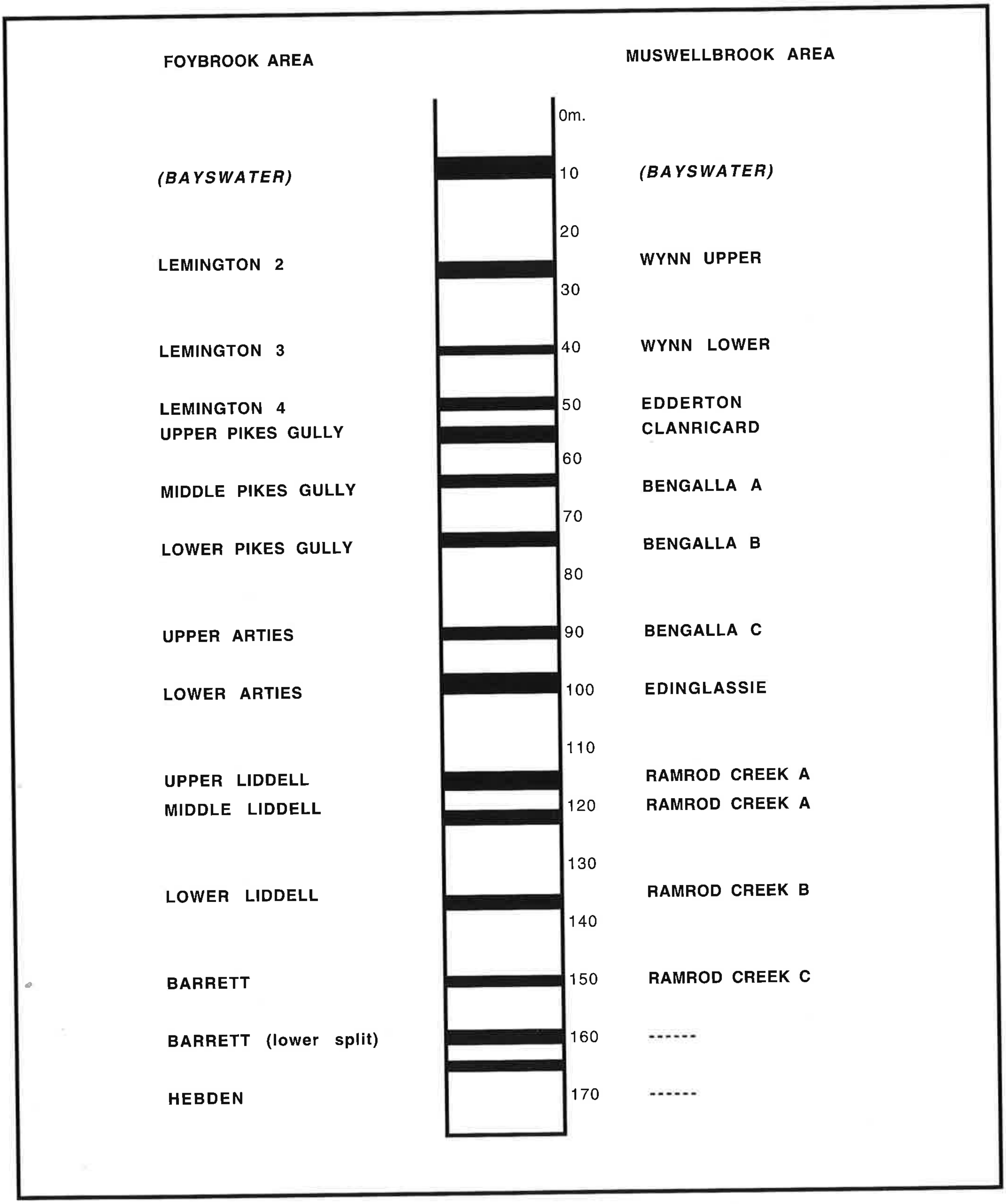

Figure 5. Coal seam nomenclature correlation, Foybrook Formation (after Hall et al 1987); Drillhole reference: Howick DDH 357, 358; BBC Strowan DDH 11 and ERL DDH 4)

The convergence or divergence of these (or similar) ply sections of seams, their deterioration or thickening and the development of new ply sections in the seams can occur over relatively short distances (less than 1 kilometre). Seam correlation and nomenclature application in such circumstances can be extremely difficult.

Note 2. Wambo–Lemington–United–Hunter Valley Mines

Figure 10 shows detail of the seam nomenclature in the Jerrys Plains Subgroup in the Wambo, Lemington, United and Hunter Valley mine areas. Lemington and United mines have not adopted the 1986 revision of the Jerrys Plains Subgroup which formally introduced

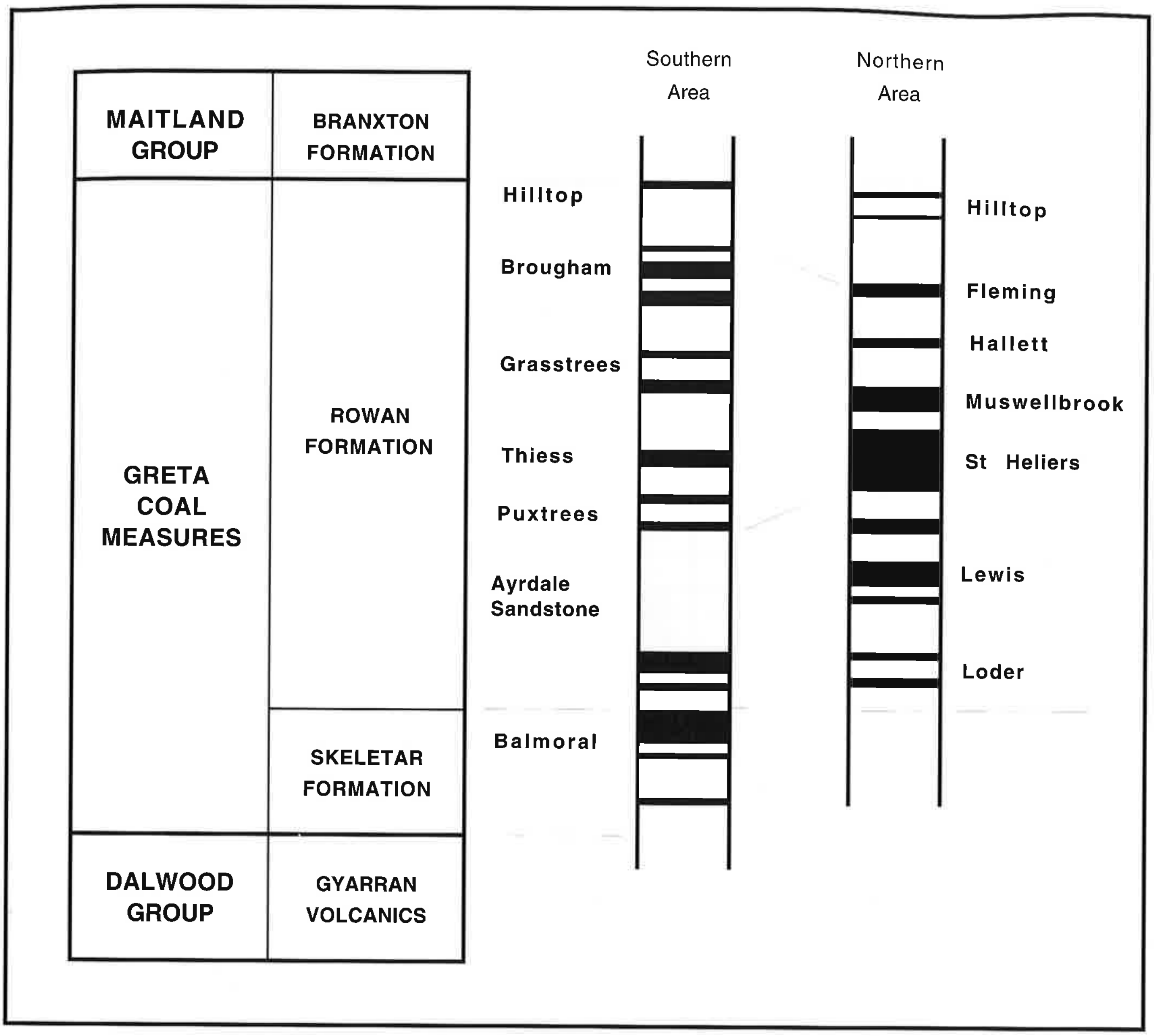

Figure 6. Stratigraphy and coal seam nomenclature of the Greta Coal Measures (after Rogis 1992)

the Arrowfield, Bowfield and Warkworth seams into the nomenclature. Lack of application of a common nomenclature as well as the convergence and splitting of seam sections means that various names are used for the one coal horizon. The lack of common application of the current stratigraphy by Wambo and Hunter Valley mines for the Glen Munro, Woodlands Hill, Arrowfield and Bowfield seams means that the problem would not be solved even if United and Lemington collieries adopted the latest stratigraphy. The splitting and coalescence of the seams is also more complex in the third dimension than can readily be presented on a two dimension section.

Note 3. Bengalla–Mount Pleasant–Dartbrook Areas

Correlation of the Jerrys Plains Subgroup in this area by Menzies (1981) involved the informal usage of the name 'Greenleek claystone' for a tuffaceous marker horizon which, in the current nomenclature, is correlated as the Fairford Formation. This was done because of an historical miscorrelation of this horizon in JEM Mt Arthur DDH-1 which was then a standard section drillhole, and the type section in DM Doyles Creek DDH-11. It is academic whether the initial miscorrelation or its 10 year usage was the more damaging, but the result was that Menzies needed a very thick Piercefield Seam to allow accurate correlation of the seams from the Mt Arthur and above in the Jerrys Plains Subgroup (figure 11).

The division of the Piercefield Seam into (multiply split) Upper, Middle and Lower Piercefield seams also contributed to the perception of a coal rich section in the sequence in comparison with seam development in the southern areas of the Hunter Coalfield. In addition, the local development of a thick, high quality, lower split of the Middle Piercefield Seam in the Dartbrook area was informally named the Kayuga seam (this now correlates as a lower split of the Mt Arthur seam).

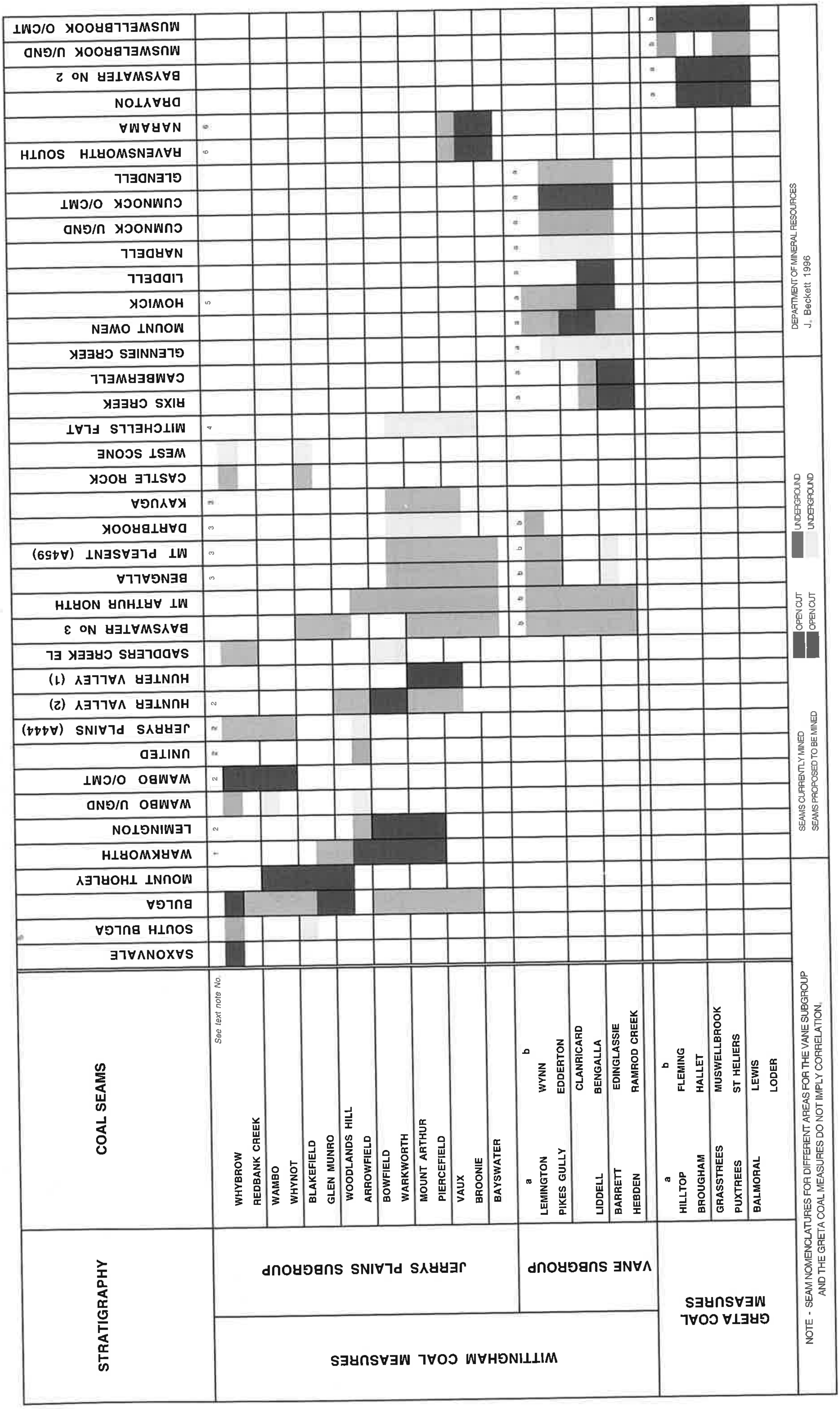

Figure 7. Coal seam nomenclature application in the Hunter Coalfield

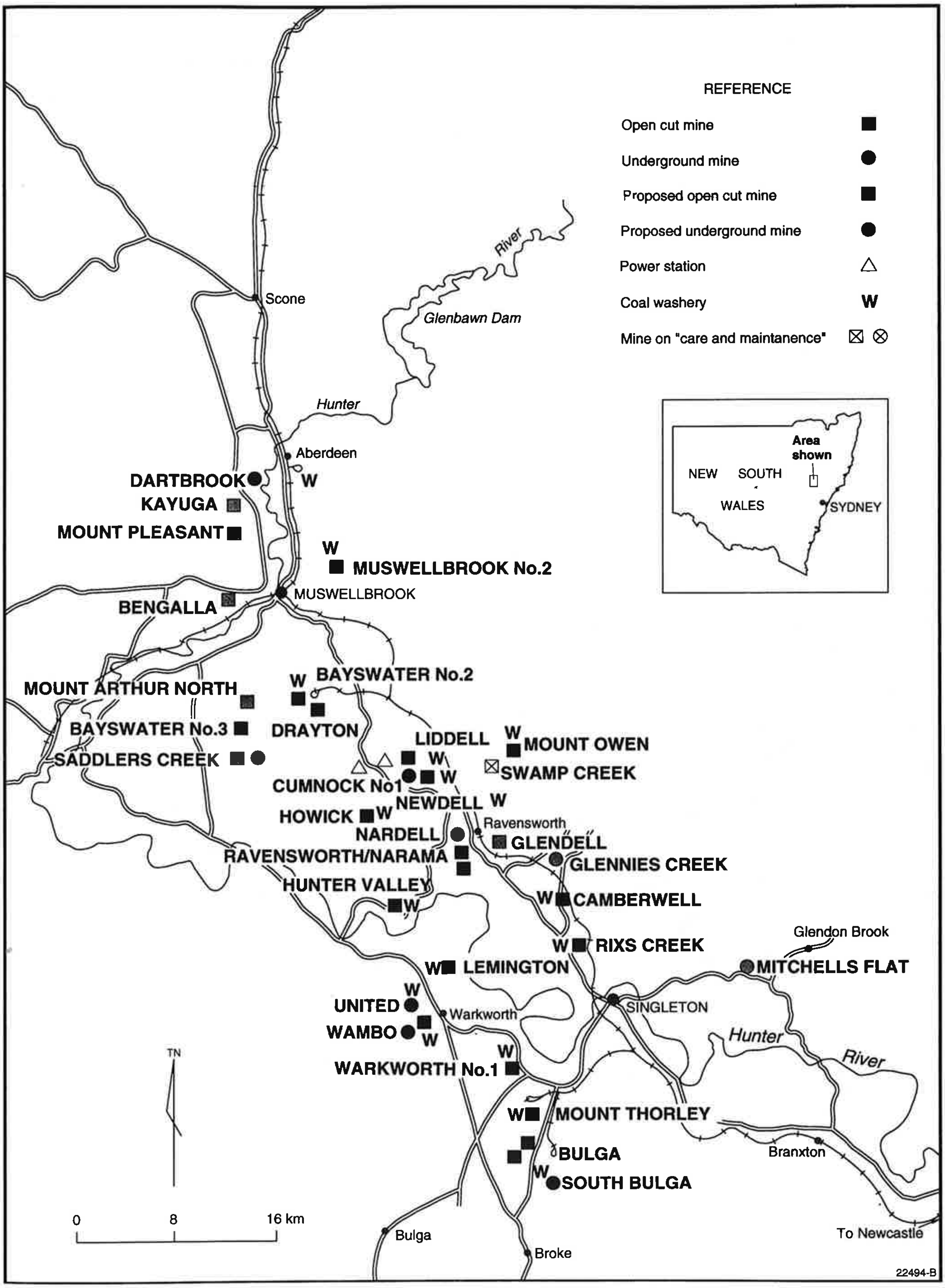

Figure 8. Location of coal mines and major development proposals in the Hunter Coalfield

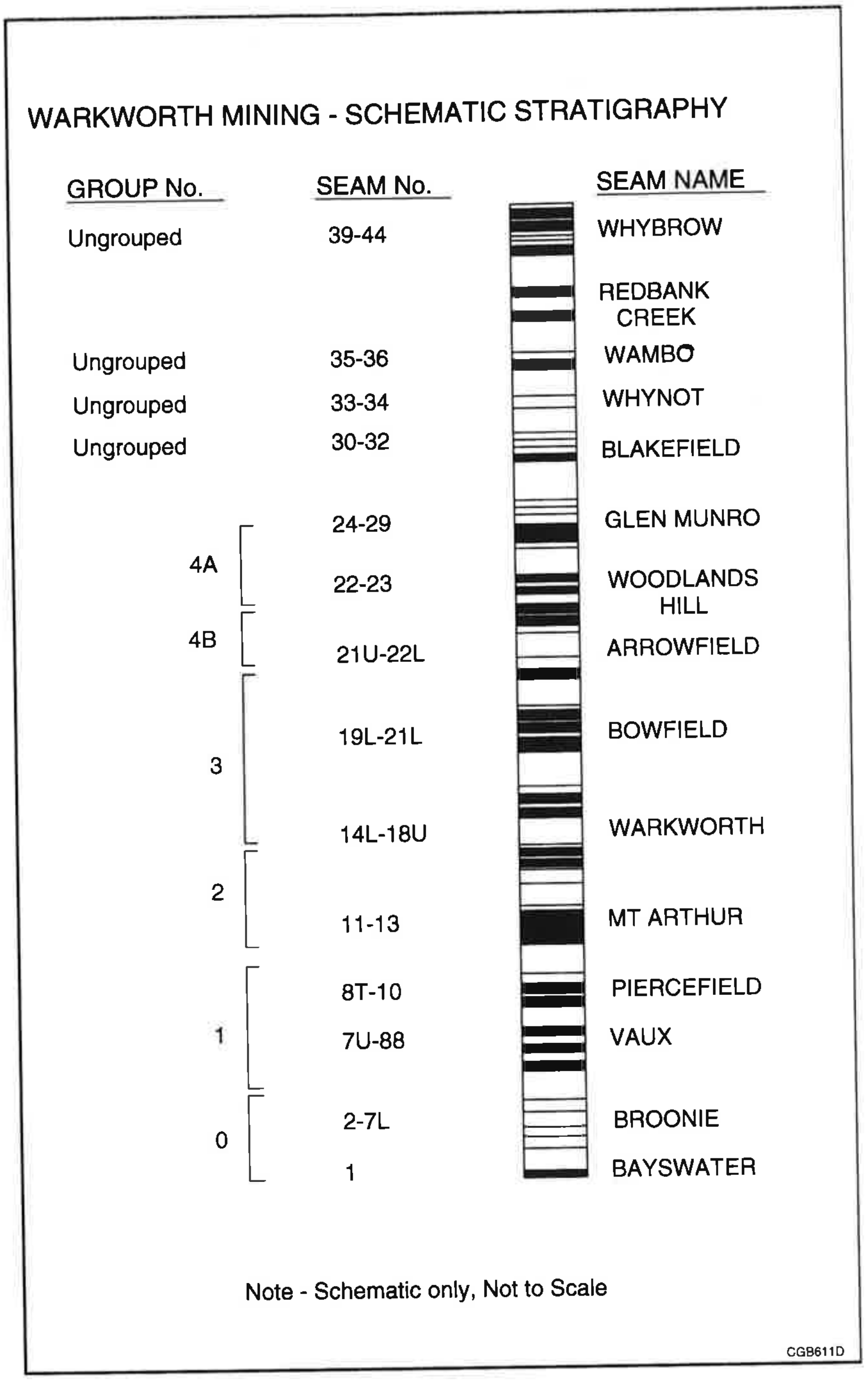

Figure 9. Schematic stratigraphy — Warkworth Mining

Bengalla and Mount Pleasant developments have successfully adopted the 1986 stratigraphy for the lower part of the Jerrys Plains Subgroup, from the Warkworth seam down.

The Dartbrook mine has retained the Piercefield Seam nomenclature of Menzies.

Difficulty with the identification of the Milbrodale Formation and the poor and irregular development of the Glen Munro, Woodlands Hill and Arrowfield seams in the area to the west of these deposits still hinders the clear identification and correlation of these seams.

Note 4. Mitchells Flat

The Mitchells Flat area is in a fault bounded block approximately 15 kilometres east of Singleton. It is isolated from other outcrop areas of the Wittingham Coal Measures. The deposit has a local coal seam nomenclature (figure 12) which is correlateable with the Jerrys Plains Subgroup and the Vane Subgroup mainly by the identification of the Fairford Formation, Bayswater Seam and Archerfield Sandstone.

Coal seams of the Foybrook Formation have been intersected only in a limited number of drillholes in the Mitchells Flat area and have not been correlated in detail.

Note 5. Howick Mine

Howick Mine uses a local nomenclature for the Lemington Seams at the top of the Foybrook Formation, (nomenclature 'a' in figure 7). Hall et al (1987), correlated these and other seams of the Foybrook Formation from the Howick Mine to adjoining areas as shown in figure 6. The nomenclature employed at the Howick Mine uses

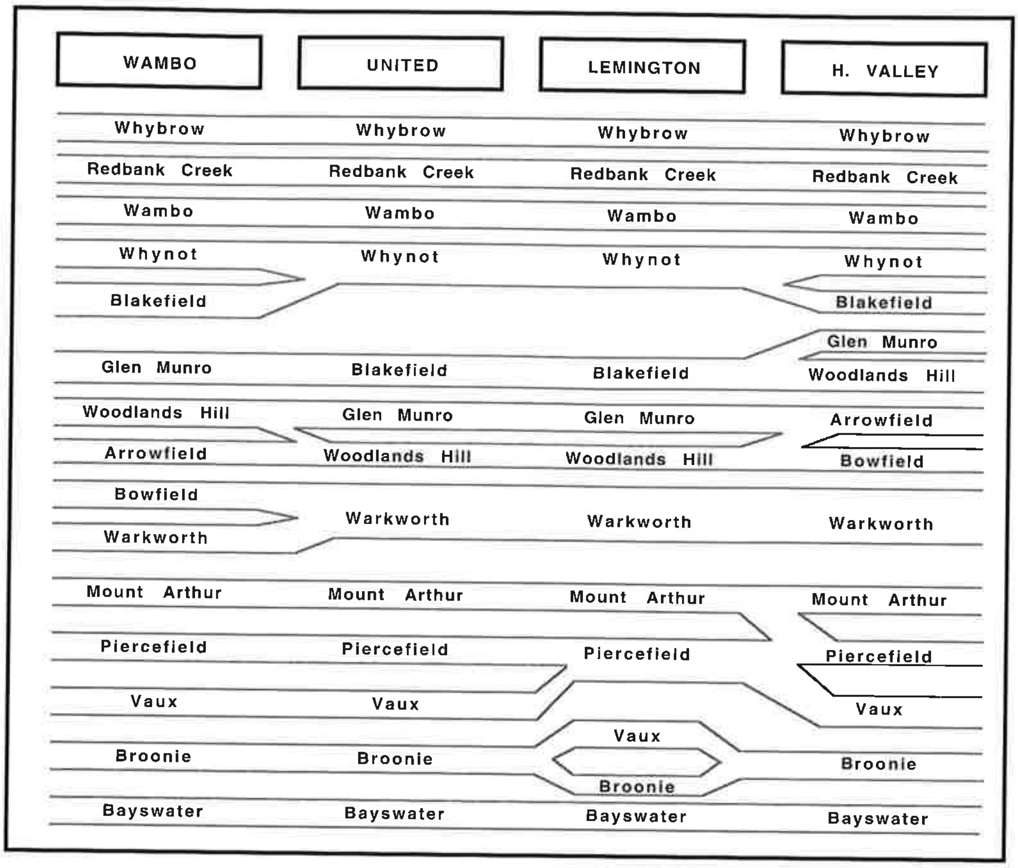

Figure 10. Coal seam development and nomenclature application in Wambo. United, Lemington & Hunter Valley collieries.

Wooton 1986	Menzies 1981
Whybrow	Whybrow
Redbank Creek	Redbank Creek
Wambo	Wambo
Whynot	Whynot
Blakefield	Blakefield
Glen Munro	Glen Munro
Woodlands Hill	Woodlands Hill
Arrowfield	Upper Mt Arthur
Bowfield	Lower Mt Arthur
Warkworth	Upper Piercefield
Mt Arthur	Middle Piercefield
Piercefield	Lower Piercefield
Vaux	Vaux
Broonie	Broonie
Bayswater	Bayswater

Figure 11. Coal seam nomenclature in the Jerrys Plains Subgroup in Bengalla, Mount Pleasant and Dartbrook areas

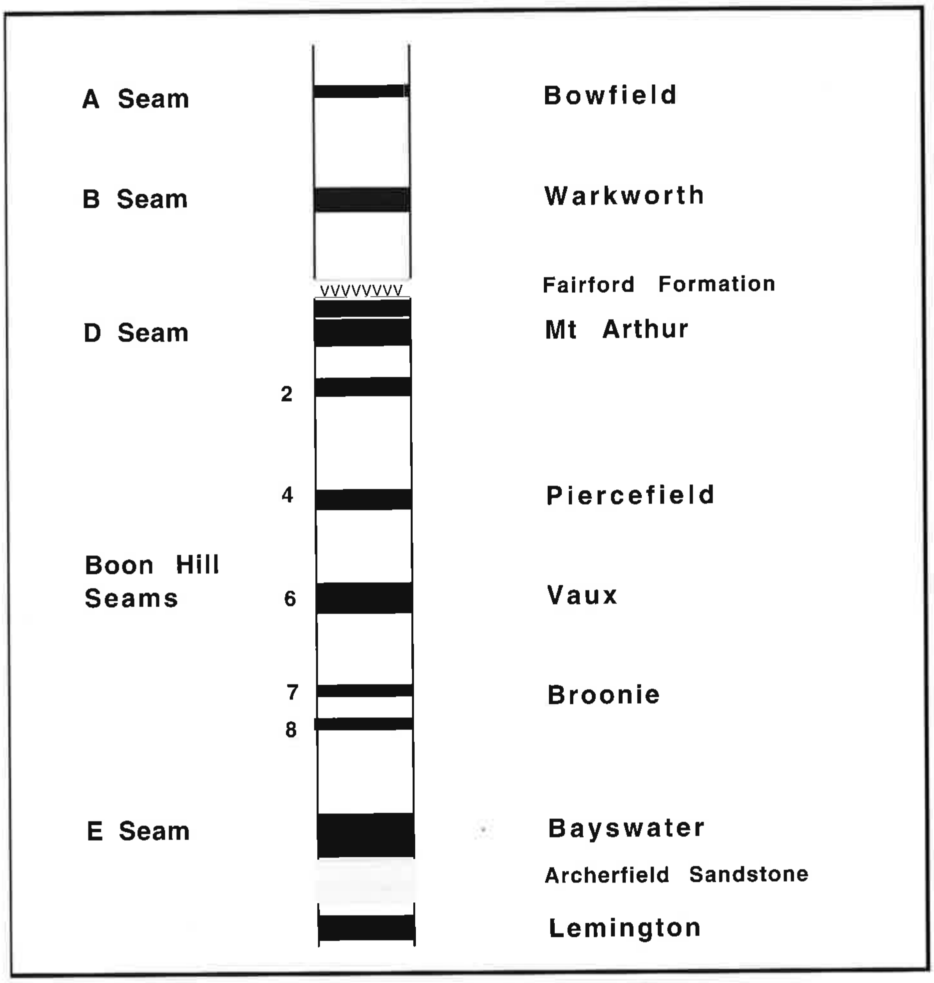

Figure 12. Coal seam nomenclature in the Mitchells Flat area

four informal names — Rotten, Rose, Roach and Roberts for the major splits of the Lemington seam developed in this area.

Note 6. Ravensworth South–Narama Mines

The adjoining Ravensworth South and Narama operations opencut mine the lower seams of the Burnamwood Formation of the Jerrys Plains Subgroup (figure 7).

An informal nomenclature, employed here and at the former Swamp Creek Mine, is used for the multiple splits of the Broonie seam which are referred to as the Ravensworth seams.

Note 7. Drayton–Bayswater No 2 Mines

The Drayton and Bayswater No 2 mines recover the Greta Coal Measures from adjoining opencut operations located on the Muswellbrook Anticline.

A previously informal seam name, the Thiess seam, was employed by both operations for an upper split of the Puxtrees Seam.

The use of the Thiess Seam name was formalised by Rogis (1992) in the redefinition of the Greta Coal Measures in this area.

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Menzies I.A. 1981. Denman–Scone coal exploration programme. Geological Survey of New South Wales, Report GS1981/067 (unpublished).

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Rogis J. 1992. Revision of the stratigraphy and coal seam nomenclature of the Greta Coal Measures — Muswellbrook Anticline. Report to Standing Committee on Coalfield Geology of New South Wales, 9 pp (unpublished).

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Standing Committee on Coalfield Geology of New South Wales 1986. Stratigraphy of the Jerrys Plains Subgroup of the Wittingham coal measures in the Singleton–Muswellbrook coal district of the Hunter Valley. *Geological Survey of New South Wales, Records* **22(1)**, 129-143.

REVISION OF THE STRATIGRAPHY OF THE NEWCASTLE COAL MEASURES

M. Ives; J. Brinton; J. Edwards; R. Rigby; C. Tobin & C.R. Weber

INTRODUCTION

The stratigraphic nomenclature and subdivision of the Newcastle Coal Measures proposed by McKenzie and Britten (1969) and modified by the Standing Committee on Coalfield Geology of NSW (1975) has been considered and revised by the Newcastle Coalfield Subcommittee.

This revision is based on definitions of litho-stratigraphic units in the International Stratigraphic Guide (1976), and thus on the mappability of rock units and their recognition and correlation by geologists working in the Newcastle Coal Measures.

Subcommittee members who were the principal contributors to the revision were

M. Ives	Joint Coal Board
J. Brunton	Coal and Petroleum Geology Branch, NSW Department of Mineral Resources
J. Edwards	Coal and Allied Operations Pty Ltd
R. Rigby	Newcastle Wallsend Coal Company Pty Ltd
C. Tobin	FAI Mining Ltd
C. Weber	Electricity Commission of NSW

REVISED STRATIGRAPHY OF THE NEWCASTLE COAL MEASURES

The area of study for this review is shown in figure 1. Figure 2 shows a generalised north–south correlation diagram for the study area. Drillhole data on the main stratigraphic units are given in table 1 and the units are described in appendix.

A comparison of the proposed and existing stratigraphy is shown in table 2.

In summary, the amendments to the stratigraphy of the Newcastle Coal Measures are:

1. Redefining the top of the Newcastle Coal Measures as occurring above the uppermost coal, usually the Vales Point seam.
2. Redefining the base of the Newcastle Coal Measures as the top of the Waratah Sandstone.
3. Reclassifying all coal formations as informal coal seams and eliminating all other formations except the Warners Bay which is renamed the Warners Bay Tuff.
4. Redefining the limits of the present subgroups and reclassifying them as formations.
5. Elevating the Awaba and Nobbys Tuff members to formation status.
6. Redefining the Vales Point Coal Member as an informal coal seam.
7. Eliminating all other members from the existing stratigraphy pending future review by a working party of the Subcommittee.

The following criteria have been used for making the amendments listed above:

1. The top of the Newcastle Coal Measures has been redefined for the following reasons:

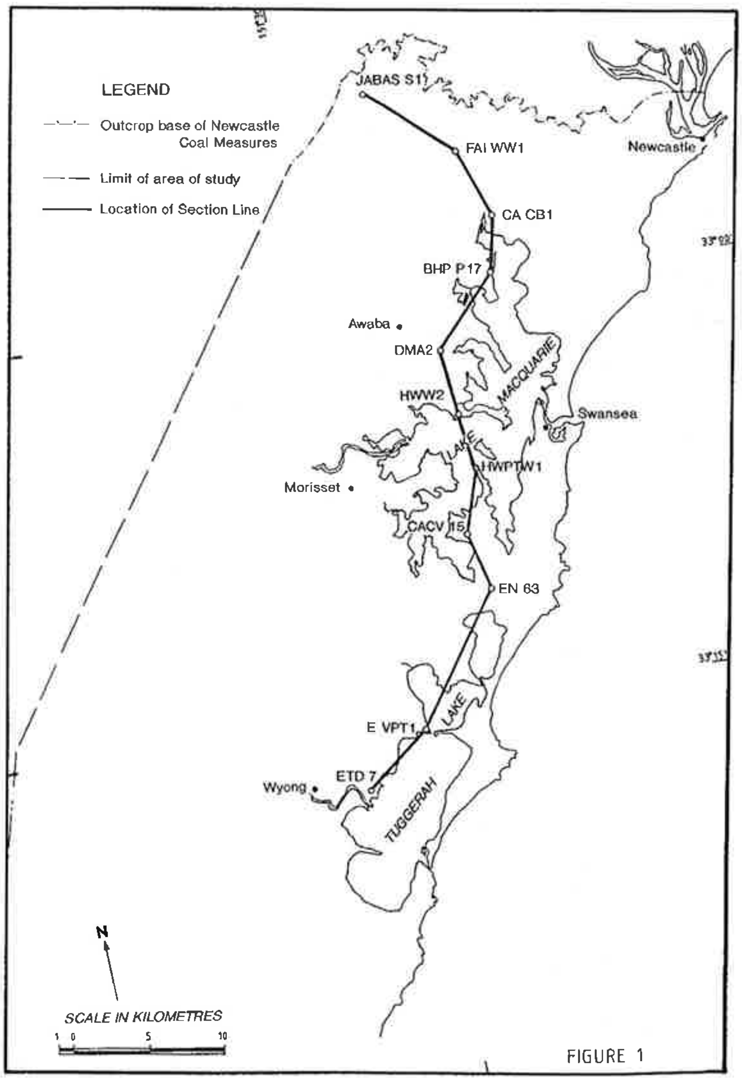

Figure 1 Newcastle Coal Measures — area of study

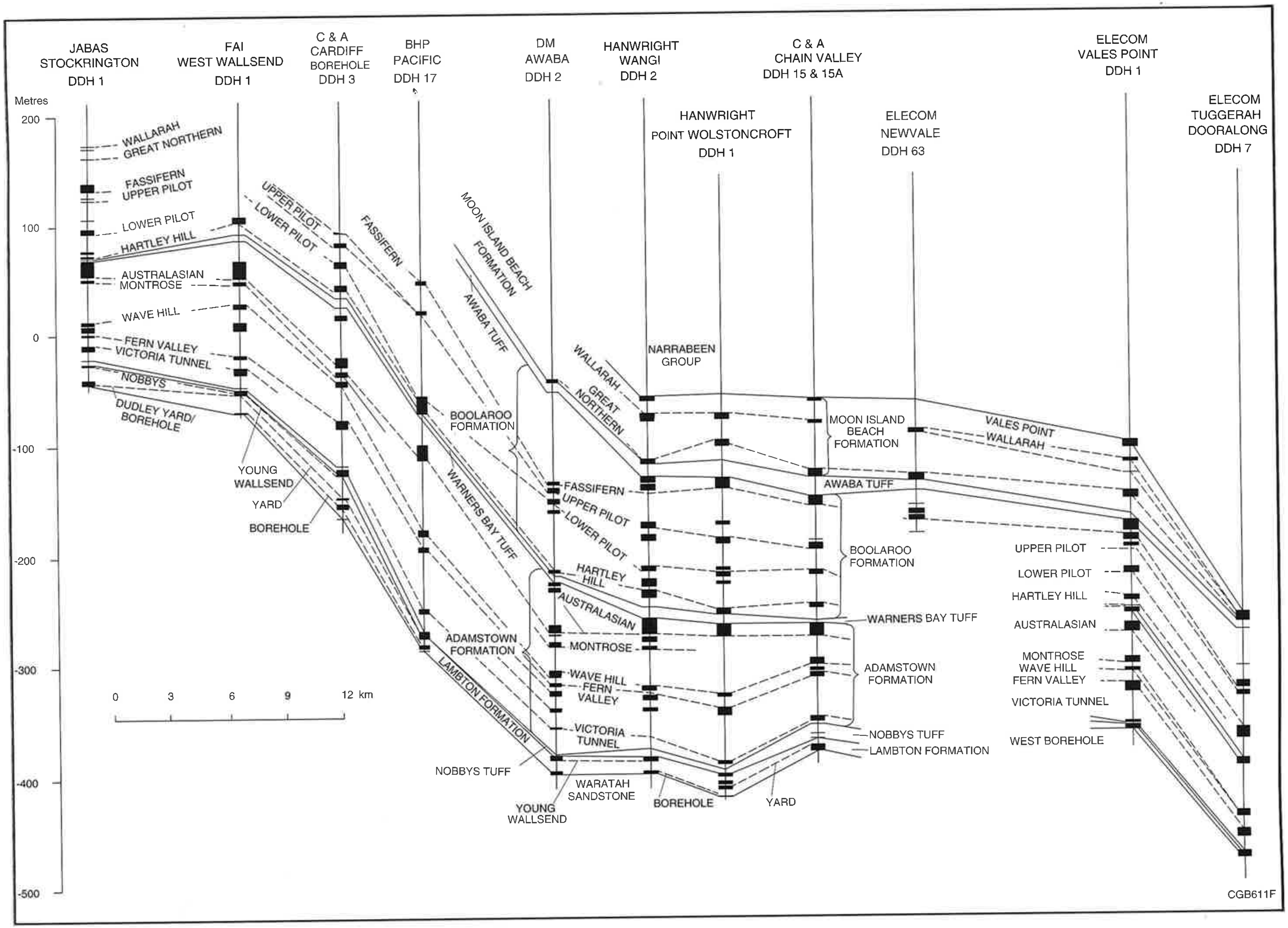

Figure 2. Newcastle Coal Measures north–south correlation diagram (New South Wales Standing Committee on Coalfield Geology Newcastle Coalfield Sub-Committee). (Figure 1 shows the location of the section line.)

TABLE 1 DRILLHOLE DATA ON MAIN STRATIGRAPHIC UNITS

DRILL HOLE	ISG CO-ORDINATES		COLLAR LEVEL (m)	DEPTH TO TOP OF NCM	DEPTH TO BASE OF			
	EASTING	NORTHING			AWABA TUFF	WARNERS BAY TUFF	NOBBYS TUFF	NCM
BHP Burwood 3	367643.000	1351542.000	26.820	BC	BC	BC	48.020	NR
BHP Coal Point	357490.000	1342100.000	5.270	BC	49.380	211.710	346.810	387.630
BHP Floraville	361720.000	1346305.000	63.103	BC	BC	100.290	310.870	357.590
BHP John Darling 2	360705.000	1344300.000	14.080	BC	BC	102.490	303.510	358.530
BHP Mount Hutton 3	362680.000	1349833.000	47.600	BC	BC	BC	195.440	248.720
BHP Pacific 17	357129.970	1348104.090	25.520	BC	BC	164.420	356.340	NR
BHP Stockton Borehole 13	348034.563	1352203.250	310.060	198.490	204.170	263.770	294.820	298.160
BHP Wakefield 1	352065.000	1352196.000	27.300	BC	BC	49.660	226.770	233.030
C&A Cardiff Borehole 1	358644.688	1352327.375	43.510	BC	BC	81.940	228.360	271.700
C&A Chain Valley 15	352313.625	1331468.750	24.470	140.340	225.920	340.170	443.820	470.030
DM Awaba 2	346991.906	1348898.250	79.700	BC	BC	36.320	57.690	391.400
DM Awaba 5	353660.031	1344391.375	25.500	126.950	48.800	219.260	375.610	236.130
Elcom Eraring 30	344265.813	1340844.75	33.500	13.900	135.680	214.150	232.910	414.070
Elcom Eraring 351	345497.000	1332880.00	16.990	95.300	143.970	213.830	318.700	324.800
Elcom Newvale 63	351531.003	1325316.14	2.622	116.400	197.240	NR	NR	NR
Elcom Tuggerah Dooralong 7	343628.500	1314882.500	1.330	329.000	336.800	461.810	544.090	546.320
Elcom Vales Point 1	348110.000	1318285.000	3.200	166.890	218.260	316.860	422.400	443.480
FAI West Wallsend 1	355995.230	1357008.080	55.300	BC	BC	28.630	167.090	187.950
Hanwright 14	359785.219	1333774.500	77.720	BC	38.820	157.300	332.880	383.000
Hanwright Pt	354059.438	1335443.625	7.530	86.660	128.950	274.910	411.980	437.590
Wolstoncroft Hanwright 2	354098.688	1338948.125	7.530	68.890	128.830	274.530	394.250	408.620
Wangi								
Jabas Stockrington 1	350705.000	1360020.000	188.976	74.040	95.350	179.160	271.540	291.730
JDP Mandalong 4	340722.094	1303214.500	28.000	543.750	574.540	708.720	798.040	807.170
Newcastle Wallsend CC 4	363630.000	1354325.000	102.110	BC	BC	BC	101.170	160.230
Wyee State Mine 30	348154.000	1328887.750	6.056	100.800	166.050	269.850	NR	NR

NCM = Newcastle Coal Measures
BC = Bore collared beyond outcrop
NR = Bore did not reach

TABLE 2 REVISED STRATIGRAPHY OF THE NEWCASTLE COAL MEASURES

PROPOSED STRATIGRAPHY

Group	Formation	Coal Seams
Narrabeen		
Newcastle Coal Measures	Moon Island Beach	Vales Point Wallarah Great Northern
	Awaba Tuff	
	Boolaroo	Fassifern Upper Pilot Lower Pilot Hartley Hill
	Warners Bay Tuff	
	Adamstown	Australasian Montrose Wave Hill Fern Valley Victoria Tunnel
	Nobbys Tuff	
	Lambton	Nobbys Dudley Young Wallsend[2] Yard Borehole West Borehole[3]
	Waratah Sandstone	

EXISTING STRATIGRAPHY[1]

Group	Subgroup	Formation	Member
Narrabeen		Munmorah Conglomerate	Vales Point Coal Karignan Conglomerate Cowper Tuff
Newcastle Coal Measures	Moon Island Beach	Wallarah Coal Catherine Hill Bay Great Northern Coal Eleebana Fassifern Coal	Mannering Park Tuff Toukley Coal Buff Point Coal Teralba Conglomerate Booragul Tuff Awaba Tuff Chain Valley Coal Bolton Point Conglomerate
	Boolaroo	Croudace Bay Upper Pilot Coal Reids Mistake Lower Pilot Coal Warners Bay Hartley Hill Coal Mount Hutton	Belmont Conglomerate Seahampton Sandstone
	Adamstown	Australasian Coal Tickhole Montrose Coal Kahibah Wave Hill Coal Glebe Fern Valley Coal Kotara	Charlestown Conglomerate Stockrington Tuff Whitebridge Conglomerate Hillsborough Tuff Tingira Conglomerate Edgeworth Tuff Redhead Conglomerate Merewether Conglomerate
	Lambton	Victoria Tunnel Coal Shepherds Hill Nobbys Coal Bar Beach Dudley Coal Young Wallsend Coal[2] Bogey Hole Yard Coal Tighes Hill Borehole Coal West Borehole Coal[3]	Nobbys Tuff Signal Hill Conglomerate Cockle Creek Conglomerate Ferndale Conglomerate
		Waratah Sandstone	

1 Standing Committee on Coalfield Geology of NSW 1975

2 The Young Wallsend Coal/seam is the combination of the Nobbys and Dudley Coals/seams

3 The West Borehole Coal/seam is the combination of the Nobbys, Dudley, Yard and Borehole Coals/seams

- the Vales Point seam, which is presently defined as occurring within the Munmorah Conglomerate — the basal formation of the Narrabeen Group, has been found to converge with the Wallarah seam, and
- the very distinctive sedimentological changes which occur at this horizon. These changes are:
  - the grey-green mottled red shales and mudstones which are characteristic of the Narrabeen Group, and are not present in the Newcastle Coal Measures, do not occur below this horizon, and
  - a major change in the nature of the conglomerates, particularly in the north of the coalfield, from generally loosely packed small to medium sized pebbles, to very tightly packed small to large pebbles and cobbles.

This redefinition of the top of the Newcastle Coal Measures was previously suggested by Uren (1977).

2. The change to the base of the Newcastle Coal Measures is based on the much easier recognition of the top of the Waratah Sandstone than its gradational base.
3. The coal formations are reclassified as informal coal seams. This reclassification is proposed because whereas some seams or coal plies are correlateable over large areas, splitting and deterioration introduces thick sequences of non-carbonaceous sediments into the seams and makes recognition of the tops and bases of existing formations, and in some cases subgroups, difficult if not impossible.
4. In particular, confusion has existed over the definitions of the Hartley Hill and Australasian seams, and thus the base of the Boolaroo Subgroup and the top of the Adamstown Subgroup. McKenzie (1969) defined the Hartley Hill seam as the interval between 70.92m (232'8") and 73.48m (241'1") in BHP John Darling DDH 3. This definition has been used extensively in the area to the north and east of Lake Macquarie.

   Bewley and Crapp (1972) showed that this seam in fact correlated with Hutton DDH 3 where the Australasian Coal is defined. They subsequently defined the Hartley Hill seam as that named by Jones (1929) in the Warners Bay area which overlies and is separated from the Australasian seam by a very characteristic tuffaceous bed which can be traced over almost the entire Lake Macquarie area. This definition for the Hartley Hill seam has subsequently been widely used to the south and west of Lake Macquarie, and in this revision.

   Recent work has confirmed the widespread development of this distinctive tuffaceous unit, and that it correlates with the type section for the Warners Bay Formation. This unit has been redefined as the Warners Bay Tuff in this revision.
5. The Awaba and Nobby Tuff Members have been elevated to formation status because of their distinctive appearance and widespread development. These characteristics enable them to be used as marker horizons by workers in the Newcastle Coalfield. The lithological component of each name is retained because of well-established and traditional use.

   To conform with the lithostratigraphic framework requiring the stratigraphic column to be completely divided into formations, the present subgroup names, ie Moon Island Beach, Boolaroo, Adamstown and Lambton, have been assigned to the intervals between the Awaba, Warners Bay and Nobbys Tuff Formations.
6. As a function of its importance as a marker horizon for the top of the Newcastle Coal Measures, the Vales Point Coal Member has been retained in the proposed stratigraphy but redefined as an informal coal seam.
7. As a consequence of often very limited areal extent, and the variability of their lithological character, all other members have been eliminated pending detailed review by the workers in the Subcommittee.

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APPENDIX
DEFINITIONS OF STRATIGRAPHIC UNITS

MOON ISLAND BEACH FORMATION

Derivation: After Moon Island Beach (now generally called Moonee Beach)

Previous Usage: After R.A. Britten (McKenzie and Britten 1969) Previously Moon Island Beach Subgroup

Type Section: Location: ELECOM NEWVALE DDH 63
ISG Zone 56/1
354153.607 mE 1327002.607 mN
116.41 m to 187.345 m
Repository: Department of Mineral Resources
Core Store, Wyee Bay, NSW

Lithology: Sandstone, shale, conglomerate, claystone, and contains the Vale Point, Wallarah and Great Northern coal seams.

Thickness: Type Section: 70.935 m
Typical Range: 5–110 m

Distribution: Extends to the south and west from outcrops in the vicinity of Catherine Hill Bay, Swansea, Belmont North, Awaba, Fassifern, Teralba and along the Sugarloaf Range south from Mount Sugarloaf.

Stratigraphic Limits and Structural Relationships: From the base on the Narrabeen Group to the top of the Awaba Tuff.

AWABA TUFF

Derivation: After township to the west of Toronto

Previous Usage: After P.J. McKenzie (McKenzie and Britten 1969)

Type Section: Location: BHP COAL POINT BORE
ISG Zone 56/1
Approx 357490mE 1342100mN
40.05 m (131'4.75") to 49.39 m (162'0.5")

Standard Section: 1. Location: DM AWABA DDH 2
ISG Zone 56/1
353660.036mE 1344391.378mN
39.37 m to 8.80 m
Repository: Department of Mineral Resources,
Core Store, Wyee Bay, NSW
2. Location: ELECOM NEWVALE DDH 63
ISG Zone 56/1
354153.607mE to 1327002.607mN
187.345 m to 197.235 m

Lithology: Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert, usually contains abundant mica in basal 0.2–0.4 m.

Thickness: Type Section: 9.43 m (30'7.75")
Typical Range: 2–20 m

Distribution: Extends south and west from outcrops in the vicinity of Swansea, Belmont, Awaba, Wakefield, Fassifern, Teralba and along the Sugarloaf Range from Mount Sugarloaf.

Stratigraphic Limits and Structural Relationships: From the base of the Moon Island Beach Formation to the top of the Boolaroo Formation.

BOOLAROO FORMATION

Derivation: After township of Boolaroo

Previous Usage: After P.J. McKenzie (McKenzie and Britten 1969). Previously Boolaroo Subgroup

Type Section: Location: DM AWABA DDH 2
ISG Zone 56/1
353660.036mE 1344391.378mN
48.80 m to 213.70 m
Repository: Department of Mineral Resources
Core Store, Wyee Bay, NSW

Lithology: Conglomerate, sandstone, shale, claystone, and contains the Fassifern, Upper and Lower Pilot and Hartley Hill seams.

Thickness: Type Section: 164.90m
Typical Range: 50–150 m

Distribution: Extends south from outcrops in the vicinity of Floraville, Eleebana, Warners Bay, Speers Point, Edgeworth, Barnsley and Killingworth.

Stratigraphic Limits and Structural Relationship: Underlies the Awaba Tuff and conformably overlies the Warners Bay Tuff.

WARNERS BAY TUFF

Derivation: Newcastle Suburb

Previous Usage: After P.J. McKenzie (McKenzie & Britten 1969) Previously Warners Bay Formation

Type Section: Location: BHP FLORAVILLE BORE
ISG Zone 56/1
Approx 361720mE 1346300mN
From 91.55 m (300'4.5") to 100.32 m (329' 1.5")

Standard Section: Location: DM AWABA DDH 2
ISG Zone 56/1
353660.036mE 1344391.378mN
213.70 m to 219.35 m
Repository: Department of Mineral Resources
Core Store, Wyee Bay, NSW

Lithology: Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert.

Thickness: Type Section: 8.77 m (28'9")
Typical Range: 0.5–15.0 m

Distribution: Extends south from outcrops around Floraville, Eleebana, Warners Bay, Speers Point, Edgeworth, Barnsley and Killingworth.

Stratigraphic Limits and Structural Relationship: Underlies the Boolaroo Formation and conformably overlies the Adamstown Formation.

ADAMSTOWN FORMATION

Derivation: Newcastle suburb

Previous Usage: After P.J. McKenzie (McKenzie and Britten 1969) Previously Adamstown Subgroup

Type Section: Location: DM AWABA DDH 2
ISG Zone 56/1
353660.036mE 1344391.378mN
219.35 m to 374.16 m
Repository: Department of Mineral Resources
Core Store, Wyee Bay, NSW

Lithology: Conglomerate, sandstone, shale, claystone, and contains the Australasian, Montrose, Wave Hill, Fern Valley and Victoria Tunnel coal seams.

Thickness: Type Section: 154.81 m
Typical Range: 20.0–200.0 m

Distribution: Extends south from outcrop around Dudley, Charlestown, Cardiff, Glendale, south of Minmi and Stockrington.

Stratigraphic Limits and Structural Relationship: Underlies the Warners Bay Tuff and conformably overlies the Nobbys Tuff.

NOBBYS TUFF

Derivation: Nobbys Headland

Previous Usage: Previously known as Nobbys Chert (David 1907, p34) and Nobbys Tuff Member (McKenzie and Britten 1969)

Type Section: Location: NOBBYS HEADLAND
ISG Zone 56/1
Approx 374500mE 1356000mN

Standard Section: Location: DM AWABA DDH 2
ISG Zone 56/1
353660.036mE 1344391.378mN
374.16 m to 375.6m

Repository: Department of Mineral Resources Core Store, Wyee Bay, NSW

Lithology: Tuff, tuffaceous sandstone, tuffaceous siltstone, claystone, chert.

Thickness: Type Section: 24.38 m (80 ft)
Typical Range: 0.5–25.0 m

Distribution: Widely distributed throughout the Newcastle Coal Measures district south from outcrop between Newcastle and Stockrington.

Stratigraphic Limits and Structural Relationship: Underlies the Adamstown Formation and conformably overlies the Lambton Formation.

LAMBTON FORMATION

Derivation: Newcastle suburb

Previous Usage: After P.J. McKenzie (McKenzie and Britten 1969)
Previously Lambton Subgroup

Type Section: Location: DM AWABA DDH 2
ISG Zone 56/1
353660.036mE 1344391.378mN
374.16 m to 375.69 m

Repository: Department of Mineral Resources Core Store, Wyee Bay, NSW

Lithology: Sandstone, shale, minor conglomerate, claystone, and contains the Nobbys, Dudley, Yard, Borehole, Young Wallsend and West Borehole coal seams.

Thickness: Type Section: 15.94 m
Typical Range: 3–60m

Distribution: Extends over the Newcastle Coal district from outcrops between Newcastle and Black Hill and south along the western side of Sugarloaf Range.

Stratigraphic Limits and Structural Relationship: Underlies the Nobbys Tuff and conformably overlies the Waratah Sandstone.

STRATIGRAPHY AND TERMINOLOGY FOR THE SOUTHERN COALFIELD

A. Hutton & J. Bamberry

PREFACE

The Southern Coalfield Subcommittee of the Standing Committee on Coalfield Geology of New South Wales commenced revisions to the Southern Coalfield nomenclature in the mid-1980s following drilling programs by the Department of Mineral Resources and Australian Gas Light Company (AGL). Informal meetings of interested persons commenced in 1985 and several problem areas were delineated. Representatives of the mining industry, government agencies and academic institutions were invited to attend.

At later meetings, drill core was examined at Londonderry and Yerrinbool. Extensive field work was undertaken by John Bamberry. Meetings with the Western Coalfield Subcommittee were also held.

Formal meetings of the Southern Coalfield Subcommittee were held in 1990, with the composition of the Subcommittee with affiliations at the times of the meetings being:

Adrian Hutton (University of Wollongong), Convenor

Bulent Agrali (Bellambi Collieries)

Mike Armstrong (New South Wales Department of Mineral Resources)

John Goodall (Kembla Coal and Coke)

John Hanes (BHP Collieries Division)

Bruce Kirby (Joint Coal Board)

Bill Vlahovic (Elecom)

A preliminary manuscript was compiled during 1991–1992 and circulated to members of the Standing Committee in early 1992 for comment. Following the responses, a report was presented to the Standing Committee on Coalfield Geology of New South Wales by the convenor in March 1992. Further minor changes have been made since then following comments, to the convenor, by people who read the penultimate manuscript.

This report is divided into two parts:

PART A — proposed revisions and rationale for these changes; and

PART B — definitions of the stratigraphic units.

PART A - PROPOSED REVISIONS

INTRODUCTION

The last revision of the stratigraphy and terminology of the Southern Coalfield was ratified in June 1970 (Standing Committee on Coalfield Geology of New South Wales (SCCG, 1971) following the merging of the Southern Coalfield and the then South-Western Coalfield. Terminology previously applicable to the South-Western Coalfield was discontinued. The revision was based on the work of Wood and Bunny (1969), with data mostly from the eastern portion of the coalfield. Thus the applicability of that terminology to the remainder of the coalfield requires clarification. During the twenty years since ratification of the stratigraphy, drilling programs by the Department of Mineral Resources (DMR), Elecom (now Pacific Power) and Australian Gas Light Company (AGL) have shown that a need exists for the revision of the Southern Coalfield stratigraphy.

This paper presents the revisions of the stratigraphy of the Southern Coalfield (Figure 1) as agreed to by the Southern Coalfield Subcommittee. Many of the suggested changes are based on the results of work by Hutton et al (1990) and the extensive field work of Bamberry (1992).

In the eastern part of the Southern Coalfield, the Illawarra Coal Measures remains divided into two subgroups — the older Cumberland Subgroup and the younger Sydney Subgroup.

The Cumberland Subgroup thins towards the southern and western margins of the Sydney Basin and has only been recognised in outcrop in the Wollongong area. (For example, it is not developed in the southwestern part of the basin near Berrima and Mittagong.)

The Cumberland Subgroup comprises three formations — the lower, coal-bearing, sandstone-dominated Pheasants Nest Formation, the younger, predominantly marine, Erins Vale Formation (southern and southeastern parts of the Southern Coalfield) and the lateral equivalent of the Erins Vale Formation, the Kulnura Marine Tongue.

Revisions to the Pheasants Nest Formation include the acceptance of work carried out by Carr (1983) who redefined the latite members of the "Gerringong Volcanics", a term introduced by Joplin et al (1952) but a term Carr (1983) recommended should be dropped. He argued that the latite members of the Shoalhaven Group should be included in the Broughton Formation (below the Illawarra Coal Measures).

The Sydney Subgroup extends to the base of the Triassic Narrabeen Group where, previously, the top of the Sydney Subgroup was taken as the top of the Bulli Coal which mostly coincides with the top of the working seam except where the topmost ply,

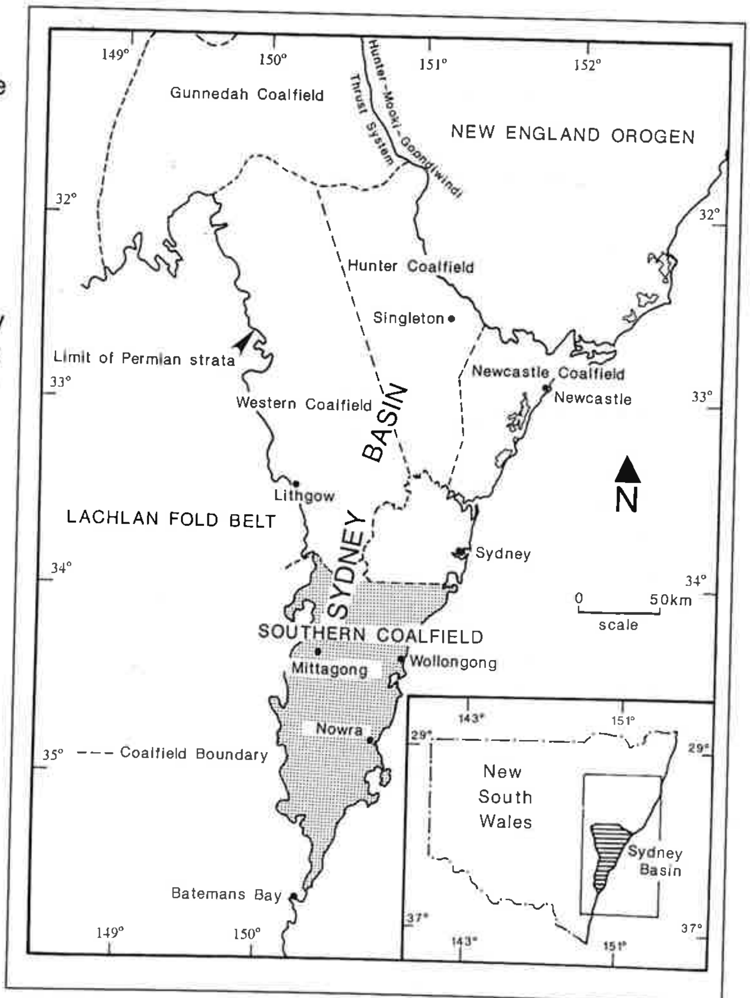

Figure 1. Location of the Southern Coalfield

colloquially called the "blacks", occurs but is not mined. In some areas, carbonaceous claystone above the latter unit should be considered part of the Sydney Subgroup.

Revisions include recognition of eight units not previously defined, acceptance of a unit previously restricted to the Western Coalfield and formalisation of one unit, Burragorang Claystone, previously only recognised informally.

Mapping of the Wilton Formation in the Southern Coalfield has identified a new member, Wanganderry Sandstone Member, in the western part of the Southern Coalfield, and has required recognition of a new formation, the Thirroul Sandstone, in the eastern part of the Coalfield.

Detailed investigation of drill holes in the northern part of the Southern Coalfield and in the central part of the Sydney Basin north of the Southern Coalfield shows that a mappable coal unit occurs near the middle of the Loddon Sandstone (the unit below the Bulli Coal). It is proposed to name this coal unit the Balmain Coal Member, with the underlying clastic unit to be called the Penrith Sandstone Member and the overlying clastic unit the Dural Sandstone Member.

The revised stratigraphy and nomenclature is given in Figure 2.

RECOMMENDED REVISIONS TO THE STRATIGRAPHY OF THE SOUTHERN COALFIELD

CUMBERLAND SUBGROUP

Whilst only relatively few boreholes have drilled the Cumberland Subgroup, compared to the number that have intersected the Sydney Subgroup, additional boreholes that have intersected the Cumberland Subgroup, have been drilled since the last revision of the stratigraphy. Those additional data includes boreholes drilled by DMR and AGL drill holes in the Picton–Camden area and boreholes drilled in the Robertson area by Elecom. No recent drilling has intersected the Cumberland Subgroup in the Wollongong area but additional outcrop and geochemical data on the latite flows, which occur in both the Illawarra Coal Measures and the underlying Shoalhaven Group, are available. Drill hole data of AGL and the work of Carr (1983) indicate the need for revision of the Pheasants Nest Formation.

PHEASANTS NEST FORMATION

The SCCG (1971) defined the base of the Pheasants Nest Formation as the top of the first extensive marine sandstone unit following the last occurrence of coal or carbonaceous shale. The base is commonly gradational with the uppermost marine strata of the Shoalhaven Group except in the Wollongong–Berry area. There the base of the coal measures is marked by the top of latite members of the Broughton Formation of the Shoalhaven Group. For example, in the Unanderra area, the sandstone of the Pheasants Nest Formation overlies the Dapto Latite. Wilson (1969) reported that where the Cambewarra Latite Member or the equivalent boulder bed is absent, the contact between the Shoalhaven Group and the Illawarra Coal Measures is transitional. Following redefinition of the latite members, and a detailed account of the distribution of the units by Carr (1983), it was apparent that definition of the Pheasants Nest Formation needed revision. (A summary is included in Part B — Definitions.)

Carr (1983) recognised nine latite flows (four in the Illawarra Coal Measures (Figure 2) and five in the underlying Shoalhaven Group); provided type areas for each; and gave each flow member status. This contrasted with the publications of Bowman (1974; 1980), who recognised two latite flows in the Illawarra Coal Measures but the same five flows in the Shoalhaven Group. The two authors also differed as to the stratigraphic positions of the flows in the Shoalhaven Group.

The distribution of the flows was plotted by Carr (1983) using outcrop and drill hole data. Four of the five flows in the Shoalhaven Group, the Blow Hole Latite, Bumbo Latite, Saddleback Latite and Dapto Latite Members, do not crop out north of the known southern limit of the Illawarra Coal Measures and the inferred distribution pattern of each of the flows does not overlap that of another. The distribution pattern of the youngest of the flows in the Shoalhaven Group, the Cambewarra Latite Member, does overlap the distribution pattern of the Illawarra Coal Measures. However, the Cambewarra Latite Member is easily distinguished from all other latite and intrusive rocks that may be encountered, irrespective of whether the occurrence was in the Shoalhaven Group or Illawarra Coal Measures, because it contains numerous vesicles and amygdules.

The latite members recognised in the Pheasants Nest Formation are the Five Islands Latite, Calderwood Latite, Minnamurra Latite and Berkeley Latite Members.

Five Islands Latite Member *(revised definition)*

The Five Islands Latite Member, defined as the Five Islands Flow by Harper (1915), is of restricted occurrence and crops out only on Flinders Islet, the northernmost island of the group of five islands east of Wollongong, after which the flow was named. The unit comprises latite which was extruded into a subaqueous environment as indicated by pillow structures up to 1 m in diameter.

The position of this unit in the stratigraphic column has been inferred as only outcrops on the island are known and the unit has not been observed in juxtaposition with older or younger units either in drill core or outcrop. Carr (1983) argued that a regional

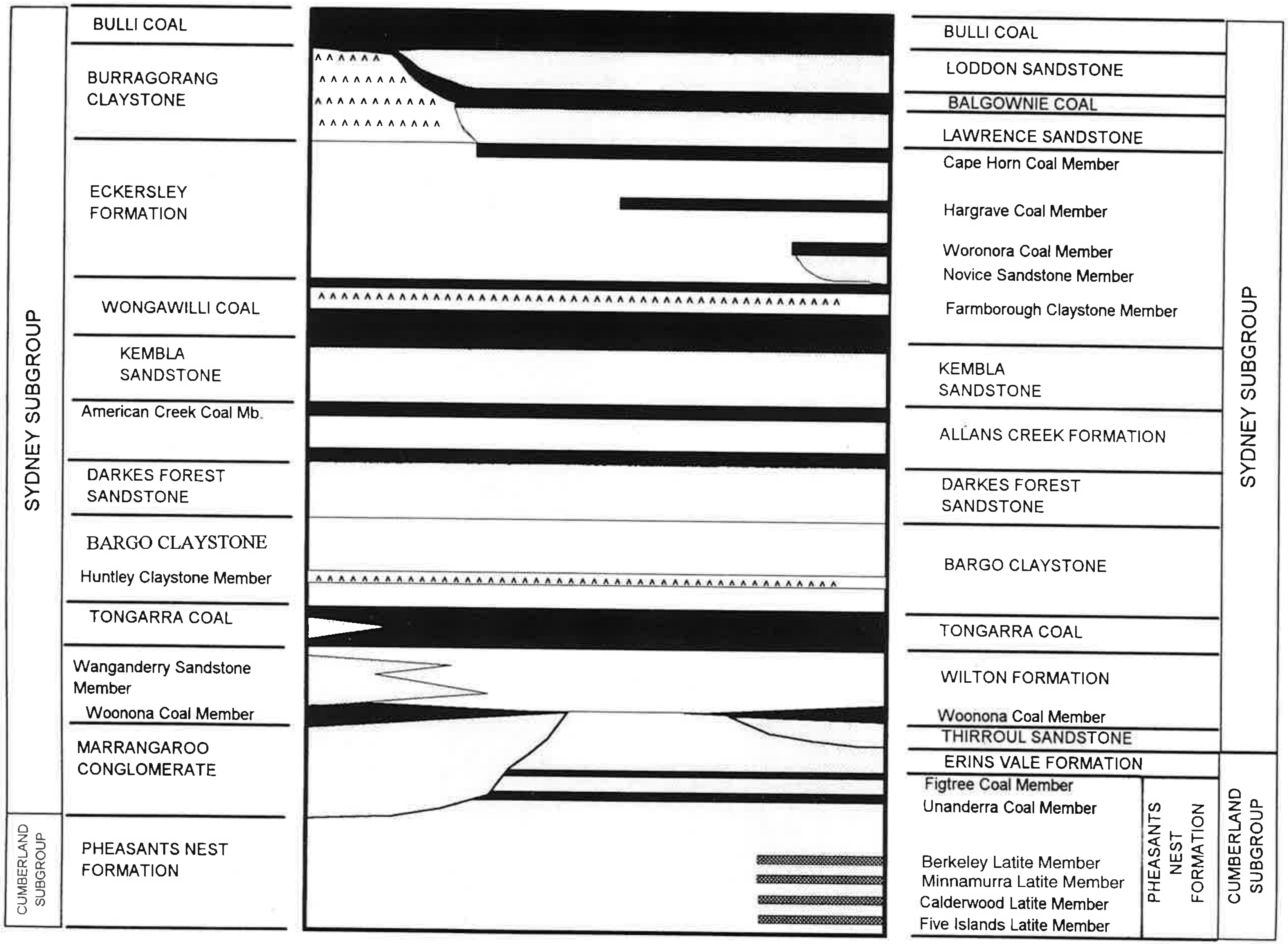

Figure 2. Revised stratigraphy of the Southern Coalfield

dip of 2° to 3° for the Broughton Formation, on the mainland, indicated that the latter was older than the Five Islands Latite Member and the regional dip also suggested a maximum separation of 90 m between the Five Islands Latite Member and the older Dapto Latite Member.

Calderwood Latite Member *(new member)*

The Calderwood Latite Member crops out near Calderwood where it has a maximum thickness of 38 m. This unit thins to the north, south and west but extends discontinuously from the northeastern side of Stockyard Mountain (GR 958685 Albion Park (9028-I-N)) for 9 km towards the north-northeast. The unit comprises latite that was probably extrusive, as indicated by the abundance of volcaniclastic material in the sedimentary rocks above and below the latite.

This unit has not been previously recognised as a separate unit, although outcrops have been mistakenly assigned to other latite members. An outcrop of the Calderwood Latite Member at Stockyard Mountain was originally mapped by Jaquet et al (1905) and Lowder (1964) as the Saddleback Latite Member and was thought to occur at the top of the Cambewarra Latite Member. The field observations of Carr (1983) clearly showed that the outcrop is 3 m, stratigraphically, above the Cambewarra Latite Member of the Broughton Formation and is separated from the latter by sandstone and shale of the Cumberland Subgroup. The anomalous stratigraphic position of this outcrop of the 'Saddleback Latite Member' at this locality was attributed by Jaquet et al (1905, p. 13) to a topographic high at the time of eruption.

Minnamurra Latite Member *(revised definition)*

The Minnamurra Latite Member extends as a discontinuous sheet from the northern side of Saddleback Mountain to a point 15 km west of Port Kembla. This unit occurs 40 m above the base of the coal measures sequence. Horizontally-bedded sandstone, shale and siltstone fill depressions, up to 0.5 m deep, in the top surface of the unit. Maximum thickness, 35 m, is at Minnamurra River (spelling "Minumurra River" in Harper (1915), although he also used "Minnamurra" for the locality). The unit comprises latite that was extruded onto the Permian land surface or into a shallow subaqueous environment.

Jaquet et al (1905) originally defined the unit as the Minnamurra Flow but it was renamed as Minnamurra Latite by Joplin et al (1952). Subsequent useage of the name has resulted in the term Minnamurra being used extensively (cf Lowder, 1964; Raam, 1969; and Bowman, 1970, 1974). In these notes the common useage of "Minnamurra"as the preferred spelling has been followed.

Berkeley Latite Member *(revised definition)*

The Berkeley Latite Member has approximately the same stratigraphic level as the Minnamurra Latite Member, although the base of the unit occurs between 15 m and 40 m above the top of the Shoalhaven Group. The maximum thickness of the unit is 35 m in the Figtree area, where the unit consists of two flows separated by approximately 3 m of sandstone of the Illawarra Coal Measures, and it thins to the north and southwest. The unit consists of an extrusive latite, although an intrusive origin was assigned by McElroy (1952).

Card (1907) described the Berkeley Flow, from near the Berkeley Trigonometrical Station. However, Harper (1915) named the unit the Berkeley Flow and it was renamed Berkeley Latite by McElroy (1952) and Berkley Latite by Joplin et al, 1952). The incorrect spelling has been extensively used in many publications but because the modern spelling ("Berkeley") is now widely used, that is preferred here.

Recent drilling shows that the Pheasants Nest Formation contains lithic sandstone, few coal seams, and more abundant conglomerate in the Robertson area than in other areas of the basin. It is suggested that the descriptions that accompany the definition of the Pheasants Nest Formation, be modified to accommodate this lateral change.

ERINS VALE FORMATION

Drilling in the western and northern areas of the Southern Coalfield has indicated that the upper sections of the Erins Vale Formation contain significant thicknesses of conglomerate interbedded with coarse-grained sandstone and bioturbated siltstone. The conglomeratic sequences are gradational with, and pass laterally into, the commonly massive, bioturbated, fine-grained sandstone that are the more typical strata of the Erins Vale Formation.

Revision of the existing descriptions that accompany the definition of the Pheasants Nest and Erins Vale Formations (SCCG, 1971) accommodates recognition of the conglomeratic sequences.

SYDNEY SUBGROUP

The Sydney Subgroup comprises a predominantly fluvial-deltaic sequence that extends from the top of the Cumberland Subgroup where developed to the base of the Narrabeen Group.

MARRANGAROO CONGLOMERATE *(revised definition)*

Bamberry (1992) stated that both the conglomerate and the coarse-grained sandstone underlying the Woonona Coal Member have sharp erosive basal contacts and occur in two separate developments, namely, in the western and eastern parts of the Southern Coalfield (Figure 3). Along the western margins, outcrop of up to 15 m of conglomerate and very coarse- to coarse-grained sandstone underlie the Woonona Coal Member. This extensively developed unit has been correlated by several authors with the Marrangaroo Conglomerate of the Western Coalfield (McElroy & Relph, 1961; Bembrick, 1983; Havord et al, 1984; Hunt et al, 1984). Whiting and Relph (1956; 1969) referred to this unit as the "Higgins Creek Conglomerate" and traced it from central Burragorang to Bullio and Mittagong.

Bamberry (1992) recorded the conglomeratic facies as extending as far south as Sutton Forest, but to the east it has a less continuous, and in places, sporadic distribution. Given the distribution of the conglomeratic facies in the Southern Coalfield and its identical stratigraphic position, this unit should be recognised as the Marrangaroo Conglomerate. Thus, the Marrangaroo Conglomerate, in the Southern Coalfield, is dominated by pebbly to coarse-grained sublitharenite with minor conglomerate and lenticular carbonaceous siltstone interbeds (Figures 4 and 5) and has a sharp, commonly erosive basal contact with the upper Erins Vale Formation (Figure 6), coaly sedimentary units of the Pheasants Nest Formation or marine sedimentary units of the Berry Siltstone of the Shoalhaven Group. Apart from its composition and common association with carbonaceous beds, it is distinguished by its fining-upward character. These features are particularly useful for determining the stratigraphy where the Marrangaroo Conglomerate overlies conglomerate of the upper Erins Vale Formation.

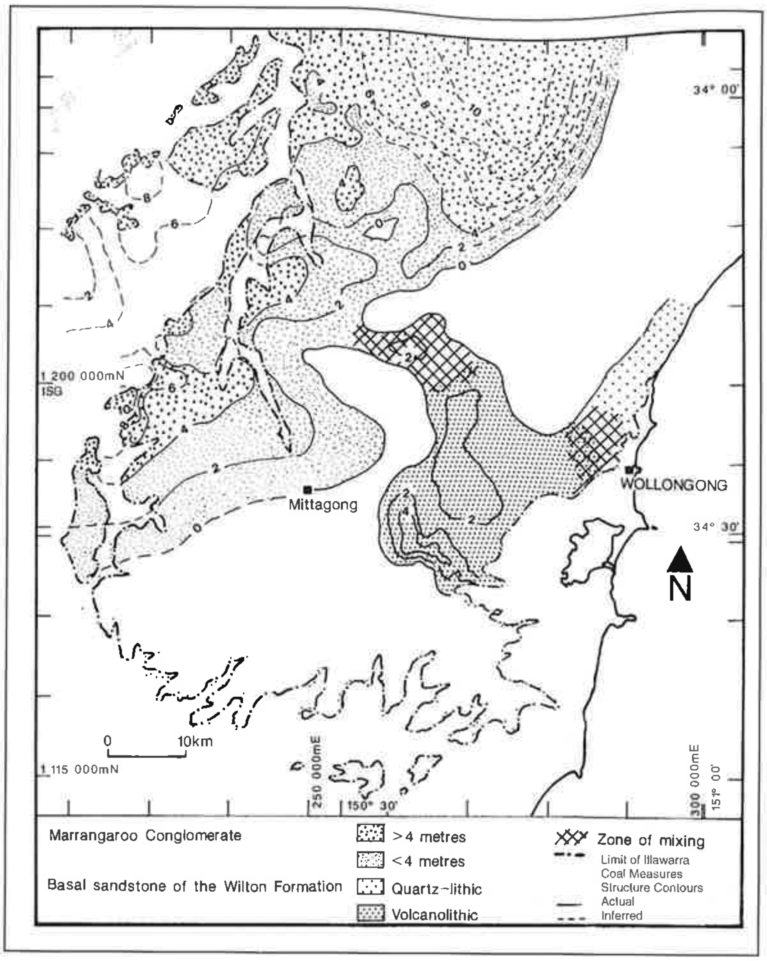

Figure 3. Isopach map of the Marrangaroo Conglomerate and basal sandstone of the WIlton Formation

The names "Marangaroo Beds", "Marrangaroo beds" and "Marangaroo Conglomerate", were used by Stephens (1883a, b), respectively. Widespread current useage of the spelling " Marrangaroo Conglomerate" supports that as the preferred spelling. The Marrangaroo Conglomerate was formally recognised by the SCCG (1986) following the work of Bembrick (1983) in the Western Coalfield.

In the central part of the Southern Coalfield, a narrow 'bridge' of sandstone represents an area showing the mixed influence of the source areas of the Marrangaroo Conglomerate and the sandstone of the Wilton Formation. To the north and south of this area, either the Woonona Coal Member or claystone of the Wilton Formation rest directly upon the uppermost strata of the Cumberland Subgroup.

THIRROUL SANDSTONE *(new member)*

The Wilton Formation has been defined as the unit that:

"immediately underlies the Tongarra Coal and extends to the base of the conglomerate where this is present or to the base of the Woonona Coal Member when the conglomerate is absent. In the absence of both the conglomerate and the coal, the base of the formation is placed at the top of the first massive sandstone." (SCCG, 1971, p. 121)

Conglomerate in the above definition probably refers to the "coarse-grained to conglomeratic quartzo-feldspathic sandstone", which occurs below the Woonona Coal Member in coastal outcrops (considered by Bowman (1970, 1974) to be part of the Wilton Formation). Neither the distribution nor character of the "conglomerate" to which the SCCG (1971) referred, is clarified in the definition.

Mapping of this "quartzo-feldspathic sandstone" indicates that it should be identified as a new formation. The name Thirroul Sandstone is proposed for this sandstone unit. This unit erosively overlies medium-grained, well-sorted sandstone of the Erins Vale Formation in outcrops between Thirroul Beach and Mount Kembla. South of Mount Kembla, the unit merges with sandstone and conglomerate of the Pheasants Nest Formation. In the Thirroul–Woonona area, the sandstone composition is an arenite with numerous chert grains, whereas at Mount Kembla, the sandstone is a volcarenite with numerous volcanic rock fragments. The unit occupies a position stratigraphically equivalent to the Marrangaroo Conglomerate but is not connected to this unit except for a small bridge of sandstone. The Thirroul Sandstone was derived from a provenance to the southeast whereas the Marrangaroo Conglomerate was derived from a western source.

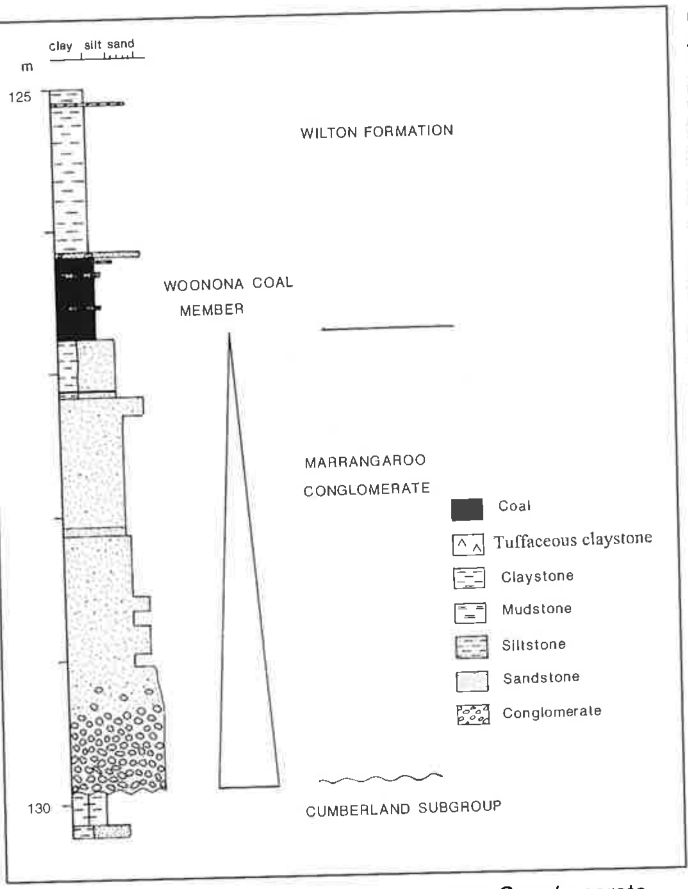

Figure 4. Sections through the Marrangaroo Conglomerate and Wilton Formation

WILTON FORMATION

The Wilton Formation is dominated by claystone and siltstone (SCCG, 1971), although Bunny (1972) stated that it loses identity near Yerrinbool and is poorly defined in the Appin area due to the ingress of sandy and silty units. Two members have been recognised and are described here: the Woonona Coal Member and the Wanganderry Sandstone Member.

Wanganderry Sandstone Member *(new member)*

Bamberry (1992) used a sandstone percentage map of the interval between the Tongarra and Woonona Seams to show that the Wilton Formation contains progressively more sand towards the western and southwestern margin of the Southern Coalfield. Mapping of the westernmost outcrops indicates that this interval is occupied by coarse- to very coarse-grained quartz arenite. Although this interval is similar in composition to the Marrangaroo Conglomerate, the sandstone contains only rare pebble bands. Similarly, thin carbonaceous shale bands are a rare component. The sandstone is herein defined as a new member of the Wilton Formation: Wanganderry Sandstone Member.

The sandstone of the Wanganderry Sandstone Member has a sharp basal contact with the Woonona Coal Member (of the Wilton Formation) and has a maximum recorded thickness of 22 m at Yerranderie, where it is well developed. The sandstone is overlain by the Tongarra Coal, where present, or the Bargo Claystone, and thins to the east, passing laterally into the finer-grained strata of the Wilton Formation.

Mapping of this unit by Bamberry (1992) showed that it extends northwards from Mount Penang (GR 389684, Hanworth (8929-II-S) to at least Goodfellows Creek (GR 455982, Barralier (8929-II-N)).

This sandstone unit occupies a similar stratigraphic position to the Blackmans Flat Conglomerate of the Western Coalfield. However, because the term Blackmans Flat Conglomerate was originally applied to the clastic wedge between the Lithgow seam and the Lidsdale seam, the name Blackmans Flat Conglomerate is not an appropriate name for this unit in the Southern Coalfield. The name Wanganderry Sandstone Member is proposed for the unit. The name is derived from the Parish of Wanganderry, where the unit is well developed.

Woonona Coal Member

The Woonona Coal Member of the Wilton Formation is not developed over parts of the central Southern Coalfield and merges with the Tongarra Coal in the southern part of the coalfield, such as near Huntley Colliery.

TONGARRA COAL

The Tongarra Coal is developed over a large area of the Southern Coalfield and is subject to splitting in the Burragorang Valley (SCCG, 1971). Bamberry (1992) showed that the seam is split in two areas, the Burragorang to Hilltop area and the Avon–Wongawilli area. The sedimentary rocks that occur between the seam splits in the latter area are up to 14 m thick, but are thinner and more widespread in the former area.

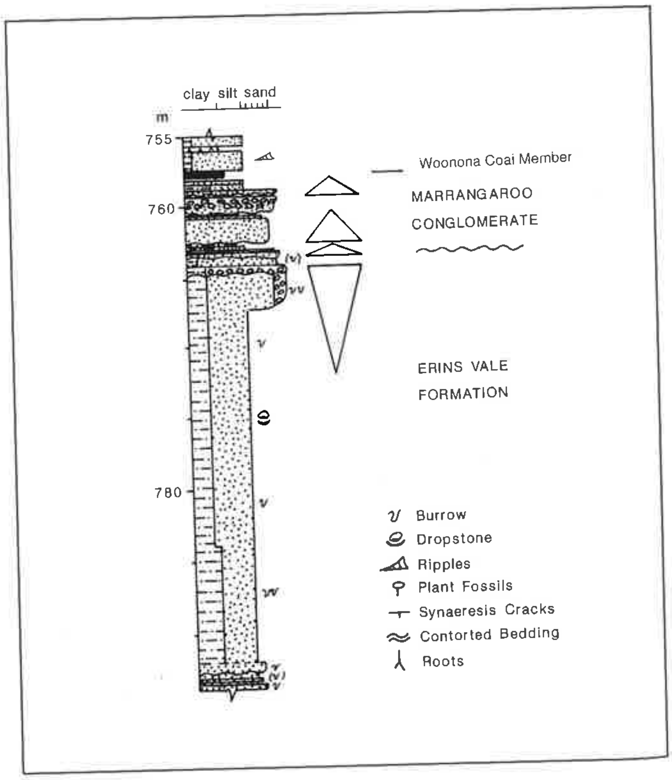

Figure 5. Typical section of the Marrangaroo Conglomerate

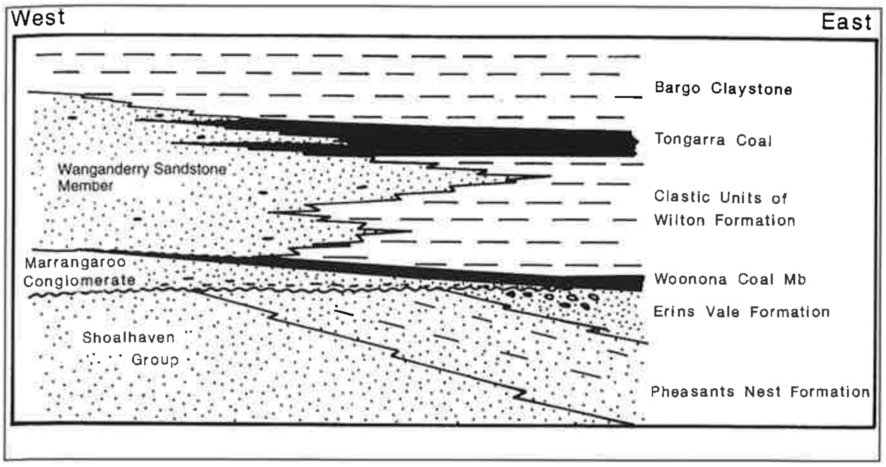

Figure 6. Stratigraphic relationships between the Marrangaroo Conglomerate and Wanganderry Sandstone Member in the western part of the coalfield and the Cumberland Subgroup in the eastern part of the coalfield

Allans Creek Formation

The Allans Creek Formation overlies the Darkes Forest Sandstone and is composed of up to four coaly or carbonaceous intervals separated by an interbedded sequence of sandstone, siltstone and claystone. It is poorly represented in the far southern and western parts of the Southern Coalfield.

The base of the unit is taken as the base of the lowermost coaly sequence in the unit and the top is taken as the erosive base of the Kembla Sandstone.

BARGO CLAYSTONE AND DARKES FOREST SANDSTONE

The Appin Formation, as defined by the SCCG (1971), is comprised of the Bargo Claystone Member and the Darkes Forest Sandstone Member. Bowman (1970, 1974) and Bunny (1972) did not use this member nomenclature and suggested that the members be considered as formations, namely, Bargo Claystone and Darkes Forest Sandstone. Mapping of these units throughout the Southern Coalfield indicates that both units are widely developed, although the claystone unit is more widespread than the sandstone unit. Because these units are distinctive and of considerable lateral extent, a change in status, from member to formation, is required for the two units and correspondingly, the term 'Appin Formation' should be abandoned. This would permit use of the term 'Austinmer Sandstone Member' (of the Bargo Claystone; Figure 7) as defined by Bowman (1970), a unit that is the basal part of the Bargo Claystone and is restricted to coastal exposures in the Southern Coalfield.

Huntley Claystone Member *(new member)*

Several metres above the base of the Bargo Claystone, a 0.4 m to 0.7 m thick bed of light-coloured, waxy claystone is present (Figure 7) and it extends over most of the Southern Coalfield. Previously, it has been referred to as the " Nolan Band" or the " calcite marker" because it is commonly filled with calcite veins. Petrographic evidence (Bamberry, 1992), including clay mineralogy, indicated that this unit consists of ash fall material which has undergone various degrees of reworking by epiclastic processes. Cas and Wright (1987) suggested that the term " tuff" should only be applied to ash-size aggregates that have been fragmented and deposited by pyroclastic processes. Although the degree of reworking cannot be accurately assessed due to modification by diagenetic processes, the ash has been reworked by roots. Therefore, the name " tuff" is not used here and the name Huntley Claystone Member (of the Bargo Claystone) is proposed.

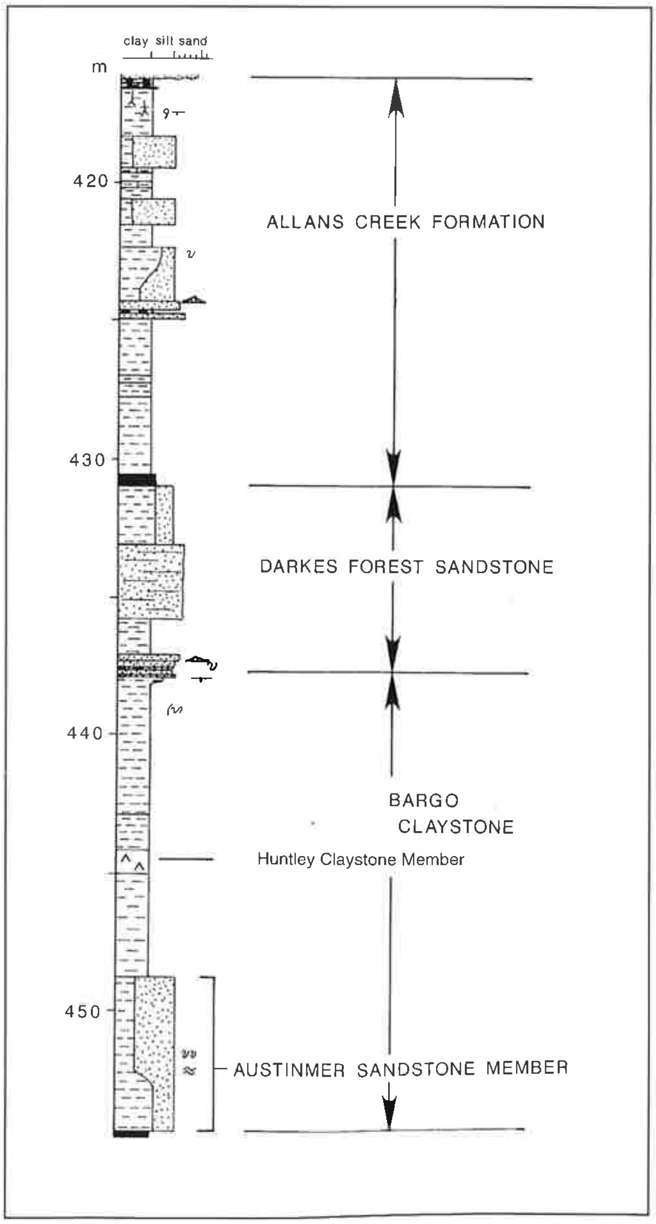

Figure 7. Section through the Bargo Claystone showing the position of the Huntley Claystone Member

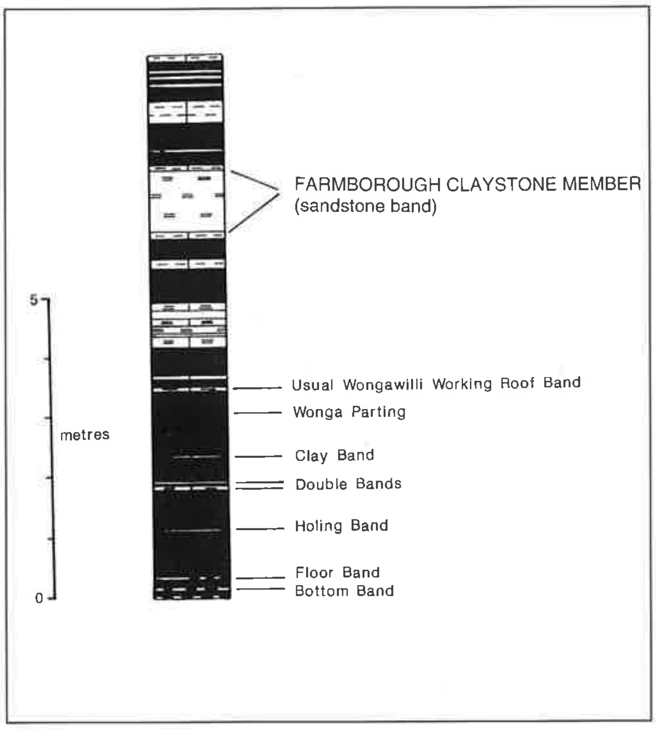

Figure 8. Section through the Wongawilli Coal showing the Farmborough Claystone Member

The upper coaly unit is the American Creek Coal Member.

Towards the west and southwest, the Allans Creek Formation contains very little or no sandstone and, in those areas, the unit consists mostly of carbonaceous claystone and coal.

Mapping of the unit throughout the Southern Coalfield has indicated that the descriptions that accompany the definition of this unit (SCCG, 1971) do not accurately account for its distribution.

WONGAWILLI COAL

The Kembla Sandstone erosively overlies the Allans Creek Formation and is, in turn, overlain by the thick Wongawilli Coal (Figure 2). This latter unit is developed over a large area of the Southern Coalfield. Relationships across the Wongawilli Coal to the Bulli Coal are shown in Figure 9.

The Wongawilli Coal does not always have sharp upper and lower limits — which leads to subjectivity in placement of the boundaries. The base is taken as the base of the lowermost carbonaceous claystone or coal. The upper boundary is commonly gradational with the base of the Eckersley Formation, that becomes very carbonaceous in the central part of the Southern Coalfield. Thus the upper boundary is taken as the top of the topmost continuous coal.

Along the southwestern margin of the basin, for example near Berrima, the Wongawilli Coal is overlain by the Triassic Hawkesbury Sandstone.

Farmborough Claystone Member *(new member)*

A unit of similar nature to the Huntley Claystone Member occurs in the Wongawilli Coal and has been informally referred to as the "sandstone band" and "3 foot band" (Figures 8 and 9). Although thicknesses up to 2 m have been recorded, this unit generally exhibits marked consistency in thickness, averaging 1 m. It is developed throughout the Southern Coalfield with the exception of a few small isolated areas. Petrographically, this unit is similar to the Huntley Claystone Member and contains a significant volcanic ash component, although the ash has altered to clay — resulting in typical claystone textures.

The term Farmborough Claystone Member is proposed for the "sandstone band" and it is considered a member of the Wongawilli Coal.

Eckersley Formation (revised definition)

The Eckersley Formation, as previously defined, encompassed the interval from the top of the Wongawilli Coal to the base of the Bulli Coal. A number of changes to the stratigraphy, such as the recognition of the Burragorang Claystone and Loddon Sandstone, and elevation of the Balgownie Coal and Lawrence Sandstone to formation status necessitates redefinition of the Eckersley Formation.

As now defined, the Eckersley Formation extends from the top of the Wongawilli Coal to the base of the Lawrence Sandstone (Figure 2). It is dominated by claystone, siltstone and thin coal seams in its lower part and, in its upper part, by sandstone, siltstone and

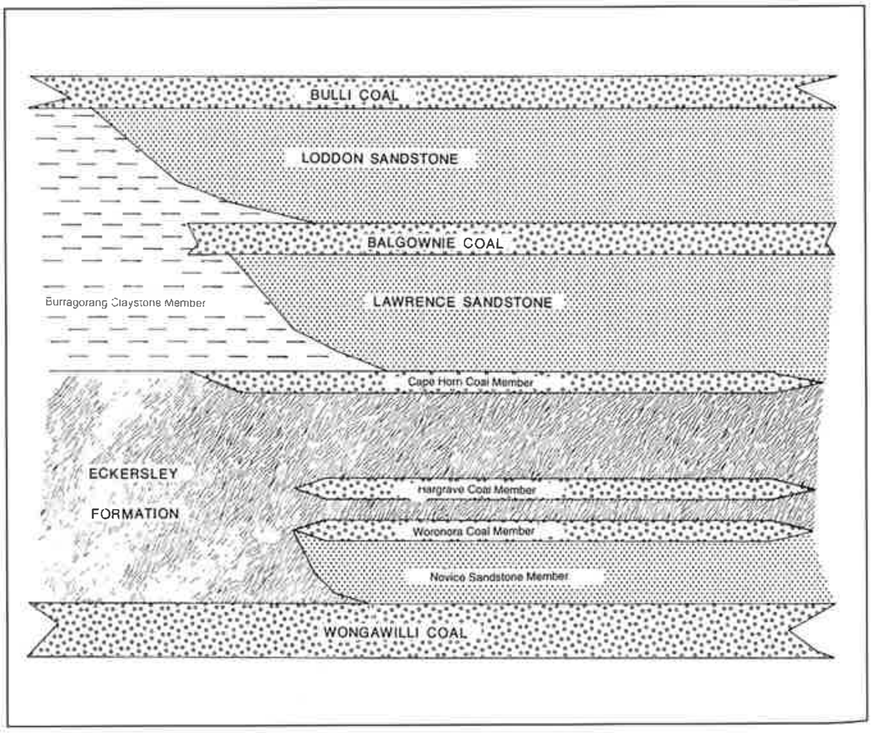

Figure 9. Stratigraphic relationships through the section Wongawilli Coal to Bulli Coal

coal. In those areas where the Burragorang Claystone is preserved, the top of the Eckersley Formation coincides with the base of the Burragorang Claystone.

The Eckersley Formation consists of the Novice Sandstone Member, the Woronora Coal Member, the Hargrave Coal Member and the Cape Horn Coal Member (Figure 9).

BURRAGORANG CLAYSTONE *(new formation)*

The Burragorang Claystone has not been formally ratified despite relatively widespread use in the literature. Originally termed the "Burragorang Chert" (Whiting & Relph, 1961), the Burragorang Claystone has been recognised as far south as Bullio and extends northwards from the Burragorang Valley into the Western Coalfield (Figures 9 and 10). It is a light-coloured, silicified, cherty claystone which forms prominent blocky outcrops. A tuffaceous origin for the Burragorang Claystone has been suggested by several authors (eg, McElroy & Relph, 1961; Whiting & Relph, 1969;) and recent petrographic evidence has confirmed this suggestion (Bamberry & Doyle, 1987).

In the Southern Coalfield, the thickest development of the Burragorang Claystone is in the western parts of the Southern Coalfield where it averages 4 m, and occupies the stratigraphic interval between the Cape Horn Coal Member and the Bulli Coal. Towards the western and southwestern margins of the coalfield, the Balgownie Coal and the Loddon Sandstone are not developed and the Bulli Coal is separated from the Burragorang Claystone by a thin interval of carbonaceous claystone. Also in those areas, the claystone and coal of the lower Eckersley Formation merge with the upper Wongawilli Coal and the Burragorang Claystone rests directly upon the Wongawilli Coal.

In the Burragorang area, the stratigraphic interval between the Cape Horn Coal Member and the Balgownie Coal is occupied by the Lawrence Sandstone, that is erosive into the Burragorang Claystone. In some areas, up to 3.7 m of tuffaceous claystone occurs between the Cape Horn Coal Member and the Lawrence Sandstone. These latter occurrences have been correlated with the Burragorang Claystone on the basis of stratigraphic position and petrography (Bamberry & Doyle, 1987). The Burragorang Claystone appears to have been eroded in a broad north-south zone in the Campbelltown–Liverpool area but further to the east and northeast is present and continuous, averaging 1 m to 1.5 m thick.

Like the Huntley and Farmborough Claystone Members, the Burragorang Claystone exhibits evidence of reworking, with only a minor portion of primary tuff components preserved.

The Burragorang Claystone has not been previously defined for the Southern Coalfield and therefore, a definition is provided in Part B. As with the Huntley and Farmborough Claystone Members, the tuffaceous origin of the unit is acknowledged in the definition.

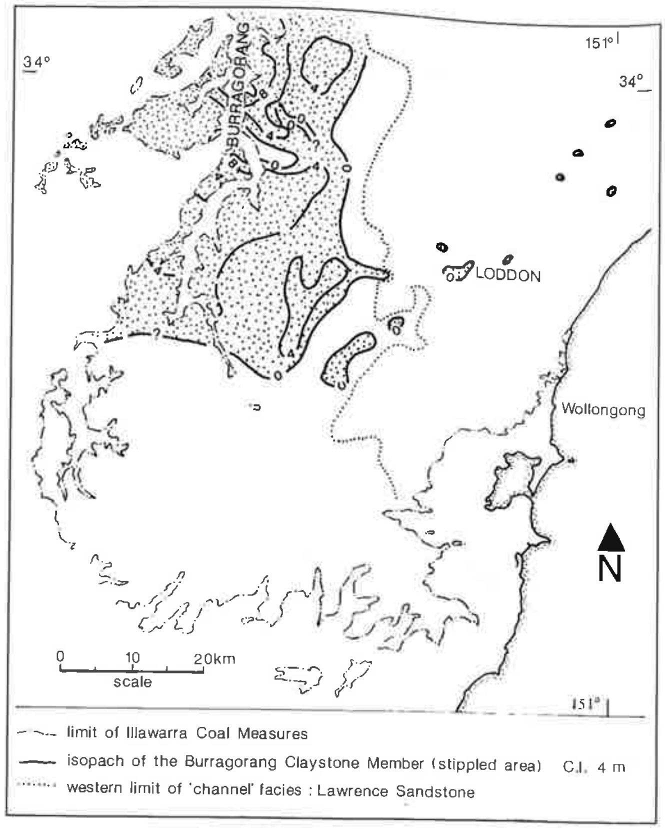

Figure 10. Isopach map of the Burragorang Claystone

LAWRENCE SANDSTONE *(new status)*

The Lawrence Sandstone is present as the interval between the Cape Horn Coal Member and the Balgownie Coal (Figure 2). The areal distribution of this unit is less than that of the Loddon Sandstone (new formation) but it is considered that the unit is sufficiently extensive to be elevated to formation status (Figures 2 and 9).

BALGOWNIE COAL *(new status)*

The Balgownie seam is a widespread, laterally continuous coal seam that has a thickness of up to 4 m but thins to less than 1 m. Previously, it had member status but several researchers have informally given it formation status. Given that it is a distinctive marker unit in the Sydney Subgroup and has an extensive distribution, the Balgownie Coal Member is elevated to Balgownie Coal, with formation status (Figures 2 and 9).

LODDON SANDSTONE *(new formation)*

The interval between the Balgownie Coal and Bulli Coal is dominated by one or more lithic sandstones with minor siltstone, claystone and rare conglomerate. It commonly comprises two or more fining-upward sequences and becomes finer grained towards the western margins of the Southern Coalfield. This interval is distinctive and is laterally continuous over a large part of the Southern Coalfield, except in the southwestern part, and is more widespread than the Lawrence Sandstone. The name Loddon Sandstone is proposed (Figures 2 and 9).

The type section of the Loddon Sandstone is in drillhole DM Wollongong DDH 21, from 426.48 m to 433.71 m. The thickness of the unit ranges from less than 1 m to 24 m. The base of the unit is the top of the Balgownie Coal and the top of the unit is the base of the Bulli Coal.

The Loddon Sandstone occurs over most of the Southern Coalfield, except in the southwest. Generally, the Loddon Sandstone contains two fining-upward sequences. However, in the Appin area three fining-upward sequences have been recognised. North of the townships of Narellan, Campbelltown and Heathcote a thin coal unit is recognised near the middle of the Loddon Sandstone. The clastic units above and below this coal seam fine upward and are continuations of the fining upwards units found further to the south where the coal seam does not occur. The coal unit and associated clastic units of the Loddon Sandstone are recognised in Bunnerong #1, a Pacific Power drill hole in the Sydney metropolitan area. Elsewhere, this coal unit can be correlated across most the central part of the basin to the north of the Southern Coalfield (Hill et al, 1994).

Subdivision of the Loddon Sandstone can thus be correlated across the northern Southern Coalfield boundary. It is therefore expedient to formally recognise the subdivisions as the Penrith Sandstone Member (basal unit), Balmain Coal Member and Dural Sandstone Member, as proposed by Hill et al (1994).

Bulli Coal

Figures 2 and 9 show the position of the important Bulli Coal at the top of the Sydney Subgroup in the Southern Coalfield. The Bulli Coal overlies the Loddon Sandstone. In parts of the Southern Coalfield the working Bulli seam is overlain by a carbonaceous claystone, containing numerous slickensides, colloquially known as the "blacks". Geologically, the "blacks" is continuous with and is part of the Bulli seam, although this lithology is not always recorded on lithological logs. The "blacks" attains a thickness of at least 40 cm. In order to introduce consistency in nomenclature, the top of the Bulli Coal should be defined as the top of the coal or the top of the "blacks" where the latter ply occurs.

Further study is needed to determine if claystone and siltstone, locally carbonaceous, that are conformable with and above the Bulli Coal in some parts of the Southern Coalfield, should be included in the Bulli Coal.

REFERENCE DRILL HOLE

RATIONALE FOR REFERENCE DRILL HOLE

Twenty two formal units (of varying levels) were recognised and descriptions of the type sections and a stratigraphic section given in the SCCG (1971) (Table 1). Many of the 22 type sections have been defined in both drill core and from outcrop. A comparison of the data for the outcrop and core sections shows discrepancies between the two. For example, the Unanderra Coal Member type section is 4.26 m thick at outcrop but only 1.42 m thick in core. Conversely, the Allans Creek Formation is much thicker in the core type section than the outcrop section. For the Unanderra seam, the two sections are relatively close together spatially and it is difficult to explain the differences between the two. However, for the Allans Creek Formation, the two type sections are quite some distance apart and changes in thickness, and probably lithologies, are easily related to lateral variation. For example, the Nebo Colliery outcrop is near the southern limit of the basin sequence and the outcrop type section is probably indicative of thinning and lateral variation, compared to the centre of the basin, caused by being closer to the basin margin. The thicker, core type section is likely to be more representative because it is located nearer to the centre of the basin.

Several problems are now apparent with the existing type sections. One problem needing to be addressed is whether any of the type sections, be they outcrop or core section, represent either marginal facies areas (such as the Robertson area) or are representative of the deeper, more central parts of the basin.

As well as the above discrepancies relating to thickness of the core and outcrop type sections, the present stratigraphy has a number of other problems.

1. Many of the outcrop type sections, as originally defined, have been continually weathered and are relatively inaccessible. Thus recognition of the sections is severely restricted and continued effective use of the sections must now be questioned.

2. The core type sections are from several drill holes and storage of the core is at two localities. This raises the question of accessibility, especially as some of the type sections can no longer be found. The core type sections are distributed over ten holes at BHP Collieries Division core shed and Londonderry Core Library of the Department of Mineral Resources. The core from which the Unanderra Coal Member and Figtree Coal Member of the Cumberland Subgroup were defined no longer exists, and the American Creek seam was not defined in any drillhole.

3. For at least one type section there is no correlation between the core and written geological logs. Examination of the Wilton Formation type section in DM Wollongong 35 revealed that the core trays for the bottom section of this unit contained lithic sandstone whereas the geological log shows laminites and other finer-grained lithologies. How this "change" occurred is not known. Irrespective of the reason, it raises the question of the usefulness of core as type sections. On the positive side, it could be argued that the core was

TABLE 1. TYPE SECTIONS OF THE SOUTHERN COALFIELD AS PREVIOUSLY DEFINED. (adapted from SCCG, 1971)

UNIT	Core			Outcrop		Maximum Thickness	
	Hole	Thickness	Repository	Locality	Thickness	(m)	Hole/Locality
SYDNEY SUBGROUP							
Bulli Coal	Camden 53	2.44	Londonderry	Coalcliff	1.30	2.44	Glenlee Bore
Eckersley Formation	Camden 78	121.94	Londonderry	none		122.02	
Balgownie Coal	Camden 61	1.17	Londonderry	Sth Bulli Colliery	1.30	2.21	Wollongong 45
Lawrence Sandstone	Metropolitan 10	10.27	BHP#	Scarborough	11.07	13.88	Corrimal 1
Novice Sandstone Mb	Camden 78	37.13	Londonderry	none		37.13	Camden 78
Woronora Coal Mb	Camden 78	11.25	Londonderry	none		11.90	Camden 64
Hargrave Coal Mb	Metropolitan 10	0.1	BHP#	Scarborough	0.46	0.46	Scarborough
Cape Horn Coal Mb	Metropolitan 10	0.79	BHP#	Scarborough	1.32		
Wongawilli Coal	Nebo 10	9.15	BHP#	West Dapto	8.26	11.21	Wollongong 79
Kembla Sandstone	Camden 68	17.82	Londonderry	West Dapto	12.3	23.79	Liverpool 91
American Creek Coal Mb	no core			Nebo Colliery	4.44		
Allans Creek Formation	Camden 78	44.65	Londonderry	Nebo Colliery	6.99	44.65	Camden 78
Darkes Forest Sandstone	Camden 56	11.87	Londonderry	Nebo Colliery	9.14	24.07	Camden 63
Bargo Claystone	Camden 56	15.20	Londonderry	Nebo Colliery	16.64	38.58	Camden 75
Appin Formation	Camden 56	27.07	Londonderry	Nebo Colliery	25.78	45.74	Camden 78
Tongarra Coal	Wollongong 17	1.86	Londonderry	Austinmer	2.52	5.64	Mount Cotapaxi 2
Wilton Formation	Wollongong 35	28.7	Londonderry	none		100.64	Camden 75
Woonona Coal Mb	Wollongong 5	1.72	Londonderry	Thirroul	2.21	5.67	Kembla Mountain 3
CUMBERLAND SUBGROUP							
Pheasants Nest Formation	Wollongong 35	75.83	Londonderry	none		122.0	Camden 53
Figtree Coal Mb	Kembla Mtn 1	0.7	no core	Nebo Colliery	0.22	1.17	Kembla Mountain 2
Unanderra Coal Mb	Kembla Mtn 1	1.42	no core	Nebo Colliery	4.26	4.84	Kembla Mountain 2
Erins Vale Formation	Wollongong 35	53.13	Londonderry	none		119.55	Camden 63

Londonderry - Department of Mines Core Library, Londonderry
BHP# - BHP Collieries Core Library

lost before being placed in the existing core shed and that such a "loss" or "exchange" would not occur now that better storage facilities are available.

4. At least one of the type sections in DM Wollongong 35 has been left in the weather and has deteriorated to such an extent that is now of very dubious value. With better storage facilities this deterioration might not occur in the future. One question that does need an answer is — to what extent does core, especially claystone and other lithologies containing clays (especially expanding clays) deteriorate with minor wetting? Many companies and researchers wet core before logging and before photographing the core. It is possible that this act alone could lead to deterioration of the core.

5. The descriptions of the type sections given in SCCG (1971) clearly fall short of that recommended by Staines (1985) when he stated that geological descriptions "should cover thickness, lithology, palaeontology, mineralogy, structure, geomorphic expression and other geologic features..." (p. 94). In addition, few of the units have clearly defined boundaries. For example, the Wilton Formation "immediately underlies the Tongarra Coal" (p. 121). However, the Tongarra Coal is "bounded by the Appin Formation above and the Wilton Formation below" (p. 122). Nowhere is there any description that clearly signifies where the boundary between the two is located. At the type locality, the Tongarra Coal consists of coal and tuffaceous claystone overlying carbonaceous claystone. It could be argued that the carbonaceous claystone is spatially and genetically related to either the overlying coal, the underlying claystone or both.

6. If correlation between the Southern Coalfield and the Western Coalfield is to be a reality, rationalisation of the terms is needed in line with the priority guidelines. To what extent names have to be changed or deleted remains to be seen. A clear understanding of the geology is needed if any correlation is to be successful. Recent studies by Bamberry (1992) suggested that some of the units recognised in the Western Coalfield, and not previously recognised in the Southern Coalfield, may extend further to the east and southeast than previously thought. These premises have been incorporated in this document. All correlations must clearly define the lateral extent of all units.

7. The type sections were defined before geophysical logs were commonly used. A case can be argued that any change in the terms or stratigraphic boundaries of the type sections should take into account geophysical signatures, especially as many companies are using geophysical logging rather than coring holes nowadays.

Staines (1985) defined a type section as "... the original or subsequently designated type of a named stratigraphic unit..." (p. 92) that constitutes "... the standard for definition and recognition of the stratigraphic unit" (p. 92). Because the type section can be the "subsequently designated type section" (p. 92), a type section can be redefined if it is "...permanently destroyed, or it has been found to have been established in violation of accepted stratigraphic principles" (p. 93). If a new type section is to be defined, preferably it should be in the type area.

The most important criterion of a type section is that it adequately represents the essentials of the concepts for which it is the material type (Staines, 1985). A further requisite is that the type section be accessible to all who may be interested, regardless of any circumstance.

Clearly, several of the type sections for the Southern Coalfield do not meet one or more of the above criteria. These problems can be overcome in one of two ways. Firstly, the type sections could be redefined, thus creating a new holostratotype, or alternatively, it is possible to designate one or more reference sections (hypostratotypes) which are better exposed or more accessible than the original type section. In this second case the hypostratotype is subsidiary to the original holostratotype.

For the Southern Coalfield, the second option has been selected in a modified form in that one drill hole, AGL Bootleg 8 (Figure 11) has been selected as a reference drill hole. The reasons for selecting this hole include:

i. the hole is located near the central part of the basin and is therefore reasonably representative of the sequence in this region and, similarly, it is far enough away from the margins of the Sydney Basin not to show marginal facies characteristics;

ii. the core is in good condition and is housed in the DMR Core Library at Londonderry;

iii. the hole has a set of good quality geophysical logs; and

iv. all of the important units, such as major coal seams, and most of the lesser units are represented.

Drill Hole AGL Bootleg 8

In general, units of the Sydney Subgroup are well developed in AGL Bootleg 8, with the major seams developed and easily identified in core and on geophysical logs. The Pheasants Nest Formation in this hole is significantly different to the same unit in the Illawarra area. In AGL Bootleg 8 several thin coals seams occur but correlation of either of both the Unanderra Coal Member and the Figtree Coal Member is difficult.

(Note that the Penrith Sandstone Member, Balmain Coal Member, and the Dural Sandstone Member are not shown in Figure 11 nor discussed below because they were not examined by the Southern Coalfield Committee. Those members were recognised after the Southern Coalfield Committee had completed its deliberations.)

Bulli Coal. The Bulli Coal is 3.35 m thick and contains four thin claystone layers, the thickest being 0.19 m. Above the coal is a laminite, part of the Wombarra Claystone, which grades downwards to a claystone which is sideritic in part.

Loddon Sandstone. The Loddon Sandstone (27.38 m thick) consists of two packages of stacked beds of grey lithic sandstones, which contain interbedded siltstone and fine upwards to siltstone and mudstone or laminite. At the top of the lower package is a 0.71 m coal seam which contains several inferior coal beds interbedded with dark greyish brown claystone. These minor units are pelletoidal in part.

Balgownie Coal. The Balgownie Coal is 3.17 m thick with a 0. 05 m clayey bed near the base.

Lawrence Sandstone. The Lawrence Sandstone is 14.80 m thick and is composed of medium-grained lithic sandstone.

Eckersley Formation. The Eckersley Formation is 48.78 m thick and is represented by the Cape Horn Coal Member and a fine-grained sequence above the Wongawilli Coal. At the base of the Eckersley Formation is 38 m of interbedded claystone and laminite. The Novice Sandstone Member is absent.

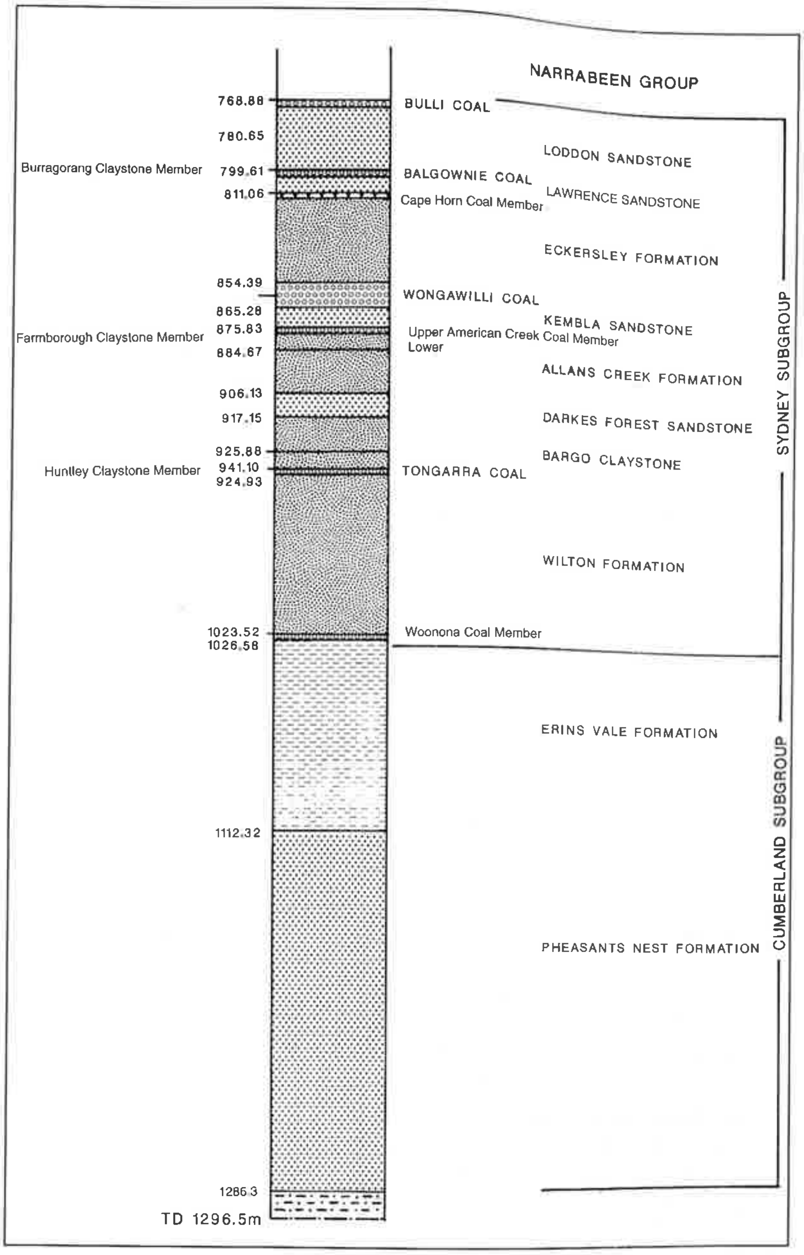

Figure 11. Stratigraphic units in AGL Bootleg 8

Wongawilli Coal. The Wongawilli Coal is 13.72 m thick and comprises an upper coal with thin claystone beds separated from a middle coal bed with thin claystone beds by 0.45 m of grey siltstone with numerous plant fragments. The Farmborough Claystone Member is 1.2 m thick and grades from a calcitic claystone at the base to the typical "sandstone band" which in turn grades through a siltstone to a buff claystone and above that a black to dark greyish brown claystone. The basal coal bed is 3.2 m thick and contains several 0.02 m to 0.10 m claystone bands.

Kembla Sandstone. The Kembla Sandstone is 10.55 m thick and consists of a basal polymictic pebble to granule conglomerate overlain by fine- to coarse-grained sandstone with a 0.02 m coaly layer near the middle.

Allans Creek Formation. The Allans Creek Formation is 29.57 m thick and consists of the upper and lower splits of the American Creek Coal Member (2.55 m and 0.73 m thick respectively), separated by 6.3 m of siltstone, laminite and claystone; and a lower 20 m sequence of interbedded laminite claystone and siltstone with a 0.06 m coaly layer near the base. Claystone beds are less than 0.01 m thick and are derived from tuffaceous detritus in part.

Darkes Forest Sandstone. The Darkes Forest Sandstone is comprised of 11.75 m of interbedded grey fine- to medium-grained sandstone and laminite with minor siltstone. Beds are 0.3 m to 1 m thick.

Bargo Claystone. The Bargo Claystone is 23.9 m thick, and contains interbedded claystone, laminite and minor siltstone. The Huntley Claystone Member is 0.7 m thick, is pale greyish brown with carbonate veins near the middle.

Tongarra Coal. The Tongarra Coal is 1.83 m thick and includes three beds of generally dull banded coal separated by two claystone layers, the upper one containing siltstone as well as claystone.

Wilton Formation. The Wilton Formation is 80.6 m thick, with an upper succession consisting of a package of fining-upwards sequences at the base overlain by a package of coarsening-upwards sequences in the middle overlain by alternating sandstone and claystone/laminite beds at the top. Overall, the unit is coarser at the top than at the bottom. The Woonona Coal Member is 3 m thick and has several thin claystone bands. Below the Woonona Coal Member is a 2.8 m sandstone with some pebbly intervals, fining up to siltstone with thin coal laminae at the top.

Erins Vale Formation. The Erins Vale Formation consists of 24.7 m of predominantly burrowed sandstone with angular polymictic, poorly-sorted conglomerate, conglomeratic sandstone and rare siltstone or claystone beds. The sandstone contains rare brachiopod shells. The basal 56.8 m is predominantly sandstone, containing sparse pebbles, with thin siltstone and claystone beds.

Pheasants Nest Formation. The Pheasants Nest Formation 174 m, to the base of the hole. It consists of interbedded sandstone, siltstone, claystone and laminite. Ten coal seams ranging in thickness from 0.2 to 3 m occur in the top 130m, with the uppermost coal being 2 m below the top of the unit. Seam thickness generally increases with depth. The two basal seams, the thickest, contain numerous claystone bands. The Pheasants Nest Formation is distinguishable from the overlying Erins Vale Formation by the lack of bioturbation, and the greater abundance of finer-grained lithologies.

REFERENCE CROSS SECTIONS

RATIONALE FOR REFERENCE CROSS SECTIONS

When revising the stratigraphic nomenclature of the northern coalfields of the Sydney Basin, the committees of the Hunter and Newcastle Coalfields used reference cross sections. Those cross sections have been selected from strategic core or outcrop such that the core or outcrop is representative of the units nearby. The reference cross sections do not substitute for the type sections but reflect lateral and vertical changes across a coalfield or coalfields. The main function of each core or outcrop on the reference cross section is that is should give the likely lithology if a hole is drilled nearby. In this way uniformity of stratigraphic names across a coalfield can be achieved.

The use of reference cross sections by the Southern Coalfield subcommittee is one way of overcoming the problems associated with the type sections. Inclusion of one or more of the recent holes, such as those of the Picton series, would show variations in the geology of the coal measures sequence towards the centre of the basin. Whether type sections were redefined or not would not affect the use of the reference cross sections.

Given the nature of the geology in the Southern Coalfield two reference cross sections (one north-south, the other east–west) have been selected. The sections cover the marginal facies to the south and southwest of the Coalfield as well as representing the deeper, more central parts of the basin.

The top of the Wongawilli Coal is used as a reference horizon because it is the topmost prominent coaly unit that is found in all holes lying on the cross sections.

The latite members have not been included in either of the sections because of their areal distribution and the lack of borehole information. No attempt has been made to name or correlate the seams in the Pheasants Nest Formation. Drill holes DM Wollongong 35 and DM Wollongong 21 do not have coaly intervals in the Pheasants Nest Formation.

North to South Cross Section

The north to south cross section (Figure 12) has AGL Bootleg 8 at the northern end, and traverses southwards through AGL Bootleg 9, DM Picton 3, AGL Moonshine 7A, DM Wollongong 35, DM Wollongong 21, Elecom Huntley 7, Elecom Huntley Robertson 6C, with the southernmost drill hole being Elecom ER9. The depths to the tops of the formations and coal units are given in Table 2.

The most notable features are the thickening of clastic units towards the north, the lack of the Bulli Coal in the Robertson area and the poor discrimination between the Wilton Formation and the Pheasants Nest Formation. The Erins Vale Formation pinches out southwards at Mount Kembla and is therefore not recognised in the Robertson area.

West to East Cross Section

This west to east cross section (Figure 13) has DM Oakdale 1 as the westernmost hole and passes eastwards through DM Picton 1, linking with the north-south cross section through DM Picton 3 and AGL Moonshine 7A and proceeding eastwards through DM Camden 53 and DM Wollongong 45. The easternmost datum is a measured composite outcrop section on the Illawarra coast. The measured section does not give the complete stratigraphic section but is a useful end point from an historical aspect. Table 3 gives the depths to the tops of the formations and coal units.

ACKNOWLEDGMENTS

One presentation on the stratigraphy of the Southern Coalfield was made to meetings of the Standing Committee on Coalfield Geology of New South Wales during preparation of this report and a second presentation was made to the Standing Committee after completion of the report. The Southern Coalfield Subcommittee thanks those Standing Committee members who provided relevant discussion and constructive criticism at the meetings. We also acknowledge and thank those members who presented written comment when the final draft was circulated prior to ratification.

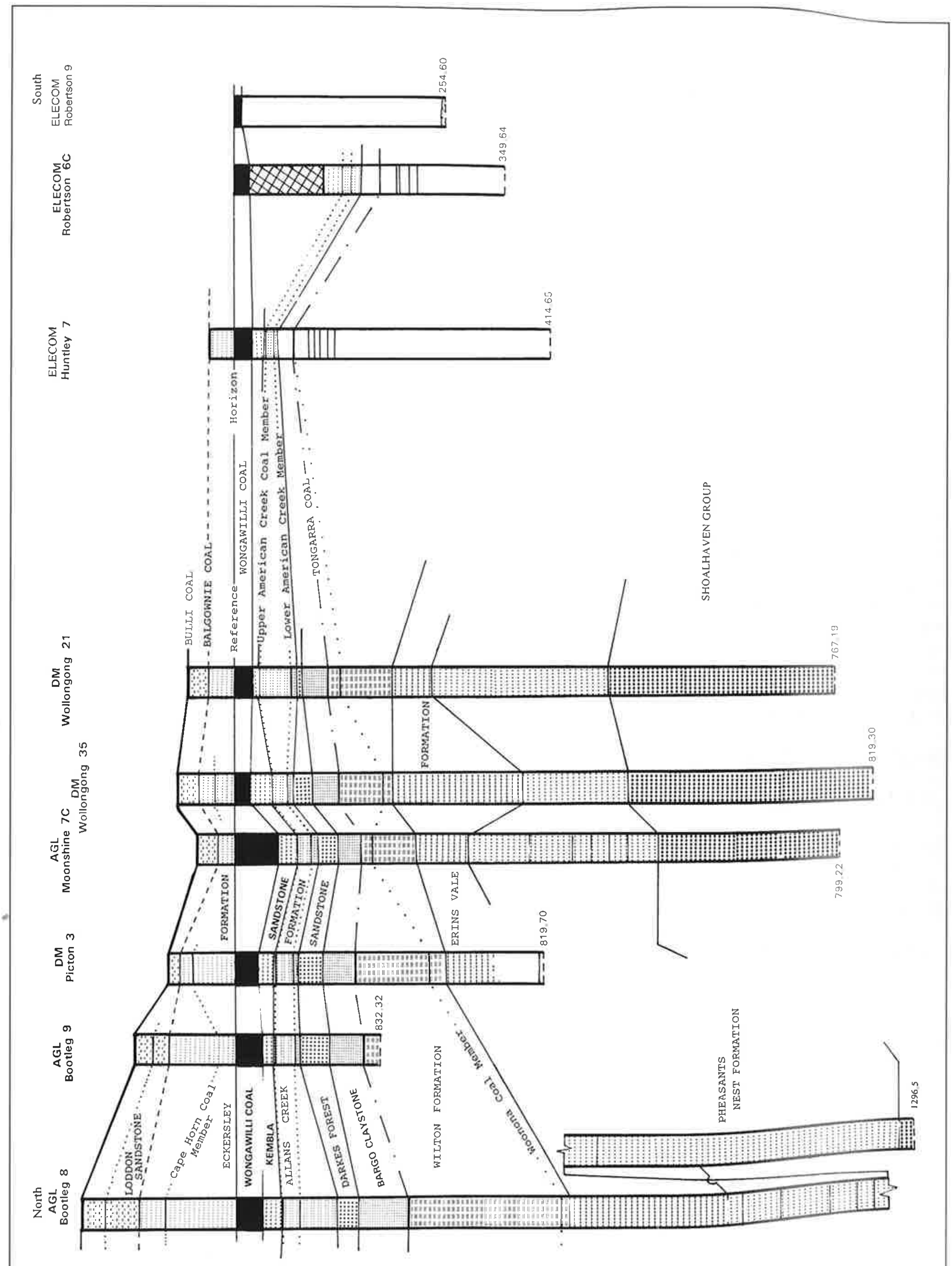

Figure 12. North to south cross-section through the Southern Coalfield

TABLE 2. DEPTHS TO TOPS OF UNITS, NORTH-SOUTH CROSS SECTION

Unit	Drill Hole								
(Depth in metres)	Boot 8	Boot 9	Pic 3	Moon 7A	Wol 35#	Wol 21#	Hunt 7	ER 6C	ER 9
BULLI COAL	768.88	701.60	18.42	457.98	447.46	423.71	-	-	-
BALGOWNIE COAL	799.61	710.62	25.15	469.41	458.92	433.71	232.71	-	-
Eckersley Formation	802.78	713.02	625.92	470.21	460.20	434.89	233.44	-	-
WONGAWILLI COAL	851.56	755.41	654.19	487.94	481.31	447.87	247.12	205.42	155.60
Kembla Sandstone	865.28	770.29	666.97	501.72	489.99	455.85	256.33	253.95?	161.22
Allans Creek Formation	875.83	776.52	676.80	510.20	498.98	461.78			
U/American Ck Coal Mb	875.83	776.52	676.80	511.40	498.48	461.78	252.61	263.46	-
L/American Ck Coal Mb	885.40	784.75	684.09	518.20	506.00	477.96	-	-	-
Darkes Forest Sandstone	905.39	791.61	684.60	523.11	509.96	478.02	266.51	257.48	-
Bargo Claystone	917.15	806.81	700.63	534.00	518.90	479.79			
TONGARRA COAL	941.10	823.07	717.91	543.97	531.48	497.76	277.60	282.91	-
Wilton Formation	942.93	827.46	720.16	545.98	533.36	499.74	286.00	291.09	-
Woonona Coal Mb	1023.52	-	757.47	551.49	556.61	505.54	286.49	293.78	?
Erins Vale Formation	1029.35	-	-	574.73	562.06	533.24	?	?	?
Pheasants Nest Formation	1114.33	-	-	603.89	615.19	554.85	?	?	?
Shoalhaven Group	1248.37	-	-	703.03	688.06	649.21			
Total Depth	1296.45	832.32	819.70	799.22	819.30	767.49	414.65	349.64	254.6

- Log originally recorded in feet and inches
? - Correlation uncertain

Abbreviations for Drill Holes
Boot 8 - AGL Bootleg 8; Boot 9 - AGL Bootleg 9; Pic 3 - DM Picton 3; Moon 7A - AGL Moonshine 7A;
Wol 35# - DM Wollongong 35; Wol 21# - DM Wollongong 21; Hunt 7 - Elecom Huntley 7; ER 6C - Elecom Robertson 6C;
ER 9 - Elecom Robertson 9.

<u>Note</u>: Although not defined as two stratigraphic units, the American Creek Coal Member commonly is divided into the Upper American Creek Coal Member and Lower American Creek Coal Member by many geologists. This terminology is used here because the two are good marker beds.

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TABLE 3. DEPTHS TO TOPS OF UNITS, WEST-EAST CROSS SECTION.

Unit	Drill Hole						
(Depth in metres)	Oak 1	Pic 1	Pic 3	Moon 7A	Cam 53#	Wol 45#	Comp. Sect.
BULLI COAL	380.58	456.14	618.42	457.98	460.53	366.80	0.00
BALGOWNIE COAL	390.59	463.11	625.15	469.41	474.94	376.78	9.07
Eckersley Formation	390.72	463.80	625.92	470.21	476.52	379.00	9.77
WONGAWILLI COAL	407.38	486.85	654.19	487.94	491.77	400.02	27.34
Kembla Sandstone	412.45	493.66	666.97	501.72	500.20	408.58	37.54
Allans Creek Formation	429.25	511.63	676.80	510.20	511.41	416.19	-
Upper American Ck Coal Mb	429.25	513.74	676.80	511.40	511.41	416.19	55.04
Lower American Ck Coal Mb	462.84	518.89	684.09	518.20	524.47	-	57.04
Darkes Forest Sandstone	463.33	519.11	684.60	523.11	524.80	433.28	57.64
Bargo Claystone	470.73	525.95	700.63	534.00	536.47	437.06	-
TONGARRA COAL	502.16	539.55	717.91	543.97	550.30	454.33	80.89
Wilton Formation	507.38	543.71	720.16	545.98	552.23	456.17	83.16
Woonona Coal Mb	516.67	580.61	757.47	551.49	560.59	65.46	106.68
Erins Vale Formation	-	582.45	-	574.73	588.85-	-	-
Pheasants Nest Formation	-	587.24	-	603.89	709.20	-	-
Shoalhaven Group	522.45	649.31	-	703.03	827.17	-	-
Total Depth	634.39	800.05	819.70	799.22	908.91	500.79	-

- Log originally recorded in feet and inches

Abbreviations for Drill Holes
Oak 1 - DM Oakdale 1; Pic 1 - DM Picton 1; Pic 3 - DM Picton 3; Moon 7A - AGL Moonshine 7A;
Cam 53 - DM Camden 53; Wol 45# - DM Wollongong 45; Comp Sect - Composite coastal outcrop section.

Note: Although not defined as two stratigraphic units, the American Creek Coal Member commonly is divided into the Upper American Creek Coal Member and Lower American Creek Coal Member by many geologists. This terminology is used here because the two are good marker beds.

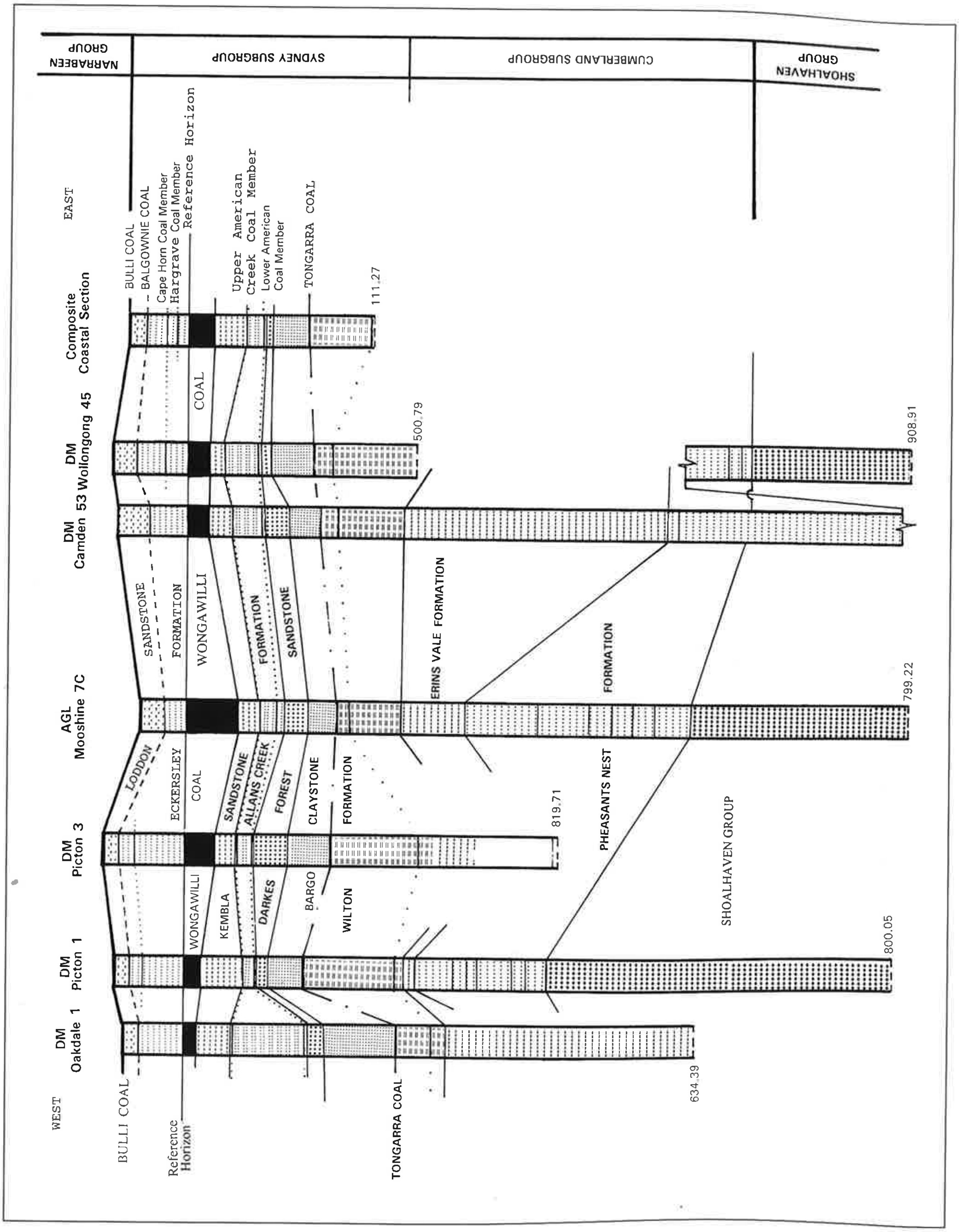

Figure 13. East to west cross-section through the Southern Coalfield

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PART B - DEFINITIONS OF UNITS IN THE ILLAWARRA COAL MEASURES, SOUTHERN COALFIELD

NOTES:

1. In 1971 the Standing Committee for Coalfield Geology (SCCG) published the definitions for the Southern Coalfield. These definitions are used as the basis for the definitions in this document. The names of organisations that house drill core have been left the same as those published by the SCCG.

2. Most of the interval thickness given below were originally given in feet and inches. These have been converted to metres.

PHEASANTS NEST FORMATION

Derivation: Pheasants Nest Pass, Nepean River

Previous Usage: SCCG (1971)

Type Section: Outcrop: none

Core (1) Location: DM Wollongong DDH 35 — 615.19 m to 691.02 m (GR 271 691E, 1 207 684N Bulli 1:25 000 topographic map, 9029-II-N)

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Coarse- to fine-grained lithic sandstone, siltstone and claystone with lenticular coal seams and minor tuffaceous claystone and latite flows. In the southeastern portion of the Southern Coalfield, it contains abundant very coarse-grained lithic sandstone and granule conglomerate beds with coal seams and the Five Islands Latite Member, the Calderwood Latite Member, the Minnamurra Latite Member and the Berkeley Latite member. At Mount Kembla, it contains the Unanderra and Figtree Coal Members.

Thickness: (1) Type Section: 75.83 m

(2) Range: <1m to 122 m

Distribution: Occurs throughout most of the Southern Coalfield but to the west and southwest of the Coalfield it is overlapped by the Sydney Subgroup.

Stratigraphic Limits: Base is gradational and is placed at the top of the uppermost marine sandstone of the Shoalhaven Group following the lowermost coal or carbonaceous claystone. In the southeastern part of the Southern Coalfield, the base is placed at the top of the Cambewarra Latite Member.

FIVE ISLANDS LATITE MEMBER

Derivation: Five Islands, east of Wollongong

Previous Usage: Five Islands Flow (Harper, 1915)

Type Section: Not defined

Lithology: Porphyritic, holocrystalline, dark grey to black shoshonitic basaltic andesite (latite) with phenocrysts 1.5 mm to 4 mm diameter. Phenocrysts generally comprise plagioclase, clinopyroxene (commonly zoned) and titanomagnetite; also chlorite pseudomorphs after olivine. Also has pillow structures up to 1 m diameter.

Thickness: Thickness not known as base not exposed.

Distribution: Single outcrop on Flinders Island, northernmost island of the Five Islands, east of Wollongong.

Stratigraphic Limits: Restricted in outcrop to Flinders Island. Maximum separation from the underlying Dapto Latite Member estimated to be 90 m. Relationship to other latite members of the Pheasants Nest Formation is unknown.

CALDERWOOD LATITE MEMBER

Derivation: Village of Calderwood

Previous Usage: New name. Some outcrops mapped as Saddleback Latite (Jaquet et al, 1905 and Lowder, 1964) and Dapto Latite (Bowman, 1970; 1974)

Type Section: Not defined

Lithology: Porphyritic, holocrystalline, dark grey or black shoshonitic basaltic andesite (latite) with phenocrysts 1.5 mm to 4 mm diameter. Phenocrysts generally comprise plagioclase, clinopyroxene and titanomagnetite; also chlorite pseudomorphs after olivine.

Thickness: Range: Maximum thickness of 38 m near Calderwood (GR 908728; Robertson 1:25 000 topographic map sheet 9028-IV-N, 1st Edition)

Distribution: Crops out discontinuously from the northeastern side of Stockyard Mountain towards the north-northwest for approximately 9 km. Subsurface distribution not known.

Stratigraphic Limits: Occurs 3 m stratigraphically above the Cambewarra Latite Member of the Broughton Formation. Volcaniclastic material in the sedimentary rocks above and below the unit is possibly equivalent to Bowman's (1974) Tapitallee Mountain Tuff Member.

MINNAMURRA LATITE MEMBER

Derivation: Minnamurra River

Previous Usage: Previously the Minumurra Flow (Jaquet et al, 1905; Harper, 1915), Minumurra Latite (Joplin et al, 1952) and Minnamurra Latite (Lowder, 1964; Raam, 1969; Bowman, 1970, 1974).

Type Section: Not defined

Lithology: Grey, dark grey to black porphyritic shoshonitic basalt (latite) with phenocrysts of plagioclase, clinopyroxene, titanomagnetite and chlorite pseudomorphs after olivine. Phenocrysts in aggregates giving glomeroporphyritic texture and may be vesicular or amygdaloidal. Groundmass commonly contains analcite.

Thickness: Range: Maximum thickness of 13 m

Distribution: Outcrops as a discontinuous sheet from the northern side of Saddleback Mountain to a point 15 km west of Point Kembla. Subsurface distribution not known.

Stratigraphic Limits: The Minnamurra Latite Member occurs approximately 40 m above the base of the Pheasants Nest Formation. The top of the unit has an undulating surface with local relief of up to 0.5 m.

BERKELEY LATITE MEMBER

Derivation: Suburb of Berkeley, Wollongong

Previous Usage: Previously described by Card (1907) as the Berkeley Flow; the Berkley Flow (by Harper (1915); the Berkley Latite (by Joplin et al, 1952); and the Berkeley Latite (by McElroy, 1952; Raam, 1969; and Bowman, 1970, 1974).

Type Section: Not defined

Lithology: Grey, dark grey to black porphyritic shoshonitic basalt (latite) with phenocrysts of plagioclase, clinopyroxene, titanomagnetite and chlorite pseudomorphs after olivine. Phenocrysts in aggregates giving glomeroporphyritic texture, may be vesicular or amygdaloidal.

Thickness: Range: Maximum thickness of 35 m in the Figtree area

Distribution: Crops out at Figtree and to the north-northeast for approximately 1.5 km, Mount Kembla and Flagstaff Hill (Port Kembla) and to the west and east for approximately 2 km

Stratigraphic Limits: Base of the unit occurs 15 m to 40 m above the base of the Pheasants Nest Formation at approximately the same stratigraphic level as the Minnamurra Latite Member. Two flows, separated by 3 m of lithic sandstone, are recognised in the Figtree area (GR 026875; Wollongong 1 : 25 000 topographic map sheet 9029-II-S, 1st Edition).

UNANDERRA COAL MEMBER

Derivation: Unanderra, suburb of city of Wollongong

Previous Usage: Called the Unanderra seam by the Joint Coal Board (unpublished)

Type Section: Outcrop: Nebo Colliery, Mount Kembla, in a creek east of the colliery haulage portal.

Core: (1) Location: Kembla Mountain No 1 (GR 281280 E, 1 186 906N; Wollongong 1:25 000 topographic map 9029-II-S)

(2) Repository: No core available

Lithology: Shale and coal

Thickness: (1) Type Section: Outcrop: 4.27 m
Core: 1.42 m

(2) Range: 0 to 4.84 m; maximum thickness in Kembla Mountain No 2 (GR 282290E, 1 186 700N; Wollongong 1 : 25 000 topographic map 9029-II-S)

Distribution: Maximum development in the Mount Kembla area. Correlation across the Southern Coalfield is difficult at present due to lack of outcrop and drillhole intersections.

Stratigraphic Limitations: Lowermost coaly unit in the Pheasants Nest Formation.

FIGTREE COAL MEMBER

Derivation: Figtree, suburb of city of Wollongong cf Cordeau seam by the Joint Coal Board (unpublished)

Type Section: Outcrop: Nebo Colliery, Mount Kembla, in a creek east of the colliery haulage portal.

Core: (1) Location: Kembla Mountain No 1 (GR 281280E, 1 186 906N; Wollongong 1:25 000 topographic map 9029-II-S)

(2) Repository: No core available

Lithology: Coal and carbonaceous shale

Thickness: (1) Type Section: Outcrop: 0.22 m
Core: 0.71 m

(2) Range: 0 to 1.18 m; maximum thickness in Kembla Mountain No 2 (GR 282290E, 1 186 700N; Wollongong 1:25 000 topographic map 9029-II-S)

Distribution: Maximum development in the Mount Kembla area. Correlation across the Southern Coalfield is difficult at present due to lack of outcrop and drillhole intersections.

Stratigraphic Limitations: Occurs at least 10 m above the Unanderra Coal Member.

ERINS VALE FORMATION

Derivation: Erins Vale property, Parish of Wilton

Previous Usage: SCCG (1971)

Type Section: Outcrop: none

Core: (1) Location: DM Wollongong DDH 35 — 562.06 m to 615.19 m (GR 271 691E, 1 207 683N Bulli 1:25 000 topographic map, 9029-II-N)

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Fine- to medium-grained, commonly bioturbated, silty, lithic sandstone with minor dark siltstone or mudstone interbeds. The upper portion of the unit is conglomeratic in the central portion of the Southern Coalfield whereas, in coastal outcrops, the uppermost beds consist of medium-grained, well-sorted sandstone.

Thickness: (1) Type Section: 53.13 m

(2) Range: <1 m to 120 m

Distribution: Occurs mostly in the eastern half of the Southern Coalfield; to the west, southwest and south, it is overlapped by the Sydney Subgroup

Stratigraphic Limits: The Erins Vale Formation is gradational with the uppermost Pheasants Nest Formation; the base is placed at the top of the uppermost coal or carbonaceous layer of the Pheasants Nest Formation or where these lithologies are absent, at the top of the uppermost extensive siltstone or claystone layer. The top of the Erins Vale Formation is marked by the erosive base of the Marrangaroo Conglomerate (western area) or the Thirroul Sandstone (eastern area) or the Wilton Formation (central and northern area).

MARRANGAROO CONGLOMERATE

Derivation: Marrangaroo railway station, Parish of Marrangaroo

Previous Usage: SCCG (1986)

Type Section: Outcrop: none

Core: (1) Location: Austen and Butta Hartley Vale DDH 3 — 250.12 m to 253.94 m (GR 224 552E, 1 291 973N, Lithgow 1:50 000 map sheet)

(2) Repository: NSW Department of Mineral Resources Core library, Londonderry

Lithology: Lithic–quartz to quartz–lithic, pebbly coarse-grained sandstone, locally a pebble or cobble conglomerate; minor claystone and siltstone; a few coaly stringers; commonly locally contains a thick bed of framework conglomerate in the basal part of the unit; locally the Marrangaroo Conglomerate and Blackmans Flat Conglomerate merge, forming a thick sandstone unit.

Thickness: (1) Type Section: 3.82 m

(2) Range: <1 m to 16 m

Distribution: Widespread unit along the western margin of the Sydney Basin (including both Southern and Western Coalfields) but wedges towards the eastern part of the basin.

Stratigraphic Limits: Conformably overlain by the Lithgow Coal Member (Western Coalfield) or Woonona Coal Member (Southern Coalfield); commonly has an erosive basal contact with the coaly sediments of the Nile Subgroup (Western Coalfield) or Pheasants Nest Formation (Southern Coalfield), sandy siltstones of the Berry Formation or marine sandstones of the Erins Vale Formation (eastern part of Southern Coalfield).

THIRROUL SANDSTONE (new formation)

Derivation: Thirroul township, now a suburb of Wollongong

Previous Usage: New name

Type Section: Outcrop: Southern end of Thirroul Beach (GR 294 100E, 1 201 100N, Bulli 1:25 000 topographic map, 9029-II-N)

Core: none

Lithology: Very coarse to fine-grained lithic sandstone with minor siltstone, claystone and granule conglomerate. The sandstone is a chert arenite in the Thirroul–Woonona area, and a volcarenite in the Mount Kembla area.

Thickness: (1) Type Section: 1.5 m

(2) Range: 0 to 2 m

Distribution: Developed in the eastern part of the Southern Coalfield. Where the Erins Vale Formation wedges out, the Thirroul Sandstone merges southwards with the upper units of the Pheasants Nest Formation. The Thirroul Sandstone lenses out westwards.

Stratigraphic Limits: Erosively overlies the Erins Vale Formation. South of Mount Kembla, where the Erins Vale Formation wedges out. The Thirroul Sandstone overlies lithic sandstone and conglomerate of the Pheasants Nest Formation.

WILTON FORMATION

Derivation: Village of Wilton, Parish of Wilton

Previous Usage: SCCG (1971)

Type Section: Outcrop: none

Core: (1) Location: DM Wollongong DDH 35 — 533.36 m to 562.06 m, (GR 271 691E, 1 207 683N, Bulli 1:25,000 topographic map, 9029-II-N))

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Bioturbated, dark-coloured claystone and siltstone with subordinate fine-to medium-grained sandstone interbeds and coal.

Thickness: (1) Type Section: 28.7 m
(2) Range: <1 m to 101 m

Distribution: Occurs over most of the northern half of the Southern Coalfield. The Wilton Formation becomes sandier towards the western and southern parts of the basin, where it is recognised as the Wanganderry Sandstone Member.

Stratigraphic Limits: The Wilton Formation includes the Woonona Coal Member and Wanganderry Sandstone Member. It is overlain by the Tongarra Coal and the top of the Wilton Formation is taken as the base of the Tongarra Coal Member. The base of the Wilton Formation is taken as the base of the Woonona Coal Member; where the Woonona Coal Member is absent, the base of the Wilton Formation is taken as the top of the uppermost massive sandstone of the Erins Vale Formation or the Thirroul Sandstone or the top of the uppermost stratum of the Marrangaroo Conglomerate.

WOONONA COAL MEMBER

Derivation: Woonona, suburb of Wollongong

Previous Usage: Seam defined by Hanlon (1956a)

Type Section: Outcrop: midway along outcrop, old rock pool, southern end of Thirroul Beach

Core: (1) Location: DM Wollongong DDH 5 — 338.52 m to 340.73 m
(GR 254410E, 1 196 162N, Hilltop 1:25 000 topographic map, 8929-II-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Coal, carbonaceous claystone and tuffaceous claystone.

Thickness: (1) Type Section: Outcrop — 2.21 m
Core — 1.72 m
(2) Range: <1 m to 5.67 m

Distribution: Developed over most of the northern part of the Southern Coalfield but absent over much of the central part of the Coalfield; merges with the Tongarra Coal to the south of Avondale Colliery.

Stratigraphic Limits: In the eastern part of the Southern Coalfield, the Woonona Coal Member occurs at the base of the Wilton Formation, overlies the basal sandstone bed of the Wilton Formation or in the western part of the coalfield, overlies the Marrangaroo Conglomerate; along the western margin of the coalfield, the Woonona Coal Member is overlain by the Wanganderry Sandstone Member of the Wilton Formation.

WANGANDERRY SANDSTONE MEMBER (new member)

Derivation: Parish of Wanganderry

Previous Usage: New name

Type Section: Outcrop: section near tunnel, Wombeyan Caves Road, west of Mittagong
(GR 228240E, 1 198 500N, Barrallier 1:25 000 topographic map, 8929-III-N)

Core: none

Lithology: Medium- to very coarse-grained quartzose sandstone, with rare bands of carbonaceous siltstone and claystone, and pebble conglomerate

Thickness: (1) Type Section: 5.61 m
(2) Range: 0 to 22 m

Distribution: Western margin of the Southern Coalfield, recognised as far south as Mount Penang, west of Moss Vale

Stratigraphic Limits: Erosively overlies the Woonona Coal Member, merges laterally eastwards into the top of undifferentiated Wilton Formation. Overlain by the Tongarra Coal.

TONGARRA COAL

Derivation: Tongarra Creek

Previous Usage: Harper (1915), SCCG (1971)

Type Sections: Outcrop: Bells Point, Austinmer

Core: (1) Location: DM Wollongong DDH 17 — 441.20 to 443.07 m
(GR 263279E, 1 202 380N, Bargo 1:25 000 topographic map, 9029-IV-S)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Coal, carbonaceous claystone and tuffaceous claystone

Thickness: (1) Type Section: Outcrop — 2.52 m
Core: — 1.86 m
(2) Range: <1 m to 5.64 m

Distribution: Developed over most of the Southern Coalfield except in the southwest; between Burragorang and Hilltop, the Tongarra Coal is split by interbedded lithic-quartz sandstone, siltstone and carbonaceous claystone; in the Avon–Wongawilli area, the Tongarra Coal is split by lithic-quartz sandstone up to 14 m thick. Within the Tongarra Colliery area, the Tongarra Coal contains lithic sandstone beds

Stratigraphic Limits: The Tongarra Coal conformably overlies the Wilton Formation and is overlain by the Austinmer Sandstone Member (where developed) or claystone and siltstone of the Bargo Claystone. South of Avondale Colliery, the Tongarra Coal merges with the Woonona Coal Member.

BARGO CLAYSTONE

Derivation: Bargo township

Previous Usage: SCCG (1971), formerly Bargo Claystone Member

Type Section: Outcrop: East of Nebo Colliery haulage portal, Mount Kembla

Core: (1) Location: DM Camden DDH 56 — 565.32 m to 580.52 m
(GR 283457E, 1 213 646N, Appin 1:25 000 topographic map, 9026-I-S)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Dark grey to black, interlaminated bioturbated claystone and siltstone

Thickness: (1) Type Section: Outcrop — 16.64 m
Core — 15.20 m
(2) Range: <1 to 38.58 m

Distribution: Occurs throughout the Southern Coalfield.

Stratigraphic Limits: Conformably overlies the Tongarra Coal and is overlain by the Darkes Forest Sandstone; contains the Austinmer Sandstone (eastern Southern Coalfield only) and Huntley Claystone Members near the base of the unit.

AUSTINMER SANDSTONE MEMBER

Derivation: Austinmer township

Previous Usage: Bowman (1970)

Type Section: Outcrop none

Core: (1) Location: DM Camden DDH 54, 460.43 to 463.22 m
(GR 287319E, 1 209 422N, Appin 1:25 000 topographic map, 9029-I-S)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Fine-grained sandstone, siltstone and claystone, generally represented by an interlaminated sequence of sandstone, siltstone and claystone showing soft sediment deformation structures

Thickness: (1) Type Section: 2.79 m
(2) Range: <1 m to 4 m

Distribution: Sporadic development throughout the Southern Coalfield, mostly in the eastern parts

Stratigraphic Limits: Occurs within the lower half of the Bargo Claystone, commonly several metres below the Huntley Claystone Member. Commonly overlies the Tongarra Coal but may be several metres above that unit.

HUNTLEY CLAYSTONE MEMBER (new member)

Derivation: Huntley Colliery, near Mount Murray

Previous Usage: None

Type Section: Outcrop: none

Core: (1) Location: DM Wollongong DDH 21 — 491.55 to 492.22 m (GR 276350E, 1 200 730N, Bulli 1:25 000 topographic map, 9029-II-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Tuffaceous claystone

Thickness: (1) Type Section: 0.67 m
(2) Range: 0.6 m to approximately 1 m

Distribution: Occurs throughout most of the Southern Coalfield.

Stratigraphic Limits: Occurs within the lower half of the Bargo Claystone and usually several metres above the Austinmer Sandstone Member.

DARKES FOREST SANDSTONE

Derivation: Darkes Forest village

Previous Usage: SCCG (1971)

Type Section: Outcrop: east of Nebo Colliery haulage portal, Mount Kembla

Core: (1) Location: DM Camden DDH 56, 553.54 to 565.41 m (GR 282457E, 1 213 646N 00N, Appin 1:25 000 topographic map, 9026-I-S)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Medium- to fine-grained lithic sandstone with subordinate siltstone and claystone interbeds.

Thickness: (1) Type Section: Outcrop — 9.14 m
Core — 11.87 m
(2) Range: <1 m to 24.07 m

Distribution: Occurs throughout most of the Southern Coalfield, except in the southwestern and western parts

Stratigraphic Limits: The top of the Darkes Forest Sandstone is placed at the base of the lower coaly sequence of the Allans Creek Formation and the base is placed at the top of the Bargo Claystone.

ALLANS CREEK FORMATION

Derivation: Allans Creek

Previous Usage: Bunny (1969), (SCCG, 1971) although the unit was previously incorrectly referred to as the American Creek Formation

Type Section: Outcrop: east of the Nebo Colliery haulage portal, Mount Kembla

Core: (1) Location DM Camden DDH 78, 763.32 to 807.95 m (GR 299717E, 1 228 218N, Port Hacking 1:25 000 topographic map, 9129-IV-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Medium- to fine-grained quartz-lithic sandstone, siltstone, claystone, coal, carbonaceous claystone and tuffaceous claystone. Two or more coaly intervals, separated by clastic beds occur in this unit; toward the southern and western parts of the Southern Coalfield, the coaly intervals merge to form one seam; towards the northeastern part of the Coalfield, the sandstone beds between the coal thicken.

Thickness: (1) Type Section: Outcrop — 6.99 m
Core — 44.65 m
(2) Range: <1 m to 44.65 m

Distribution: Occurs throughout most of the Southern Coalfield but is poorly represented in the far southern and western parts.

Stratigraphic Limits: The Allans Creek Formation contains the American Creek Coal Member and the base of the unit is taken as the lowermost coaly sequence of that member. The top of the unit is taken as the erosive base of the Kembla Sandstone.

AMERICAN CREEK COAL MEMBER

Derivation: American Creek, Wollongong

Previous Usage: American Creek seam (Hanlon, 1956a)

Type Section: Outcrop: Nebo Colliery, Mount Kembla, east of the colliery haulage portal (GR 287080E, 1 191 075N, Wollongong 1:25 000 topographic map, 9029-II-S)

Core: none

Lithology: Generally interbedded claystone, carbonaceous shale and coal shale; commonly two splits

Thickness: (1) Type Section: Outcrop — Upper split 4.45 m thick and separated from the 0.20 m lower split with 0.99 m
Core — none

(2) Range: Top split ,0.5 m up to 4.45 m thick; bottom split generally thinner.

Distribution: Originally only recognised at the type section outcrop (SCCG, 1971) but since been found to be quite widespread.

Stratigraphic Limits: Upper split sometimes ocurs at the top of the Allans Creek Formation in some localites.

KEMBLA SANDSTONE

Derivation: Mount Kembla

Previous Usage: Unit was called the 'Kembla Greywacke Member' by Hanlon (1956b)

Type Sections: Outcrop: Near water pipeline from Avon Dam at West Dapto

Core: (1) Location: DM Camden 68, 681.37 to 699.17 m (GR 291860E, 1 222 502N, Campbelltown 1:25 000 topographic map, 9026-I-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Very coarse- to medium-grained lithic sandstone with interbeds of claystone and siltstone; abundant fossil plant debris; the Kembla Sandstone commonly is a fining-upward unit in which the top part of the unit is mostly interbedded claystone and siltstone

Thickness: (1) Type Section: Outcrop — 12.30 m
Core: — 17.82 m
(2) Range: <1 m to 23.79 m

Distribution: Occurs throughout the Southern Coalfield.

Stratigraphic Limits: The base of the Kembla Sandstone is taken as the erosive basal contact with the Allans Creek Formation. The top is marked by the lowermost coaly or carbonaceous layer of the Wongawilli Coal.

WONGAWILLI COAL

Derivation: Wongawilli Colliery, Parish of Wongawilli

Previous Usage: Hanlon (1956a); previously referred to informally as the Dirty or No. 3 seam

Type Section: Outcrop: near water pipeline from Avon Dam, West Dapto

Core: (1) AIS Nebo 10, 104.90 m to 114.04 m (GR 279646E, 1 190 588N, Wollongong 1:25 000 topographic map, 9029-II-S)
(2) Repository: Core no longer available

Lithology: Coal, carbonaceous claystone, siltstone and tuffaceous claystone.

Thickness: (1) Type Section: Outcrop — 8.26 m
Core — 9.15 m
(2) Range: <1 m to 11.21m

Distribution: Developed throughout the Southern Coalfield.

Stratigraphic Limits: The base of the unit is taken as the base of the lowermost carbonaceous claystone or coal. The top is taken at the top of the topmost continuous coal interval; the top may be gradational with the overlying Eckersley Formation. Near Berrima, the Wongawilli Coal is overlain by the Hawkesbury Sandstone. The Wongawilli Coal contains the Farmborough Claystone Member.

FARMBOROUGH CLAYSTONE MEMBER (new member)

Derivation: Farmborough Heights

Previous Usage: New name; unit previously referred to, informally, as the "three-foot band" (Harper, 1915) or the "sandstone band"

Type Section: Outcrop: none

Core: (1) Location: Wollongong DDH 21 — 449.64 to 450.73 m (GR 276350E, 1200730N, Bulli 1:25 000 topographic map, 9029-II-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Tuffaceous claystone or siltstone. The Farmborough Claystone Member is uniform in thickness but thins slightly in the western and southwestern parts of the Southern Coalfield. The term sandstone is related to the texture of the claystone and siltstone which contain abundant siderite aggregates up to 1 mm diameter. Contains up 0.26 m shaly coal in South Bulli Colliery.

Thickness: (1) Type Section: 1.09 m
(2) Range: <1 m to 2 m

Distribution: Occurs throughout the Southern Coalfield.

Stratigraphic Limits: The base of the unit occurs within four to six metres of the base of the Wongawilli Coal.

ECKERSLEY FORMATION (Redefined)

Derivation: Eckersley Point

Previous Usage: SCCG (1971)

Type Section: Outcrop: none

Core: (1) Location: DM Camden DDH 78 — 630.85 to 752.81 m (GR 299717E, 1 228 218N, Port Hacking 1:25 000 topographic map, 9129-IV-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Claystone, siltstone, coal, carbonaceous claystone and lithic sandstone; the Eckersley Formation comprises coarsening-upward sequences dominated by siltstone and claystone with subordinate medium-grained sandstone and coal.

The Eckersley Formation contains the following members, Cape Horn Coal Member, Hargrave Coal Member, Woronora Coal Member and Novice Sandstone Member.

Thickness: (1) Type Section: core: 121.94 m
(2) Range: <1 m to 122 m (122.02 m)

Distribution: Occurs throughout most of the Southern Coalfield. Overlapped by the Narrabeen Group or Hawkesbury Sandstone in the southwestern part of the Southern Coalfield.

Stratigraphic Limits: The Eckersley Formation conformably overlies the carbonaceous units of the Wongawilli Coal. The base of the unit is taken as the top of the uppermost coal or carbonaceous layer of the Wongawilli Coal. The top of the unit is taken as the top of the Cape Horn Member.

NOVICE SANDSTONE MEMBER

Derivation: Novice Trigonometrical Station

Previous Usage: SCCG (1971)

Type Section: Outcrop: none

Core: (1) Location: DM Camden DDH 78 — 705.83 to 742.96 m (GR 299717E, 1 228 218N, Port Hacking 1:25 000 topographic map, 9129-IV-N)
(2) Repository: NSW Department of Mineral Resources Core library, Londonderry

Lithology: Fine to medium grained lithic sandstone with minor conglomerate.

Thickness: (1) Type Section: 37.13 m
(2) Range: <1 m to 37.13 m

Distribution: Occurs in the northeastern part of the Southern Coalfield and is confined to the subsurface.

Stratigraphic Limits: The top of the unit is taken as the base of the Woronora Coal Member and the base is the top of the Wongawilli Coal.

WORONORA COAL MEMBER

Derivation: Woronora River

Previous Usage: SCCG (1971)

Type Section: Outcrop: none

Core: (1) Location: DM Camden DDH 78 — 694.58 m to 705.83 m (GR 299717E, 1 228 218N, Port Hacking 1:25 000 topographic map, 9129-IV-N)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Coal, carbonaceous claystone and fine-grained sandstone. The Woronora Coal Member merges with other rocks of the lower Eckersley Formation in the southwestern and western parts of the Southern Coalfield.

Thickness: (1) Type Section: 11.25 m
(2) Range: <1 m to 11.90 m

Distribution: Subsurface unit in the northern and eastern parts of the Southern Coalfield where its subcrop approximates that of the Novice Sandstone Member.

Stratigraphic Limits: The base of the Woronora Coal Member is taken as the top of the Novice Sandstone Member although a transitional sequence commonly occurs between the two units. The top of the unit is taken as top of the uppermost coal or carbonaceous unit.

HARGRAVE COAL MEMBER

Derivation: Lawrence Hargrave Drive, northern suburbs of Wollongong

Previous Usage: SCCG (1971); unit called Hargrave seam by Hanlon (1956b)

Type Sections: Outcrop: Cape Horn, Clifton, Scarborough

Core: (1) Location: Metropolitan Colliery No. 10 — 525.3 m to 525.4 m (GR 295876E, 1 215 519N, Appin 1:25 000 topographic map 9029-I-S)
(2) Repository: Australian Iron and Steel Coal Geology Department; core not available

Lithology: Coal and carbonaceous claystone.

Thickness: (1) Type Section: Outcrop — 0.46 m
Core — 0.1 m
(2) Range: <0.1 m to 0.46 m

Distribution: Northern and eastern parts of the Southern Coalfield; difficult to recognise north of the Woronora Anticline where several splits have been recorded.

Stratigraphic Limits: Occurs above the Woronora Coal Member and usually 1.5 m to 3 m below the base of the Cape Horn Member.

CAPE HORN COAL MEMBER

Derivation: Cape Horn, Clifton

Previous Usage: SCCG (1971); unit called Cape Horn seam by Hanlon (1956b)

Type Sections: Outcrop: Cape Horn, Clifton, Scarborough

Core: (1) Metropolitan Colliery No 10 — 510.44 m to 511.23 m GR 295876E, (1 215 519N, Appin 1:25 000 topographic map, 9029-I- N)
(2) Repository: Australian Iron and Steel Coal Geology Department; core not available

Lithology: Coal, carbonaceous claystone and tuffaceous claystone.

Thickness: (1) Type Section: Outcrop — 1.32 m
Core — 0.79 m
(2) Range: <0.05 m to 1.32 m

Distribution: Most of the northern and eastern parts of the Southern Coalfield.

Stratigraphic Limits: Top of the unit is defined by the erosive base of the Lawrence Sandstone or the base of the Burragorang Claystone.

BURRAGORANG CLAYSTONE (new formation)

Derivation: Burragorang Valley

Previous Usage: Referred to as the Burragorang Chert by Whiting and Relph (1956), Burragorang Claystone (Goldbery, 1972) and the Burragorang Claystone Member (Bembrick, 1983)

Type Section: Outcrop: Victoria Pass, Great Western Highway, Mount Victoria

Core (1) Location: Clutha Burragorang DDH 104 (u/g) — 14.27 m to 23.4 m (GR 249950E, 1 238 550N, Warragamba 1:25 000 topographic map, 9030-III-S)
(2) Repository: Clutha Development core shed, Narellan

Lithology: Pale, hard tuffaceous claystone, siltstone and minor sandstone.

Thickness: (1) Type Section: Outcrop — 7.56 m
Core — 9.13 m
(2) Range: <1 m to 16 m

Distribution: Prominent unit along the western and eastern margins of the Southern Coalfield. Also occurs as isolated remnants between the Lawrence Sandstone and Cape Horn Coal Member in the eastern and southern parts of the Coalfield. In the eastern part of the Southern Coalfield, the Burragorang Claystone directly overlies the Cape Horn Coal Member and is overlain by the Lawrence Sandstone.

Stratigraphic Limits: Along the western margin of the Southern Coalfield, it overlies Cape Horn Coal Member, claystones of the lower Eckersley Formation or the top coal/carbonaceous claystone of the Wongawilli Coal. The top of the unit is the base of the Bulli Coal (where the Loddon Sandstone and Balgownie Coal are absent), the base of the Lawrence Sandstone or the base of the Balgownie Coal (Burragorang Area).

LAWRENCE SANDSTONE (new formation)

Derivation: Lawrence Hargrave Drive, northern suburbs of Wollongong

Previous Usage: SCCG (1971); previously called Lawrence Greywacke Member (Hanlon, 1956b)

Type Section: Outcrop: cliff below Scarborough Hotel, Scarborough
Core: (1) Location: Metropolitan Colliery No. 10 — 500.18 m to 510. 44 m (GR 295876E, 1 215 519N, Appin 1:25 000 topographic map, 9029-I-2)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Lithic sandstone, minor siltstone and claystone and rare conglomerate. Generally consists of fining-upward sequences.

Thickness: Type Section: Outcrop — 11.07 m
Core — 10.27 m
Range: 0 to 13.88 m

Distribution: Occurs in the eastern half of the Southern Coalfield.

Stratigraphic Limits: Sharp basal contact with the Cape Horn Coal Member, claystone of the lower Eckersley Formation or the Burragorang Claystone where developed. The top of the unit is the base of the overlying Balgownie Coal.

BALGOWNIE COAL (new formation)

Derivation: Balgownie township, now a suburb of Wollongong

Previous Usage: SCCG (1971). Unit previously called No. 2 seam, Four Foot seam and Balgownie seam (Hanlon, 1956a)

Type Sections: Outcrop: South Bulli Colliery
Core: (1) Location: DM Camden DDH 61 — 540.51 m to 541.68 m (290732E, 1 215 421N, Appin 1:25 000 topographic map 9029-I-S)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Coal and carbonaceous shale with local carbonaceous claystone splits; may merge with carbonaceous sediments of the Bulli Coal near the western limit of the Southern Coalfield

Thickness: (1) Type Section: Outcrop — 1.3 m
Core — 1.17 m
(2) Range: <1 m to 4 m

Distribution: Occurs throughout most of the Southern Coalfield, except the far southwestern parts.

Stratigraphic Limits: The base of the unit is the top of the Lawrence Sandstone or the Burragorang Claystone. The top of the unit is the base of the Loddon Sandstone.

LODDON SANDSTONE (new formation)

Derivation: Loddon River

Previous Usage: New name

Type Section: Outcrop: none

Core: (1) Location: DM Wollongong DDH 21 — 426.48 m to 433.71 m (GR 276350E, 1 200 730N, Bulli 1:25 000 topographic map, 9029-II-N)

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Lithic sandstone, minor siltstone and claystone, rare conglomerate and coal; commonly comprised of two or more fining-upward sequences; becomes shalier towards the margins of the unit.

Thickness: (1) Type Section: 7.23 m

(2) Range: <1 m to 27.42 m

Distribution: Occurs over most of the Southern Coalfield, except the southwestern areas.

Stratigraphic Limits: The base of the unit is the top of the Balgownie Coal. The top of the unit is the base of the Bulli Coal. Contains the Dural Sandstone Member, the Balmain Coal Member and the Penrith Sandstone Member.

PENRITH MEMBER (new member)

Derivation: Penrith

Previous Usage: New name

Type Section: Outcrop: none

Core: (1) Location: AGL Bootleg 8 — 781.34 m to 799.61 m (GR 275744E, 1 235 211N, Camden 1:25 000 topographic map 9029-IV-N)

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Lithic sandstone, minor siltstone and claystone and rare conglomerate

Thickness: (1) Type Section: 18.3 m

(2) Range: 0 m to 25 m

Distribution: Occurs to the north of the townships of Narellan, Campbelltown and Heathcote.

Stratigraphic Limits: The member is the lowest part of the Loddon Sandstone, underlying the Balmain Coal Member. It is only defined where the Balmain Coal Member is present. The Penrith Sandstone conformably overlies the Balgownie Coal.

BALMAIN COAL MEMBER (new member)

Derivation: Balmain Colliery, Birthday Shaft

Previous Usage: New name

Type Section: Outcrop: none

Core: (1) Location: AGL Bootleg 8 — 780.65 m to 781.34 m (GR 275744E, 1 235 211N, Camden 1:25 000 topographic map, 9029-IV-N)

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Coal and carbonaceous claystone

Thickness: (1) Type Section: 0.7 m

(2) Range: 0 to 1 m

Distribution: Occurs to the north of the townships of Narellan, Campbelltown and Heathcote.

Stratigraphic Limits: The Balmain Coal Member occurs near the middle of the Loddon Sandstone and conformably overlies the Penrith Sandstone Member.

DURAL MEMBER (new member)

Derivation: Dural township

Previous Usage: New name

Type Section: Outcrop: none

Core: (1) Location: AGL Bootleg 8, 772.23 m to 780.65 m (GR 297473E, 1 324 859N, Camden 1:25 000 topographic map, 9029-IV-N)

(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry

Lithology: Lithic sandstone, minor siltstone and claystone and rare conglomerate.

Thickness: (1) Type Section: 8.42 m
(2) Range: 0 to 16 m

Distribution: Occurs to the north of the townships of Narellan, Campbelltown and Heathcote.

Stratigraphic Limits: The Dural Sandstone Member is the upper part of the Loddon Sandstone, overlying the Balmain Coal Member. It is only defined where the Balmain Coal Member is present and conformably overlies the latter.

BULLI COAL

Derivation: Bulli township, now a suburb of Wollongong

Previous Usage: SCCG (1971); previously called Bulli seam (Wilkinson, 1878) and the No. 1 seam

Type Sections: Outcrop: Tunnel at Clifton

Core: (1) Location: DM Camden DDH 53 — 460.59m to 463.03 m (GR 284260E, 1 210 842N, Appin 1:25 000 topographic map, 9020-I-S)
(2) Repository: NSW Department of Mineral Resources Core Library, Londonderry; coal used for analysis, crushed samples only

Lithology: Coal and carbonaceous claystone.

Thickness: (1) Types Section: Outcrop — 1.73 m
Core — 2.44 m
(2) Range: <1 m to 7 m

Distribution: Occurs throughout almost all of the Southern Coalfield except in the southwest.

Stratigraphic Limits: The base of the Bulli Coal is the top of the Loddon Sandstone or the Burragorang Claystone (western margin of the Southern Coalfield). The Bulli Coal is overlain by the Narrabeen Group. The top of unit is taken as the top of the carbonaceous claystone, which contains numerous slickensides and is colloquially known as the "blacks".

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