ASSESSMENT OF HYDROCARBON POTENTIAL:

SOUTHERN BRIGALOW BIOREGION PILLIGA, NEW SOUTH WALES.

PREPARED FOR:

NEW SOUTH WALES
DEPARTMENT OF MINERAL RESOURCES
BY
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EXECUTIVE SUMMARY

This Report, prepared for the New South Wales Department of Mineral Resources, is an assessment the hydrocarbon potential of the Southern Brigalow Bioregion – Pilliga – located in central-northern New South Wales. The purpose of this Report is to establish the region's prospectivity for hydrocarbons. It provides an objective framework to any subsequent evaluation of the likely impact on future exploration and development of hydrocarbons that might flow from consideration of changes to land-use within the Bioregion.

Geologically speaking, the Pilliga region is located within the Permo-Triassic aged Gunnedah Basin. The Gunnedah Basin has similar geological characteristics to the Permo-Triassic aged Cooper and Bowen basins of central and eastern Australia, both of which are significant producers of conventional hydrocarbons. Additional hydrocarbon potential in the Bowen Basin comes from coal seam methane (CSM), produced from buried coal seams. The common thread in each of these basins is the association of hydrocarbons with Permian aged coaly sediments. There is a correlation over large areas of these basins between the prospectivity for, and distribution of, conventional oil and gas and of CSM, with the geological occurrences of coal.

The Gunnedah Basin is prospective for both CSM and conventional hydrocarbons. Coal seam, or coal bed, methane is the natural gas formed during the coalification process whereby peat and other organic matter is turned into coal as a consequence of compaction and heat associated with depth of burial. CSM is essentially similar to natural gas found in conventional sedimentary reservoirs, although it is generally higher in pure methane concentration. However, and unlike conventional natural gas reservoirs where gas is trapped in the pore or void spaces of a rock such as sandstone, methane trapped in coal is adsorbed onto the coal grain surfaces or micropores and held in place by reservoir (water) pressure. The coal therefore acts as a source, reservoir, and seal for the methane and as such is to be distinguished from conventional gas accumulations within reservoir rocks. Because the micropore surface area is very large, coal can potentially hold significantly more methane per unit volume than most conventional reservoirs such as sandstones and carbonates.

This assessment of the hydrocarbon resources was conducted on a regional scale, for the whole of the Pilliga, and is based on data and recent geological reports provided by the DMR and industry. The principal geoscientific data sets used in this assessment are :

- Geological maps for surface and solid geology.
- Gravity.
- Magnetics.
- Seismic Reflection.
- Borehole results.

The hydrocarbon prospectivity of the Pilliga region has been assessed using accepted industry methods that make reference to the likehood of finding hydrocarbon deposits within the geological framework as known, or believed, to exist.

Regions of CSM potential and conventional hydrocarbon potential are mapped over much of the Pilliga, associated with sediments in Troughs constituting the Gunnedah Basin. Two coal bearing sequences, constituting the CSM resource within the Pilliga region, are contained within the Early Permian Bellata Group (principally the Maules Creek Formation) and the Late Permian Black Jack Group.

The Pilliga region is currently under petroleum exploration licences (PELs) and the subject of significant exploration programs. For example, in PEL 238, between March 1998 and February 1999, some $30 million was expended on CSM and conventional petroleum exploration. Exploration has already resulted in the establishment of two CSM pilot plants, at Wilga Park and Bohena, and the identification of some 15 conventional oil and gas targets. Conventional gas production is also being considered at Wilga Park, Bohena and Coonarah. Elsewhere in the Gunnedah Basin significant exploration activity is occurring, including PEL's 1, 10, 12 and 286 where Pacific Power is coventuring with Australian Coalbed Methane Pty Limited.

Departmental and industrial geoscientific data confirm that the Bellata, Bohena and Bando Troughs within the East Pilliga contain the main CSM fairways and are most prospective for CSM exploration. The Bohena Trough has been the site of much of the recent exploration activity. Conventional oil and gas potential is more widespread, due to the dispersive nature of the migration processes, following oil and/or gas generation and expulsion. Each of the Bellata, Bohena and Bando troughs are established, by drilling results, to contain active petroleum systems currently generating hydrocarbons. By analogy, and from available seismic and borehole data, the adjacent Tooraweenah and Pilliga Troughs are interpreted to contain, or are likely to contain, petroleum systems. Geological structural highs adjacent to each of these troughs are likely sites for hydrocarbon migration. Traps, both on the flanks of these highs, and within the Troughs themselves, are likely foci for hydrocarbon concentration and the sites of possible accumulations. A number of petroleum "plays" are recognised and their regionality described in terms of prospective fairways. These fairways, defining prospective tracts in which the exploration risks for conventional oil and gas targets are considered similar, encompass much of the East and West Pilliga Forest areas and Pilliga Nature Reserve.

Yields of gas from the principal CSM units, and production testing to date, are consistent with the CSM resource within the Pilliga region of the South Brigalow Bioregion being potentially extremely large. One industry assessment of the natural gas resources within PEL 238 has been put at over 35 TCF - 35 trillion cubic feet (Morton, 2000). PEL 238 covers

approximately half of the Pilliga region considered in this Report.

However, and at this time, caution needs to be exercised. At the current stage of exploration and production assessment it is not yet possible to quantify what percentage of this resource will be ultimately recoverable. Notwithstanding this, the exploration potential and possible economic impact of this cannot be ignored. Put into context, just 1TFC of gas reserves, for example, would supply, at current consumption levels, the entire Newcastle-Sydney-Wollongong gas market for approximately 10 years.

The conventional gas resource within the Pilliga region, although sub-ordinate to CSM, also has significant potential. In PEL 238, where seismic coverage is most extensive, some 15 targets have been identified. Each could contain gas volumes in the range of 10-20 billion cubic feet (BCF), sufficient to supply local markets for many years. Multiple gas discoveries and collective production from these targets could supply Newcastle and provide feedstock into the State-wide pipeline grid.

For both CSM and conventional hydrocarbon potential, the Pilliga region represents the most prospective portion of the State yet identified. In terms of current knowledge, and ranked on a state-wide basis, its prospectivity is outstanding. There are no other basins within the State in which two conventional hydrocarbon accumulations have been discovered**, **let alone under evaluation. Moreover, CSM evaluation in the Gunnedah Basin is to be favourably distinguished from that in the Sydney Basin because of its more advanced stage of assessment.

To reiterate, assessment of the prospectivity of the Gunnedah Basin in this Report is based not only on perceptions of exploration potential but on actual testing and exploration (drilling) results to-date. Although it is too early to quantify actual recovery rates and quantities, the CSM and conventional traps may have the potential to provide the Newcastle-Sydney-Wollongong gas market for several years, and may be of comparative size to the Cooper Basin reserves. Industry assessment is on-going and although the commercial viability will depend ultimately upon the outcome of these, and future production tests, there is a reasonable expectation that the exploration in this portion of the Gunnedah Basin will yield results that could be significant at three levels:

- At a regional level, by providing gas related energy to the regional community based around Narrabri.
- At a State level, by providing gas feed-stock to the state-wide pipeline system, enabling greater diversification and stability of supply and first significant domestic production of gas within New South Wales.
- At a national level, by reducing the reliance upon black coal fired power within the State and so impacting upon Australia's greenhouse targets and diversity and stability of gas supply throughout Eastern Australia.

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The assistance of Dennis Morton and Andy McGee in obtaining data from Forcenergy and First Source Energy is gratefully acknowledged.

Whilst every endeavour has been made to ensure the accuracy and currency of the data, information contained in this Report is subject to on-going exploration and review, and will change over time. This Report was prepared through special joint-funding of DMR and RACAC during the months of January to March, 2000.

1. INTRODUCTION

1.1 REPORT OBJECTIVES

This Report, prepared for the New South Wales Department of Mineral Resources, is an assessment the hydrocarbon potential of the Southern Brigalow Bioregion – Pilliga – located in central-northern New South Wales. The purpose of this Report is to provide an assessment of this region's prospectivity for hydrocarbons based on geoscientific data derived from both Departmental and industry sources. In turn, this assessment will provide an objective basis for evaluations of the likely impacts on future hydrocarbon exploration and development that might flow from any consideration of changes to land-use within the Bioregion.

1.2 GEOLOGICAL SETTING/DEFINITION

The Gunnedah Basin forms part of the Sydney-Bowen sedimentary basin complex which extends some 1700 km along the eastern margin of Australia, from central Queensland in the north to the edge of the continental shelf off southeastern New South Wales. Lying between the Lachlan Fold Belt in the west and the New England Fold Belt in the east, the Gunnedah Basin roughly forms the middle portion of the Sydney-Bowen basin complex. The precise eastern subsurface extent of the Basin is not known, but in part it coincides with the Hunter-Mooki Fault along which the predominantly Devonian to Carboniferous New England Fold Belt overthrusts it.

The Gunnedah Basin occupies an area of 15,000km^2. Structurally, it can be divided by the north-northwest to south-southeast trending Boggabri Ridge into the Mullaley, (or West Gunnedah Sub-basin), to the west, and the Maules Creek Sub-basin, to the east (Steward & Alder, 1995; cf. Tadros et al., 1993). The Gunnedah Basin contains up to 1200 m of marine and non-marine Permian and Triassic sediments resting unconformably upon Early Permian (and possibly Late Carboniferous) volcanics. These volcanics constitute a significant portion of the economic basement (Tadros, 1993; *p.9*). The Sydney - Bowen Basin complex contains vast coal resources which provide sources for both coal seam methane (CSM) (Miyazaki & Korsch, 1993) and conventional oil and gas. In respect of the latter, the Gunnedah Basin has similar geological characteristics to the Permo-Triassic aged Cooper and Bowen basins of central and eastern Australia, both of which are prolific producers of conventional hydrocarbons. A common thread in each of these basins is the association of hydrocarbon prospectivity with the presence of Permian aged coaly sediments. There is a correlation between both the prospectivity and distributions of conventional oil and gas and of CSM occurrences, with the

distribution of coaly sediments of the Cooper and Bowen basins. The Cooper, Bowen and Gunnedah basins exhibit may similarities which, in turn, reflect similarities in their respective geological histories and tectonic settings (Miyazaki & Korsch, 1993).

1.3 CURRENT LAND USE PRACTICES

The southern Brigalow Bioregion, and specifically the Pilliga region the subject of this Report, encompasses a variety of land-uses. As shown in **Figure 1** it includes population centres such as Narrabri and Gunnedah, cultivated and cleared farming lands east and west of Narrabri, two major forestry regions, the West and East Pilliga Forests, and a number of smaller forests to the south. The Pilliga Nature Reserve lies to the south and is juxtaposed to these forest areas (**Map 1**). The East and West Pilliga Forests and Pilliga Nature Reserve, and other conservation areas to the south, form an extensive area covered by mature vegetation including Brigalow, Cypress, and Ironbark and is to be distinguished from the cleared and semi-cleared cultivated lands to the east and north.

Main access routes into the region are principally via the Newell Highway which connects Narrabri to Coonabarabran and Moree. The Newell Highway, and adjacent railway, traverses the Pilliga Nature Reserve and Pilliga East State Forest. A series of secondary roads forming an irregular grid traverse the region and service population centres such as Gunnedah, Boggabri and Bellata.

As shown on **Map 1** much of the Pilliga region of the Southern Brigalow Bioregion is currently under exploration licence for both conventional oil and gas and CSM (Section 2).

1.4 NATURE OF EXPLORATION AND LAND ACCESS ISSUES

Exploration is a process of searching for and assessing petroleum and mineral deposits. Although discovery and delineation are the primary reasons for exploration, lack of discovery from an exploration program does not imply that the effort yielded no benefit. Information gained from exploration will increase the understanding of a region's geology. Typically the exploration history in a region involves several phases, with a steadily increasing knowledge base, building on successive phases. There are many reasons why exploration has continued in some areas. New technology, changes in economic climate and better understanding of geological processes all influence levels of exploration activity. The exploration history of the Pilliga region, outlined in Section 4, is typical of many sedimentary basins in onshore Australia. Exploration occurs in distinct phases, the initial phase usually involving the collection of reconnaissance or regional data; surface mapping, acquisition of remote sensing landsat, airborne magnetics and gravity data which are used to define broad scale geological features and highlight areas for more intense future investigations. Subsequent, and more mature phases of exploration tend to be "prospect" oriented, focusing on specific targets or "sweet-spots" in fairways where perceived exploration risk is lowest and prospectivity highest.

Coal mining, conventional oil and gas and CSM exploration have taken place mainly to the east and north within the more intensely cleared and cultivated portions of the Basin. Some CSM production testing and exploration has occurred in the more heavily vegetated areas, as illustrated in the aerial photograph in **Figure 2.**

Conventional petroleum, and increasingly CSM, exploration makes extensive use of seismic reflection techniques which involve an energy source on the surface (previously dynamite, now a passive vibratory source) and a series of listening devices (geophones) spread out over a distance of up to 4-5 km, usually along a straight traverse. Seismic data is collected along “lines” and vehicular access is required during acquisition. **Figure 3** shows vibroseis vehicles which have routinely replaced dynamite seismic surveys. A hydraulic pad mounted beneath each truck is vibrated rapidly over a period in order to provide the energy source. Vibroseis surveys can negotiate a variety of terrains and are consistent with current industry practice of minimizing both vegetation clearing and surface soil disturbance. Seismic acquisition is a transient process, with daily production at 5- 15 km, most seismic lines are subject to activity, including surveying and remedial work, for a maximum of 2-3 days for any given survey.

Exploration drilling requires clearing of a well site, and levelling of the land surface for the safe installation of drilling equipment. An earth dam for water and drilling mud supply and detention is also usually built, the total area involving 1-3 acres. Clearing of surrounding vegetation is also necessary in the event of controlled release of gas and liquids which may be encountered during drilling. Facilities to flare any gas tested also need to be in-place (**Figure 4**). Exploration wells may be drilled over a period of 2 to 3 weeks. In the event of a dry or plugged and abandoned well the site is rehabilitated so that there are no, or minimal, permanent impact. Development drilling is a more permanent feature, well-head infra-structure being put in place for the life of the deposit. Production testing, particularly for CSM, may occur over a period of several months during which time the reservoir and gas characteristics are monitored and evaluated. Once production commences, pipelines connect well heads to the collection facilities, the surrounding area rehabilitated, although there must remain access to the well-head for routine monitoring, maintenance and servicing. **Figure 2** shows testing facilities within the East Pilliga region involving several well sites linked by collecting facilities. Some aspects of land-use impact connected with CSM have been described previously (eg. NSWDMR and Office of Energy, 1992) and **Tables 1** and **2** are extracted from that Report in order to illustrate, comparatively, these impacts for the various exploration and production activities.

Because exploration is primarily an information gathering process it is necessarily dynamic, so that most regions can never be regarded as “completely explored” (BRS-DMR, 1998). The direct costs facing explorers increase as the target areas become smaller and exploration methods become more intense. The environmental impact associated with exploration also

increases as the areas being explored become smaller and the applied exploration methods become more invasive (for example close space drilling for development or 3D seismic programmes). Such methods are often of a temporary nature, especially when considered in terms of the time-frames involved in environmental protection.

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TABLE 1 : LAND USE IMPACT OF A STANDARD METHANE DRAINAGE EXPLORATION PROGRAM

OPERATION	TIME REQUIREMENT	IMPACT & COMMENTS
Geological Mapping	1-3 months (depending on area)	Minimal impact - no surface disturbance
Drilling (Coal Exploration)	2-4 weeks/hole (depending on depth and drilling conditions)	Localised impact - 500m^2 area required for each drill site. Rehabilitation required.
Drilling (Methane Targets)	3-5 weeks/hole (depending on depth and range of tests required)	Localised impact - 500 - 1,00m^2 square area required for each drill site. Rehabilitation required.
Drilling (Conventional Oil and Gas Targets)	2-6 weeks/hole (depending on depth and range of tests required)	Localised impact 500- 1,500m^2 square area required for each drill site. Rehabilitation required.
Seismic Survey: *(a) High Resolution* *(b) Vibroseis*	0.5-4 line kms/day (dependent on terrain and landuse) 5-15 line kms/day (dependent on terrain and landuse)	Localised impact x kms by 3m Rehabilitation required. Localised to minimal impact x kms by 3m. Can use existing access-ways although rehabilitation required.
Ground Geophysics	1-8 weeks (dependent on area)	Localised to minimal impact - up to 20 sq.kms. Minimal rehabilitation required.
Airborne Geophysics	1-7 days (dependent on area)	Minimal impact. Up to 10,000 km^2. No rehabilitation required

TABLE 2: LAND USE IMPACT OF PRODUCTION TEST FACILITIES

OPERATION	TIME REQUIREMENT	IMPACT AND COMMENTS
Installation Phase:		
a) Site Preparation	1-5 days	Preparation of access tracks and provision of level surfaces for drillsites and frac-pad
b) Drilling	3-5 weeks/hole	Localised impact - 1,000m^2 area required for each site (up to 5 sites). Rehabilitation required.
c) Frac-Pad	1-2 days/hole	Localised impact - 2,500m^2 pad (located centrally to service 5 drillsites). The site may be used for production phase, otherwise rehabilitation will be required.
Production Phase: **(**Subject to separate Environmental Assessment**)**		
a) Access/Utilities/ Corridors	1.5-3 years	Access roads to each production site and central production facility (if required)
b) Production Sites	1.5-3 years	Very localised impact - 50m^2 Infrastructure includes concrete pad, pump, gas and water reticulation systems, monitoring system, security fence.
c) Detention Basin (Optional)	1.5-3 years	Localised impact-up to 200m^2 Infrastructure includes basin and water treatment facility.

2. LEGISLATIVE & ADMINISTRATIVE FRAMEWORKS

2.1 LEGISLATION

The rights to most minerals in New South Wales, including oil and gas, are vested in the Crown. Exploration for petroleum (including natural gas and coal seam methane) is treated quite differently to minerals. Petroleum is regulated by separate legislation; the Petroleum (Onshore) Act 1991. The following general conditions are relevant to the exploration for, and extraction of, oil and gas in New South Wales. These are set out in detail in the Petroleum (Onshore) Act 1991, No. 84 and Regulations, and in the New South Wales Mining Act 1992 No. 29 and Regulations. At the time of preparing this Report no separate coal seam methane legislation has been provided for, although this has occurred in some other jurisdictions (eg. Queensland). In New South Wales coal seam methane is currently extracted under the authority of a Production Licence.

Petroleum (Onshore) Act 1991 No. 94 and Petroleum (Onshore) Regulation No. 435 - New South Wales define a range of parameters and procedures for the exploration and production of petroleum (including coal seam methane) for onshore areas, such as the Brigalow Bioregion of New South Wales.

There are three titles which are relevant to the exploration for, and evaluation of, oil and gas, including coal seam methane.

a) Exploration Licence
b) Assessment Lease
c) Special Prospecting Authority

These titles are to be distinguished from a **Production Licence** which is a separate title permitting the extraction and sale of oil and gas.

An **Exploration Licence** for petroleum can be granted over private or Government-owned land unless exempted from such grant. The size of any single Exploration Licence ranges from :

- maximum of 140 contiguous blocks; to
- minimum of 1 block.

(One block is 5 minutes of latitude and 5 minutes of longitude along its edges).

Exploration Licences are designed for those who wish to carry out an exploration program over a specific area of land. However, Exploration Licences may encompass an area in which certain lands will nevertheless be excluded. The standard exclusions of lands are :

(a) the surface lands within or overlying the external boundaries of colliery holdings

as recorded pursuant to Section 163 of the Mining Act, 1992;

(b) national parks, nature reserves, historic sites, Aboriginal areas, state game reserves under the National Parks and Wildlife Act, 1974, as at the date of grant of the licence;

(c) flora reserves excluded from the operations of the Petroleum (Onshore) Act 19991 under the provisions of the Forestry Act, 1916, as at the date of grant of the licence and any subsequently and mutually agreed to between the licence holder and the Department of Mineral Resources;

(d) land vested in the Commonwealth of Australia.

The term of an Exploration Licence is normally for a period of up to six (6) years, subject to satisfactory work performance of the area for successive periods.

Special Prospecting Authorities can be of any size agreed by the Government and may be granted for a term not exceeding twelve months. **Assessment Leases** of not greater than four (4) blocks may be granted for a term not exceeding six (6) years in order to carry out resource evaluation. **Production Leases** of not greater than four (4) blocks may be granted for a term not exceeding 21 years. However, and before production operations can commence, development consent may be required under the Environmental Planning and Assessment Act 1979, along with approvals from Local Government bodies, as appropriate. Additionally, compensation agreements are required with the owners of surface and/or agricultural rights over land required for exploration and / or production.

A minimum State Royalty of 10% of well head value is payable (less treatment costs where these apply). Provision is made for the Government to set the Royalty at a lower rate in special circumstances. Provisions also exists for a Royalty holiday for a period of five years from the start of production. The Royalty then commences in year 6 at 6% and increases by 1% for each year to a maximum of 10% in year 10.

Where a coal lease is granted, any oil and gas within the boundaries of the lease may be owned by the proprietor of that coal lease provided that the proprietor has made a successful application for the inclusion of these commodities within the coal lease.

As in all legislation, best industry practice is required during exploration and production operations. Best industry practice is also required to ensure protection of the environment.

2.2 CURRENT LICENCE STATUS

Map 1 shows the outline of current petroleum licences within the Pilliga region of the South Brigalow Bioregion. Details of the licence holders are as follows.

- **PEL 12**

PEL 12 was granted to Australian Coalbed Methane Pty Ltd and covers an area of 39 blocks or approximately 2925 km^2. The permit expires on the 14th August 2004, when it will be subject to the normal processes of renewal. It lies to the south of PEL

238.

. PEL 238

PEL 238 was originally granted to Petroleum Securities (50%) and Great Southland Petroleum (50%) by the Government of New South Wales on 1st September, 1980. On 18th July, 1995, Eastern Energy farmed into 60% of the licence, the remaining 40% being retained by Great Southland. On 1st November, 1997, First Sourcenergy Group farmed into PEL 238, assuming a 94% working interest in CSM and 51% interest in conventional rights. Forcenergy Inc signed an agreement with First Sourcenergy Group on 9th June, 1998, whereby Forcenergy Inc will earn 57.5% interest in the licence. The licence comprises 132 blocks, covering an area of approximately 9900km^2.

. PEL 427

PEL 427 was issued to Strike Oil N.L. The area lies to the north of PEL 238 and covers an area of 122 blocks, or approximately 9150 km^2. The permit expires on the 20th May 2004, when it will be subject to the normal processes of renewal. On 21st August, 1998, Forcenergy Australia Pty. Ltd. farmed into PEL 247 from Strike Oil. In return for expending A$500,000 over a two year period, Forcenergy will earn a 47% interest in CSM rights and a 27.5% interest in conventional rights

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. PEL 428

PEL 428 was issued to Strike Oil N.L. The permit lies to the west of PEL 238 and covers an area of 140 blocks, or approximately 10,000 km^2. The permit expires on the 14th August 2004, when it will be subject to the normal processes of renewal. On 21st August, 1998, Forcenergy Australia Pty. Ltd. farmed into PEL 247 and PEL 248 from Strike Oil. In return for expending A$500,000 over a two year period, Forcenergy will earn a 47% interest in CSM rights and a 27.5% interest in conventional rights.

3. GEOLOGICAL SETTING

3.1 OVERVIEW OF BASIN HISTORY

The following overview of the Pilliga region geology follows, with appropriate modification, that provided by Forcenergy (1999) for PEL 238 and that published by the DMR (Tadros, 1993, 1999; Pratt, 1998). The principal geological units, and their respective ages, are illustrated in **Figure 5,** and their distribution within the basin shown schematically in **Figure 6**.

Sediments of the Gunnedah Basin rest on a basement consisting of Late Carboniferous to Early Permian volcanics and Lower Palaeozoic metamorphic rocks. As outlined in Section 3.4, the Gunnedah Basin contains a sedimentary section that includes units of Permian, Triassic and Jurassic age. The patterns of post-Carboniferous deposition were largely controlled by the basement geometry developed by the beginning of the Permian. This basement geometry was modified by tectonic events at Late Permian to Early Triassic times, in the Jurassic and finally by the emplacement of major volcanic complexes in the Tertiary (Section 3.2).

In the Early Permian there was a period of lacustrine and fluvial sedimentation that allowed the accumulation of thick coal units (Maules Creek, Leard and Goonbri formations of the Bellata Group). These coals are the primary target of the current CSM exploration and production within the Basin. The onset of Late Permian deposition was marked by a marine transgression during which the Porcupine and Watermark formations were deposited. Deltaic and fluvial sedimentation returned towards the end of the Late Permian. Coal measures of the Black Jack Group that accumulated at this time have been extensively mined. As a CSM target these coals are nevertheless secondary to the Maules Creek Formation, due to lower gas contents and reduced permeability. Nevertheless, the Black Jack Group is thick and extensive and may yet prove to have very good potential. The top of the Black Jack Group is picked at the base of the distinctive Digby Formation. This interface generates a strong seismic signature which provides a convenient seismic reflection event that can be mapped across the basin in order to define structuring at this level (Forcenergy, 1999).

Uplift and erosion of Late Permian units occurred at the end of the Permian. This was followed by the deposition of the Digby Formation (Triassic), an alluvial fan and braided stream deposit. The Digby Formation is easily picked on well logs as a coarsening downward, almost exclusively, sand and conglomerate interval. This formation has proven to be gas bearing in several of the wells drilled in the Bohena area. Marine conditions returned later in the Triassic and witnessed deposition of

the Napperby Formation. The contact between the Napperby and the overlying Purlawaugh is indistinctive and difficult to pick on lithologic logs but can often be seen on electric logs and seismic.

Uplift and erosion marks the boundary between the Triassic and Jurassic. Following uplift there was a prolonged period of igneous activity throughout the Jurassic, when the Garrawilla volcanic episode occurred. The 'Garrawillas' consist of volcanic flows, tuffs, domes and various forms of intrusive. The Garrawillas are overlain by fluvial sediments of the Purlawaugh and Pilliga formations.

The last major geologic event took place in the Tertiary, when volcanic complexes located at the Warrumbungle Mountains and Mt. Kaputar (Nandewar Range) were emplaced. When encountered during drilling, Tertiary volcanics and basal volcanics are difficult to differentiate, both being generally silicic in composition. These have been penetrated by about 50% of the bores drilled in the region and comprise both sills and dykes.

3.2 TECTONIC HISTORY

The present-day structure of the Gunnedah Basin is the product of a number of discrete periods of deformation (tectonism). Local variations in the crust's response to these has produced a compartmentalisation of structural styles – defining the so called structural elements. The principal structural elements recognised within the Pilliga region are shown on **Map 2** and **Figure 6** and described in Section 3.3. The main tectonic events producing these elements are:

Early Permian Extension
Initial formation of the basin is related to out-pourings of silicic and mafic lavas of the Late Carboniferous to Early Permian Boggabri Volcanics. This is associated with a period of extensional tectonism that initiated the Gunnedah Basin and subsequently controlled the earliest phases of deposition; the Goonbri and Leard formations. This occurred in the Early Permian (Stage 4) and correlates with Reids Dome Bed deposition of the Dennison Trough in the Bowen Basin of Queensland.

Late Permian Compression
An east-west compressional event affected the area in Late Permian to Early Triassic times with the development of west verging thrust faults and high angle reverse faulting and folding. Erosion of Permian sediments from the highs followed. It produced a marked regional angular unconformity between the Permian and the overlying Early Triassic Digby Formation. Forcenergy (1999) noted that there is limited evidence of this event in the vicinity of PEL 238. The Boggabri Thrust has been mapped at the surface in the area of Boggabri town, but subsurface support is lacking. It could be argued that both Bohena and Wilga Park structures were influenced by thrusting, possibly of this age. Severe Early Triassic uplift and erosion occurred north of the Culgoora High with erosion of Late Permian units.

Late Triassic Compression
This represents a major phase of tectonism in Eastern Australia and marks the boundary between Permo-Triassic basinal systems –

such as the Gunnedah, Bowen and Cooper, and those of the overlying Jurassic-Cretaceous aged basinal systems - the Surat and Eromanga. The unconformity separating these basinal sequences in the Pilliga region involved uplift and erosion of underlying Triassic and Permian sediments, uplift being most pronounced along the Boggabri Ridge. Exhumation of up to 2000m of sediment is indicated from vitrinite reflectance (maturity) data during this Late Triassic period of erosion (Tadros, 1993; *p. 372*). This event is associated with intrusive and extrusive igneous rocks of the Garrawilla episode.

Tertiary Compression
Compressional deformation of the Surat Basin sequence indicates that the last period of structuring in the Gunnedah Basin was post-Middle Jurassic in age. Extensive volcanism at Nandewar, Warrumbungle and Liverpool Ranges imply that some of this structuring occurred during the Tertiary.

On a smaller scale, there are many examples of local uplift where Tertiary intrusives have domed up and/or intruded the overlying section (Wilga Park, Nyora, Coonarah), although these have been eroded to a present day flat surface.

3.3 Structural Elements

The structural elements of the Pilliga region of the Gunnedah Basin are illustrated on **Map 2** and replicated in **Figure 7**. These have been compiled from regional gravity (**Map 3**) and magnetic (**Map 4**) coverages, as well as seismic, borehole and outcrop data-sets. To a large extent these elements were imposed at the end of the Carboniferous and Early Permian, and subsequent tectonic episodes, together with ensuing depositional patterns, reactivated and enhanced these. As such they comprise the principal controls on depositional style, structuring and lithofacies development – all of which are important for understanding the distribution of CSM related coals and of source, seal, reservoir, and trapping mechanisms for conventional oil and gas generation. A brief description of each of the principal elements follows.

Maules Creek Sub-basin
The Maules Creek Sub-basin is bound by the Hunter-Mooki Fault system, to the east, and the Boggabri Ridge, to the west. It is a remnant basinal form that originally probably covered areas to the east of the boundary with the New England Fold Belt. However the New England Fold belt is now thrust over the eastern margin of the basin (Morton, 1995).

Mullaley Sub-basin
This extends the entire length of the Gunnedah Basin from Moree, in the north, to Mount Coricudgy Anticline, in the south. It is divided by prominent transverse highs into a number of troughs the most important of which within the Pilliga region are the Bellata, Bohena and Bando Troughs.

In Figure 6.4 of Tadros (1993) the north-south basin architecture is dissected by northeast elements so that the Mullaley Sub-basin is partitioned into a number of troughs, including the Murrurundi, Bando, Bohena and Bellata. Boundaries between the Bando, Bohena and Bellata troughs coincide with the Walla Walla High

and Narrabri High (or Culgoora High) (**Map 2**).

Bellata Trough

Lying north of the Narrabri High, this is the northermost of the depocentres comprising the Mullaley Sub-basin. It represents an area, approximately 40km wide and 70 km long, of thickened sedimentary pile overlying a basement deep bound in the west by the Rocky Glen Ridge and in the east by the Boggabri Ridge. Interestingly, it is slightly offset from a gravity high (Tadros, 1993; *his Figure 6.15*), contrary to the normal association of sedimentary basins with gravity lows. Nevertheless, the Bellata Trough is confirmed by seismic surveys (Bellata Seismic Survey and Edgeroi Seismic Survey) and drilling (Bellata-1). Depth to basement maps produced by Forcenergy (1999) indicated basement depths lies within the range of 600m to 900m (bsl) within the Trough (**Map 2**). The recovery of gas in Bellata-1 implies that this Trough contains an active petroleum system.

Bohena Trough

Also located between the Rocky Glen Ridge and the Boggabri Ridge, the Bohena Trough lies south of the Narrabri High where it covers an area of approximately 3,500 km^2. It is also offset from a gravity high which is coincident with its eastern flank, rising onto the Boggabri Ridge. To the south it is bound by the Walla Walla Ridge which to the west of the Rocky Glen Ridge may merge with the Baradine High. Depth to basement mapping, based on drilling and seismic coverage prepared by Forcenergy (1999), imply that the Walla Walla Ridge may not be as conspicuous as illustrated by Tadros (1993) and that in detail the Dampier High (the western extension of the Baradine High in the vicinity of the Rocky Glen Ridge) may be separate from the Gorman High on the western flank of the Boggabri Ridge. This alternative configuration implies continuity of deposition between the Bohena Trough and the Bando Trough during the Lower Permian. The occurrence of conventional gas in the Coonarah, Wilga Park and Bohena wells indicates that this Trough contains an active petroleum system.

Bando Trough

This is a 3,500 km^2 region of thickened sediment pile overlying basement, located between the Boggabri Ridge, in the east, and the confluence of the southern projection of the Rocky Glen Ridge and Baradine High, in the west. Forcenergy's (1999) Depth-to-Basement mapping indicates basement depths within the range of 100m to 600m (bsl) within the Bando Trough, which contains an extensive sequence of Lower to Late Permian sediments including the principal coal measures.

Tooraweenah Trough

This forms part of the Gilgandra Sub-basin which Tadros (1993) defined as lying to the west of the Rocky Glen Ridge - between the Mt Foster Structural Zone, in the south, and the Baradine High, in the north. The northern part of the Tooraweenah Trough is the site of the Warrumbungle Ranges, a series of spectacular volcanic outcrops. On regional Depth-to-Basement mapping, based on scarce borehole information, basement ranges from around 0 to 100m (bsl) (**Map 2**). The DM Pibbon DDH-1 results established the presence of Black

Jack Group (Late Permian) sediments within this Trough and Tadros (1993; *his Figure 6.10b*) interpreted continuous Late Permian sedimentation across the Rocky Glen Ridge between the Tooraweenah Trough and Bando Trough.

Pilliga Trough

The Pilliga Trough represents that portion of the Gilgandra Sub-basin located north of the Baradine High. It lies to the west of the Rocky Glen Ridge. Depth to basement, based on scarce borehole information, ranges up to 400m (bsl) (**Map 2**). Gravity and magnetic data coverages (**Maps 3** and **4,** respectively) exhibit a range of responses consistent with this Trough being underlain by a variety of basement types. A strong northwest trending series of gravity lows traverses the southern portion of the Pilliga Trough, whereas a localised gravity high (**Map 3**) appears to coincide with acid volcanics. Unlike troughs within the Mullaley Sub-basin, this Trough is largely unexplored. Drildool 1A has been drilled in the shallower northeastern portion of this Trough and established the presence of a Surat sequence, although at this relatively structurally high location, no Permian is to be expected.

Boggabri Ridge

Paralleling the Rocky Glen Ridge, this is a structural high lying along the eastern side of the Bando, Bohena and Bellata Troughs, where it is in part coincident with outcrops of Boggabri Volcanics. It separates the Maules Creek Sub-basin from the Mullaley Sub-basin to the west of which the Bohena and Bando Troughs are constituents. The Ridge was probably a high during the Early Permian, because Early Permian sediments on-lap both the eastern and western flanks. However, it may not have been a continuous barrier.

Rocky Glen Ridge

The Rocky Glen Ridge is a meridionally trending basement high which separates the Pilliga and Tooraweenah Troughs, in the west, from the Bohena and Bando Troughs in the east (Tadros, 1993; *his Figure 6.4*). Aeromagnetic and gravity data coverages confirm that it has no distinguishing character (**Maps 3** and **4**) save for an interpreted shallowing southwards towards the Baradine High which is reflected in broad regional basement contours prepared by Encom (1995) and illustrated on **Map 2.** The Rocky Glen Ridge is manifest in the Coonabarabran area as a subcrop of Ordovician-Carboniferous metasediments, Carboniferous granites and volcanics. Silicic volcanics, correlatives of the Boggabri Volcanics, form the eastern flank of the Rocky Glen Ridge. It is at least partially onlapped by Permian sediments and Yoo (1988) proposed that it extended south to the Dunedoo High and north to Wee Waa. A deep crustal seismic traverse recorded by the then Bureau of Mineral Resources (now the Australian Geological Survey Organisation) confirm its presence north to at least Boggabri (Korsch et al., 1992).

Based on depth-to-basement estimates from bore hole drilling (Encom, 1995), the northerly plunge implies a greater likelihood that sedimentation was continuous and that shallower sequences are not truncated by subsequent uplift and erosion between the Pilliga and

Bohena Troughs.

Narrabri or Culgoora High
The Narrabri High separates the Bellata and Bohena Troughs (Tadros 1993, *his Figure 6.4*) and corresponds with the Culgoora High of Forcenergy (1999). They recognised it as an important structural feature influencing depositional patterns throughout much of the area's geological history. It is located north of the Wilga Park area. This basement high, oriented NE-SW to E-W, has separated Lower Permian sedimentation of the Bellata and Bohena troughs. It also had some impact on subsequent Upper Permian, Triassic and Jurassic sedimentation, either as a positive feature or a 'hingeline'.

Walla Walla Ridge
This is a transverse basement high which locally forms the boundary between the Bohena and Bando Troughs. The continuation of this Ridge across the Rocky Glen Ridge is marked by small silicic volcanic outcrops north of Coonabarabran. On regional basement maps, the Walla Walla Ridge has a relief of approximately 500m. It was probably formed during the Late Permian and earliest Triassic. Subsequent sedimentation thins, and is draped, over this structure. As mentioned above, there is some contention as to whether this is a continuous basement high, or barrier, completely isolating deposition within the adjoining troughs. Gravity anomaly distributions used previously to support the presence of this element, are subject to alternative interpretations, including lateral changes in basement composition. Establishing whether or not it was continuous has important economic impact, due to the depositional affect it would have had on Lower Permian coal thickness in the immediate area, and whether it or not it provided a boundary creating separate petroleum systems within the Bando and Bohena Sub-basins.

Baradine High
This is a region of shallow basement defined by Tadros (1993). It separates the the Gilgandra Sub-basin into the northern Pilliga Trough and the southern Tooraweenah Trough (*his Figure 6.4*). On the gravity coverage, the eastern portion of this High, which Forcenergy (1999) interpreted as the Dampier High, coincides with a conspicuous positive anomaly (**Map 3**), in an area where basement depths lie in the range of -100 to 100 m (bsl) (**Map 2**).

3.4 STRATIGRAPHY

Principal stratigraphic features are shown on **Figure 5** and summarised as follows.

3.4.1 Basement (Early Permian and older)

The Basement of the Mullaley Sub-basin is comprised of meta-sedimentary and meta-volcanic rocks of the Lachlan Fold Belt and volcanics of Late Carboniferous to earliest Permian (Boggabri Volcanics and Werrie Basalts).

The Boggabri Volcanics and Werrie Basalts are thought to constitute Basement in most of PEL's 12, 238 and 428. Where intersected by drilling in the Mullaley Sub-basin, the basal volcanic sequence consists mostly of undeformed lavas, tuffs and intercalated

sedimentary rocks (Tadros, 1999). They comprise a biomodal volcanic suite often indicative of a rift system. The Boggabri Volcanics form, and underlie the Boggabri Ridge. The current Namoi River traces the underlying Boggabri Ridge for much of its course. Metavolcanics and metasediments and minor ignimbritic volcanics of the Lachlan Fold Belt form much of Basement underneath the western part of the Gunnedah Basin (Tadros, 1993; *p. 9*) and Gilgandra Sub-basin west of the Rocky Glen Ridge (Tadros, 1999; *p. 47*).

3.4.2 Early Permian: Bellata Group - Maules Creek, Goonbri & Leard Formations

Early Permian sediments were deposited in alluvial plain to lacustrine environments. Sediment input was predominantly from the northwest with additional input off the flanks of the Boggabri Ridge. The Goonbri Formation is the oldest Permian unit in the area and consists of basal sediments deposited on an irregular topography of weathered Boggabri Volcanics. Sediments include pelletoidal claystones, lithic sandstones and lacustrine deposits, including coals. The first major stratigraphic unit comprised the Leard – Maules Creek alluvial/lacustrine system (Tadros, 1993; *p. 147*). This system derives its name from the lowermost Leard and uppermost Maules Creek formations but includes the Goonbri lacustrine facies which, consisting of dark massive siltstones, interbedded sandstones and siltstone and overlying fine-grained sandstones, is very areally restricted. Although restricted, Etheridge recognised a distal organic rich siltstone in Bellata –1 implying that it may have been deposited in subsiding parts of the Bellata, Bohena and Bando Troughs where it could form a significant conventional oil and gas source rock sequence (Hamilton, 1985).

The Leard and Maules Creek formations consist of braided stream deposits. These have been shed and transported from the Lachlan Fold Belt, to the west and northwest, and from the Boggabri Ridge on the east. Coals were deposited as peat swamps between the areas of braided streams.

The aerial extent and thickness of Lower Permian units were determined largely by basement architecture. The most prominent pre-Permian features were the Lachlan Fold Belt/ Rocky Glen ‘High’ on the west and the Boggabri Ridge on the east, both of which were oriented generally N-S to NNW-SSE. Transverse features, discussed in Section 3.3 above, also affected deposition during this time. Embayments off the main depositional trough are interpreted east and west from a line drawn between Wilga Park and Bohena. It is possible that these areas may have been suitable for development of peat marshes and hence coal development. The Maules Creek Formation is best developed in the Maules Creek Sub-basin east of the Boggabri Ridge where it attains a maximum thickness of some 800m (Tadros, 1999, *p. 54*).

3.4.3 Late Permian: Watermark and Porcupine Formations

A marine transgression from the southeast ended deposition of the Maules Creek Formation. Initially, sedimentation was dominated by shallow marine conditions, but with continued inundation the marine

shelf setting deepened. Tadros (1993; *p. 149*) identified this phase of deposition as the Porcupine – lower Watermark marine shelf system.

The system comprises a rather monotonous marine shelf sequence of bioturbated, silty lithic sandstones. Conglomeratic detritus with a silty sandstone matrix is abundant in the lower part, whereas the upper part forms an upward-fining succession of sandy siltstone, dark-grey siltstone and finally claystone representing the maximum extent of flooding (Tadros, 1993; *p. 149*). The Porcupine Formation is dominated in the lower half by conglomerates whereas silty sandstone characterises the upper half. The sediments are strongly bioturbated and contain spinose acritarchs. The Porcupine Formation attains a maximum thickness of about 160m in the eastern part of the Basin (Hamilton, 1985). A drill stem test of sands within the Porcupine Formation at Wilga Park-1 flowed gas at a rate of 1.0 million cubic feet per day (1MMCF/D) at a pressure of 285 psi on a 3/8" surface choke. This was the first conventional gas discovery in the Basin and attests to the Porcupine Formation's potential as a reservoir sequence.

The Watermark Formation conformably overlies the Porcupine Formation and comprises a sequence of siltystone, claystone, silty sandstone and siltstone/sandstone laminite. It also exhibits extensive bioturbation, consistent with its marine origin. It is up to 220m thick in the east and thins to the west. It correlates with the Mulbring Siltstone of the Sydney Basin.

The upper part of the Watermark Formation coincides with a regressive phase of sedimentation involving southwesterly progradation of a major delta system, heralding the end of marine shelf conditions in the basin. Prodelta facies of finely laminated siltstone and claystone are thickly developed in the southern dominated deltas. Tadros (1993; *p. 151*) referred to this as the Upper Watermark- lower Black Jack delta systems.

3.4.4 Late Permian: Black Jack Group

The Black Jack Group was initially deposited in shallow marine conditions. Later these conditions gave way to fluvial, lacustrine and deltaic environments involving coal deposition, including the widely distributed Hoskissons Coal Member. At its thickest, the section is 162 m in the south-east (Denison West 1) and 140 m + at DDH Narrabri-1B in the north. Hamilton (1985) noted that to the southeast it thickens to in excess of 400m. During lower Black Jack times the second of two major delta systems was deposited in a phase dominated by regression, principally controlled by compression and uplift of the New England Fold Belt.

Sediment thickness trends show maximums towards the Hunter Mooki Fault system with thinning and onlap towards the Lachlan Fold Belt to the west, consistent with thrusting and foreland loading. Volcanic and lithic deritus deposited in a shallow marine setting occurred in the east, whereas a peripheral bulge on the eastern edge of the craton to the west initiated fluvial sedimentation along the western margin. Bulging sourced a bed load of medium to coarse grained

quartzose detritus which was transported eastwards in a fluvial system to interfinger with, and ultimately overlie, the shallow marine deposits. Widespread peat accumulation followed termination of marine conditions and yielded the regionally extensive Hoskisson Coal Member. The coal member is up to 18 m thick and represents a widespread period of non-deposition of clastics during an implied period of tectonic stability involving virtually no subsidence. The Hoskissons Coal Member correlates with the Bayswater Coal, Woonona and Lithgow Coal Members of the Sydney Basin. These units have good potential as conventional oil and gas source rocks as well as potential for CSM. Sandstones within the Black Jack Group have good to excellent reservoir potential.

3.4.5 Triassic: Digby Formation

A significant unconformity separates the Triassic and Late Permian. It reflects the onset of renewed tectonism in the New England Fold Belt that resulted in widespread deposition of coarse alluvial clastics over the Gunnedah Basin during the Early Triassic, (the Digby alluvial system). The lower part consists of thick, massive volcanic lithic pebble conglomerate. Quartz content increases higher in the sequence, and this dominates the upper part which is better sorted.

The basal unit of the Digby Formation is a conglomeratic facies infilling the palaeo-surface above the Black Jack Group. It was deposited in fluvial and alluvial fan environments. The upper section becomes sandy and is often overlain by intruded or extruded volcanics (Garawilla). Although it appears to be deposited with regionally similar thickness along a narrow north-south strip, it does thicken slightly to the southeast, where Hamilton (1985) noted that it ranges up to 200m. The Digby Formation is thin on the eastern flank of the Basin, particularly in the Gorman High region as identified by Forcenergy (1999). Although the Digby Formation has no obvious source or CSM potential its sandy facies have good reservoir potential and gas has been encountered within it at Coonarah-1 (Morton, 1995).

3.4.6 Triassic: Napperby Formation

Tadros (1993; *p. 163*) noted that the Napperby lacustrine system marked the final episode of deposition in the Gunnedah Basin. The lower part is progradational, with repetitive well-developed upward coarsening sequences of laminated siltstone/claystone, interbedded sandstone/siltstone laminites. Having suffered considerable post-depositional erosion during Middle Triassic deformation, the preserved sequence is remnant. The top of the formation is marked by regional unconformity with overlying rocks either of the Middle Triassic Garrawilla Volcanics or coeval Purlawaugh Formation of the Surat Basin.

The Napperby Formation is dominated by a shale unit, often indistinguishable from the overlying Purlawaugh Formation. Hamilton (1985) noted that several facies are recognised within the formation; a basal siltstone unit is overlain by sandstone/siltstone laminite, which in turn is overlain by interbedded siltstone and sandstone. It was laid down in a broad north-south trough with sediment input probably from the north. The thickest section is at

Bellata 1 (244m) in the north and Pilliga 1 (232m) in the south. A thick section is also present at DDH Narrabri 1B (203m). The geometry of this unit indicates a generally steep sided trough, although the western edge appears to be formed by recent erosion. From a conventional petroleum standpoint the Napperby Formation has poor reservoir and source rock potential, however the basal siltstone unit has excellent seal potential.

The Napperby Formation comprises siltstone, sandstone, siltstone laminate and quartz-rich sandstone. It ranges from 25 to 315 m in thickness. Large variations in thickness are present because the upper contact is commonly eroded (Hamilton, 1985).

3.4.7 Jurassic: Purlawaugh Formation

This formation is represented by interbedded sand, silt and shale units, unconformably overlying the Triassic Napperby. It can be seen onlapping the Coonarah and Wilga Park highs. The unit forms part of the southern extent of the Surat Basin with an erosional edge immediately south of PEL 238, in PEL's 12 and 428. Its southeastern erosional edge occurs on the eastern flank of the current day topographic high. Thickest sections are at Borehole 89 (174m), in the south, and DDH Narrabri 2 (153m), in the north. This section is thin at Wilga Park indicating a Late Triassic / Early Jurassic period of growth. The section is also relatively thin at Bohena.

3.4.8 Jurassic: Pilliga Formation

The Pilliga Formation is comprised predominantly of sandstones deposited in fluvial conditions. Outcrops of Pilliga Formation in the southeast part of PEL 238 form a present day topographic high. The thickest sub-surface section is seen at Bellata 1.

3.4.9 Tertiary: Volcanics

Tertiary lithologic units are comprised almost exclusively of extrusive and intrusive igneous rocks. Volcanics outcrop at Mt Kaputar (Nandewar Range) in the northeast (uplift of about 800 m) and at the Warrumbungles in the southwest of PEL 238 in PEL 428. A high topographic ridge runs between the two, possibly a result of the Tertiary uplift. Tertiary plugs appear in outcrop southwest of Mt Kaputar and subsurface plugs are interpreted on seismic in various parts of PEL 238. Approximately 52 wells have intersected intrusives in the Mullaley Sub-basin, although there is difficulty distinguishing between Tertiary and older intrusives. There appears to be some stratigraphic control because intrusions are preferentially emplaced in fissile rocks and in coal seams (Tadros, 1999). Martin (1993) suggested that bright (vitrinite-rich) coal allows preferential penetration by magma

4. EXPLORATION HISTORY

Hamilton (1985), Tadros (1993, *pp. 368-369*) and Morton (1995, 2000) have reviewed the exploration history of the Gunnedah Basin, from which the following is modified. Phases of exploration in the Gunnedah Basin have been restricted to four main periods; the mid-1960's, the mid-1980's, 1993 and 1998/1999. The first three periods exclusively involved conventional petroleum exploration, whereas the last has involved an increasing proportion of CSM related exploration and development drilling. To date only 19 conventional petroleum exploration wells have been drilled, 15 of these during the first period in the mid-1960's, two in the mid-1980's and one in each of 1993 and 1995. In total 7 were drilled within PEL 238. The locations of these wells are shown on **Map 1.** Exploration in the most recent phase is in part a response to increased awareness of CSM potential, following exploration campaigns in the Bowen and Sydney basins, and the NSW Department of Mineral Resources "Discovery 2000" initiative which, commenced in 1995.

One seismic reflection survey and numerous other geophysical surveys, including gravity and magnetics, were conducted in the 1960's (Sections 5.1, 5.2 & 5.3). The seismic reflection recording and processing technology at that time was relatively basic and did not have the advantage of modern high-fidelity multichannel recording using high fold multiplicity acquisition techniques. Exploration in the Gunnedah Basin during the 1970s was principally concerned with testing and proving coal resources and to this end over 180 fully cored stratigraphic boreholes have been drilled since 1975, mostly by the NSW Department of Mineral Resources. In excess of 40,000m of core were drilled and these data have made a significant contribution to the current understanding of Gunnedah Basin sub-surface geology, particularly of the distribution of coal and petroleum source rock sequences. At the time, numerous small gas shows were reported during the drilling of the coal exploration boreholes, including the Blake-1, Parsons Hill-1 and Dampier-1 holes. The majority of gas flows emanate from porous and permeable sandstone interbedded with coal seams of the Permian Black Jack Group, however shows have also been reported from the Porcupine Formation (DM Bando-1) and Digby Formation (DM Dampier-1), Pratt (1998).

In the early 1980's Hartogen Energy Ltd, as operator of three conventional petroleum exploration licences, acquired several surveys of high fold seismic data and drilled two wells. Wilga Park-1, drilled in October 1985, resulted in the first successful exploration well, and the

first well to discovery conventional gas within the Basin. It was completed as a new field gas discovery, although the accumulation was then thought to be sub-commercial, notwithstanding that it included a high percentage (0.43%) of Helium. The second well, Nyora-1 drilled in 1986, was a dry hole.

Coonarah-1 and 1A, drilled by Eastern in late 1993, resulted in a new gas pool discovery in the Digby Formation. Natural gas was tested at a rate of 340 MCF/D, which is sub-commercial - again notwithstanding that it contained 1.14% Helium, considered to be very high by world standards. A minimum 37 metre gross gas column was penetrated by the well with an estimated 80% net/gross ratio. Coonarah-2 was located 1.8 kilometres northeast of the discovery well and drilled in August 1995, with disappointing results. The objective Digby Formation, although gas bearing, was fine grained and tight. The Black Jack Group sandstones were also tight with a drillstem test conducted over the lower part of this formation flowing gas to surface at a rate too small to measure.

In October 1997 First Source Energy Inc. farmed into PEL 238 and commenced an active coal seam methane exploration programme targeting mainly coals within the Early Permian Maules Creek Formation. From February 1998 to February 1999 First Source drilled 15 wells, conducted 7 hydraulic fracture stimulations, 2 open hole cavity stimulations, recorded 486 kilometres seismic data and reprocessed existing seismic data. This exploration work has not only confirmed the huge gas potential within the coal seams but it has also discovered conventional gas reserves within the Digby Formation in the Bohena area. Bohena-1, drilled in 1963 by Amoseas, was plugged and abandoned as a dry hole. Bohena-2, located approximately 100 metres from Bohena-1 was drilled in 1998 to test the Maules Creek Formation coal seam methane potential. The well was drilled with a lighter mud weight than in the original well and Bohena-2 recorded excellent gas shows whilst drilling through the upper Digby Formation quartz sandstone. The sandstone was drillsteam tested. Bohena-2 flowed gas to surface from the Digby Formation at rates in excess of 2 MMCF/D and Bohena-7 also flowed gas to surface at high but unmeasured rates. In addition, gas has been produced from almost every formation intersected within the Permian and Triassic section. Well locations in the Bohena area have been sited without seismic data and therefore without the benefit of any structural control

As shown on **Map 1** the seismic coverage is largely confined to the region immediately to the north of the East Pilliga Forest, within PEL 238. As outlined in Section 5.3, some 3000 km of seismic data has been recorded in the entire Gunnedah Basin. By comparison, relatively well explored oil and gas producing basins, such as the Cooper-Eromanga and Surat-Bowen in South Australia and Queensland, would each have several hundred thousand kilometres of seismic coverage. Typically, prospective areas are traversed by a regional seismic grid of perhaps 4-20 km spacing, in a direction perpendicular to the main geological trends. Leads and

prospects are defined by much tighter seismic grids which may range from 0.5 to 4 km spacing. This is referred to as “2D” seismic coverage. Prospects and development oil and gas fields also may be delineated by so-called “3D” seismic coverage in which very closely spaced seismic traverses (25-75m) are recorded in order to define a “data-cell” usually over a few square kilometres. There are no 3D seismic coverages within the Gunnedah Basin and detailed 2D coverages are found only across the Coonarah – Wilga Park area.

The 1998 FSG seismic survey, in which 486 km of seismic data was acquired, is by far the largest modern survey within the Gunnedah Basin. However, and when compared to prospective basins within Australian and overseas, following this survey there is still only about 10% of the Pilliga region which has sufficient modern seismic coverage.

Notwithstanding large exploration expenditure levels in recent times, detailed knowledge of the region, as determined from seismic and bore hole information, is concentrated in the eastern portions of PEL 238 and within the depocentres of the Bellata, Bando and Bohena Troughs.

Sporadic seismic lines located in the Pilliga and Tooweenah Troughs and to the north and south of PEL 238 are generally older vintages of seismic coverage which although providing some control, is limited due to typically lack of penetration and adequate clarity of the primary reflection events.

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5. DATA SOURCES

Naturally occurring local gravity and magnetic responses of the earth are influenced by the nature, distribution and depth of nearby basement and sedimentary rocks. Accurately measured gravity and magnetic data sets provide useful regional tools for identifying areas of deeper basement upon which thickened piles of sediment might be deposited. Depths attained within thickened piles of sediment, such as those forming the Troughs and Sub-basins described in Section 3.3, may be compatible with generation of CSM and conventional oil and gas. The principal identified thickened sedimentary piles are shown on **Map 2.**

Previous experience in the region has shown that the normal relationships between Basement depths and overlying sediment thickness is not always predictable (Encom, 1995). The Pilliga area overlies a transitional tectonic zone between the Lachlan Fold Belt and the New England Fold Belt where basement composition is variable and complex, making it difficult to resolve what gravity and magnetic anomalies are due to sediment thickness, as opposed to those due to Basement compositional variations.

5.1 MAGNETIC DATA

The first aeromagnetic survey for petroleum exploration in the Surat Basin was undertaken by Australian Oil and Gas Corporation in 1959. Several other surveys have been carried out and data reprocessing has been undertaken since that time. Regional airborne surveys have been conducted by both the Department of Mineral Resources and the Bureau of Mineral Resources (now AGSO). **Map 4** shows a compilation of regional aeromagnetic data across the Pilliga region. These data comprise Total Magnetic Intensity (TMI) colour filled contours.

Encom (1995) noted that the high amplitude, short wavelength TMI anomalies (**Map 4**) are attributable to the presence of Tertiary igneous intrusions, Tertiary volcanics and the Jurassic Garrawilla Volcanics. The latter appear to be subordinate however, with best coincidence being found with Tertiary intrusives which have a higher magnetic susceptibility. Igneous intrusions are a common occurrence in coal mines of the Gunnedah Basin and nearly 50% of the departmental boreholes have intersected intrusions which occur as both dykes and sills.

Based on analysis of outcrop, borehole and magnetic anomaly distributions the principal sources of TMI anomalies within the basin are interpreted to be:

- Tertiary layered volcanics

- Tertiary igneous intrusions
- Late Carboniferous to Early Permian Boggabri Volcanics
- Jurassic Garrawilla Volcanics
- Crystalline igneous basement (including granite, andesite, dolerite and gabbro).

The Late Carboniferous to Early Permian Boggabri Volcanics beneath the Gunnedah Basin are the predominant source for the area of magnetic highs in the centre of the Basin. In the Surat Basin a definite change in the composition and bulk of constituent volcanics could be observed (Encom, 1995).

5.2 GRAVITY DATA

Regional gravity surveys have been completed by the Bureau of Mineral Resources (BMR, now AGSO). The only regional gravity survey carried out specifically for petroleum exploration in the area was undertaken by the United Geophysical Company in 1963 for Sterling Australia Corporation, although many earlier seismic surveys also recorded coincident gravity data.

Onshore gravity data are most commonly expressed in terms of Bouguer Gravity Anomalies, which are the differences between the theoretical values of the earth's gravity field and that observed at given locations. Corrections have been applied to adjust for the impact of elevation at which the gravity observation is made and for the gravimetric influence of rock layers between the observation points and sea level. The original BMR survey was on an approximate 11 km grid. These, and other gravity measurements have been contoured and colour filled to produce the contour map shown as **Map 3.** In general the gravimetric response is complex. Interestingly, there is little coincidence between gravity lows and regions of thickened sediments - depocentres. Generally, mass deficiencies associated with thickened sedimentary pile give rise to gravity lows, but this pattern is not strictly adhered to within this portion of the Basin. For example, the main Mullaley Sub-basin depocentre is not reflected in the gravimetric response. Although local coincidences can be observed, in general gravity lows and thickened sedimentary piles are not sufficiently coincident as to be a useful diagnostic tool. Locally, strong gravity highs are associated with known volcanic basement composition and also granites. Again, granites which are most commonly associated with gravity lows, appear here to be associated with basement highs, possibly reflecting the bulk of the basement response being due to interbedded volcanics and associated sedimentary sequences. The overall lack of coincidence appears to be due to complex variations in Basement composition.

5.3 SEISMIC AND WELL DATA

Map 1 shows the distribution of seismic lines within the Pilliga region. Historically, and as outlined in Section 4, these lines were recorded during exploration for conventional oil and gas accumulations. More recently seismic

reflection data have been recorded to delineate the extent of coal seams for CSM exploration.

Seismic data provide the means for imaging the subsurface down to basement depths. Depending upon the frequency of the energy source, individual beds of several tens of metres thickness can be resolved using this technique. By acquiring seismic data along lines, the geometry of individual sub-surface geological layers can be traced and mapped to produce a pseudo-3D representation of sub-surface structures down to depths of 2 – 3 kms. Conventional petroleum exploration using seismic reflection acquisition involves mapping geological layers in order to locate traps favourable to the accumulation of hydrocarbons. Following generation and expulsion, hydrocarbons migrate into these traps from source rocks under the influence of buoyancy. Typically, these traps are associated with regional structural highs and locally with anticlines, fault blocks or pinchouts of permeable beds updip onto shallowing basement.

As already mentioned, there is a paucity of seismic control in the Pilliga region. Much of the control has only been acquired over a small part of the basin. Mature exploration regions may have several tens, to hundreds of thousands of kilometres of seismic data coverage. Thirty eight seismic surveys have been recorded in this basin, beginning with a 1961 Bureau of Mineral Resources survey. The most recent seismic data is of 1989 vintage. Total seismic coverage is around 3,000 km making the Gunnedah Basin lightly explored. The general quality of these data ranges from fair to good. Much of Esso's extensive Garah and Moree seismic data and part of the MacIntyre seismic survey, covering a significant portion of the north-eastern part of the basin, is single fold, making it significantly inferior to modern high-fold data sets currently acquired using multi-channel digital recording equipment.

Recently, First Source Energy recorded a 484 km seismic programme within the central Bohena Trough. Interpreted these data show the presence of a number of structural targets at different geological levels. Shown on **Map 2** are targets recognised at the Black Jack Group level. These lie in, and across, the flanks of the Bohena Trough and highlight the dependency of target identification and density of seismic coverage. Accordingly, the lack of specific traps in other areas throughout the Pilliga reflects primarily upon the lack of adequate seismic coverage, rather than any positive knowledge of their fundamental absence.

6. MARKETS & COMMERCIALISATION

Clearly the viability of any conventional oil and gas or CSM gas project is ultimately dependent upon finding markets. New South Wales is Australia's largest domestic market for oil and natural gas. New South Wales has no conventional oil or gas production and only limited CSM production from coal mines in the Southern Sydney Basin Coalfield (Mullard, 2000). As such it is the only mainland state to have developed a distribution system based on supplies from other states. To supply the market in NSW, gas is piped from Moomba (in South Australia) to Sydney, Wollongong, Newcastle and several country centres. Within the state AGL Gas Companies (New South Wales) Ltd and its subsidiaries, are responsible for supplying more than 95% of the natural gas requirements.

Oil is to be distinguished from gas in that the former may be sold on a well established international commodity market basis which enables both forward selling and hedging. Gas on the other hand is generally sold on a one to one basis, at rates negotiated between specific producers and suppliers. Whilst New South Wales' energy appetite is large the gas component of of the overall State's energy budget is relatively small. Historically coal fired power stations generate 94% of the State's electricity. Natural gas was first supplied to NSW from South Australia in 1976. After initial demand increases, supply became limited, there being little growth since the mid 1980's (**Figure 8**). Recently, demand has jumped principally as a result of the conversion, in 1997, of the former ICI chemical plant near Botany to gas. NSW now consumes around 128 PJ per year (Mullard, 1999). Because of the supply constraint, NSW has one of the lowest gas usages per capita. One of the major factors cited for future market expansion is the lack of assured long term stable supplies (Mullard, 2000).

There are several other factors which make the development of new gas markets preferable. Firstly, there is increasing pressure to reduce, or contain, green-house gas emissions. The Kyoto climate summit resulted in 159 nations, including Australia, accepting legally binding targets for greenhouse gas emissions as part of the Kyoto Protocol. Secondly, the contracted supply of natural gas to NSW is scheduled to begin to decline this year, and contracts with SANTOS are due for renewal in 2006. This places uncertainity on existing supply as well as opening new opportunities to other industry stakeholders. Thirdly, the explosion and fire at Longford emphasised the need for both stability and diversity of gas supply within Australia. To this end, relevant State authorities throughout Australia are implimenting acreage management policies to ensure increased competition in both upstream and downstream environments. Currently the States of NSW and SA are both supplied from essentially a single source, namely the SANTOS operated gas plant

located at Moomba. This reliance on one gas supply for at least 80 percent of the combined gas market might be considered a very precarious position – only slightly better than that of Melbourne. The development of additional gas supplies for the NSW energy market will not only increase the size of the market due to competitive forces, but will significantly strengthen its security of supply.

Allied with this has been a freeing up of the pipeline system as well as significant expansion of pipelines, particularly in regional areas. In NSW construction was recently completed on a 283 km pipeline from the Moomba-Sydney pipeline to supply the towns of Forbes, Parkes, Narromine, Dubbo and Wellington. This pipeline will be extended through to Gunnedah and Tamworth. Competition between AGL and other uses has resulted from the completion of pipelines for the supply of natural gas to and from Victoria via the link between Wodonga and Wagga Wagga. A second pipeline is also under construction from Longford in Victoria to Sydney via the east coast (Mullard, 1999). This creates an opportunity for reversing gas flow and will enable physical transmission into the eastern Australian grid to supply not only local centres but also major population centres such as Newcastle and Sydney.

As discussed in Section 8, prospects and leads for conventional gas targets have been identified that have the potential to supply local markets. In respect of the Coonarah Gas Field, Morton (1995) indicated that methane from this accumulation could be used to generate electricity for the Namoi Valley Electricity (NVE) Authority. A contract of 1.25 BCF/year would be sufficient to supply all of NVE's requirements (in 1995) and that the Coonarah Gas Field would be able to provide a minimum 10 - 15 year contract (Morton, 1995). As shown in **Table 3** a number of similar sized targets are identified which, if yielding discoveries, could be developed jointly to provide significant gas supply to this portion of the State and Newcastle and perhaps beyond.

The 1997 Australian Gas Association (AGA) demand forecast for the eastern states of Australia (viz. Queensland, New South Wales, Victoria and South Australia) suggests that gas demand will increase from 474 PJ per annum in 1998 to 787 PJ per annum by 2010. Natural gas will be Australia's fastest growing energy source to the year 2030, with average annual projected growth of around 3% with the gas component of the national primary energy share rising from 18 % to 28%.

The development of gas from CSM and conventional means therefore fits in well with both State and national policy. Gas derived from the Gunnedah Basin has the advantage of proximity compared to deposits in the Gippsland Basin and Cooper Basin, and hence would attract lower transport costs. Moreover, gas development is notorious in requiring large initial project funding. The Gunnedah Basin deposits, however, are near existing or planned pipelines. For example AGL has approval to construct a pipeline to Tamworth, with a spur to Narrabri. This is of significance to the development of gas resources in the Gunnedah Basin (Balfe, 2000). This proximity to existing pipelines will allow for its physical connection to the entire Eastern Australian gas market.

7. PROSPECTIVITY OF COAL SEAM METHANE

7.1 PRINCIPLES

CSM is the natural gas formed during the coalification process whereby peat and other organically rich sediments are transformed into coal, as a consequence of compaction and heat associated with the processes of on-going deposition and burial. Coal seam methane is essentially similar to natural gas found in conventional sedimentary reservoirs, although it is generally higher in pure methane concentration. However, unlike conventional natural gas reservoirs, where gas is trapped in the pore or void spaces of a rock such as sandstone, methane trapped in coal is adsorbed onto the coal grain surfaces or micropores and held in place by reservoir (water) pressure. The coal therefore acts as a source, reservoir and seal for the methane and as such is to be distinguished from a conventional gas accumulation within a reservoir rock. Because the micropore surface area is very large, coal can potentially hold significantly more methane per unit volume than most conventional reservoirs such as sandstone.

CSM is generally regarded as an "unconventional" source of natural gas, and is distinguished from conventional hydrocarbon gas which is produced from reservoir rocks, which are typically referred to as "non-sourcing".

In Australia most CSM interest has focused on the Bowen - Gunnedah - Sydney basin system. It has been estimated that in the Bowen Basin (Queensland) the CSM resources could be of the order of 3.5 trillion m^3 or 124, 000 PJ of energy (Oldroyd referenced in Brown et al., 1996). Weber & Bocking (1993) noted that the Sydney Basin may contain 130 000 PJ of energy in CSM. Brown et al. (1996) indicated that the methane resources of the Australian coal fields may be of the order of 10 trillion cubic metres. In 1996 values this would be worth about AUD$200 billion, at the then current gas price, assuming a recovery factor of 20% (Brown et al., 1996).

In New South Wales exploration activity specific to CSM has been carried out for some years in the Gunnedah Basin, Gloucester Basin and Sydney Basin, further to the south. A report on the impact of CSM development within the Sydney Basin, including impact of land use planning and environmental issues was prepared by the DMR and Office of Energy in 1992 (DMR & OE, 1992).

Potential for CSM is not governed exclusively by the presence, or absence, of coal. In order to establish viable, commercial CSM production it is necessary to evaluate the coal seams in order to establish their potential to produce adequate gas volumes on production. The general criteria relevant to the successful discovery and development of CSM resources have been stated as follows by

Brown et al., (1996, *at pp 73-74*) and are repeated herein with appropriate modification:

Areal extent - this depends on the permeability and gas content and varies from area to area. Typically a producing field would comprise at least 250 wells at an “80 acre” (approximately 32 hectacres) spacing requiring between 80 and 100 km^2 of areal extent, depending upon site conditions.

Ash - A low ash content is generally better for CSM recovery. Coals with high (incipient, or detrital) ash content tend to have fewer fractures. Fractures can be filled to varying degrees with “mineral matter” and such mineral matter can also contribute to the ash content of the coal. Coals with high ash content also tend to have less adsorbed gas by volume.

Depth - In general terms, coal seams in the range of 250 to 1000m in depth are favoured for coal seam methane production, otherwise overburden pressures are either too small or too great.

Cleat - Cleat is a fracture or fracture system developed in coal. Face cleat is the fracture system developed parallel to bedding, and butt cleat is a fracture system at right angles to the bedding. Good cleat development is generally more common in coals with high vitrinite and bright clarain. High cleat density tends to suggest higher permeability.

Structuring - CSM prospectivity is enhanced when the coal seam has extensive lateral continuity. Significant fault displacement can restrict production potential from a coal reservoir. This is caused by the dislocation of the reservoir into small unconnected or poorly connected blocks. In some cases faulting can act to permit the escape of methane from the coal, which is deleterious for CSM reservoirs but could allow migration of methane to another reservoir - such as a conventional gas-in-sandstone reservoir. In this respect, there might be an inverse relationship between CSM and conventional oil and gas prospectivity in such areas. The presence, frequency, orientation and intensity of folds, faults, joints, and cleats influence the permeability and continuity of a coal reservoir. The presence of a tensional structural regime is preferred to enhance production potential, because such a regime favours dilation of cleats etc and hence facilitates greater permeability.

Density - There is a preference for coals, which have low bulk density or specific gravity. Specific gravities of less than 1.45 gm/cc are generally regarded as being more suitable for CSM prospectivity, whereas coals with densities of greater than 1.6 gm/cc have lower prospectivity.

Igneous Intrusions - Igneous intrusions can affect the composition of the gas in the coal reservoir by raising the proportion of carbon dioxide present. In some areas, the thermal maturity of the coals present may be altered, the consequences of which can be either favourable or unfavourable.

Insitu Stress - This, expressed in terms of effective stress, is a major control on the cleat and fracture dilation and consequently coal seam permeability. Low effective stress favours good permeability.

Permeability - Permeability is a fundamental parameter for CSM production. Ideally, this should be >5 millidarcies, but sometimes permeability values as low as 1 millidarcy can yield satisfactory gas

flows.

Reservoir pressure - This should generally be at expected hydrostatic levels below 250m depth of burial to ensure the gas is held adsorbed onto the coal, and also to ensure that there is sufficient pressure to promote production from the wells. If the pressure is low then a considerable amount of gas may have been lost. Overpressuring, although not prevalent in Australia, is important because it may help decide on potential cavitation completion targets.

Seam thickness - Generally, the preferred thickness values are coal seam and reservoir thickness> 10m for single and closely spaced completions; and> 15m for multiple completions.

Thermal maturity - The maturation of the coal should be in the range of Ro of 0.7 to 2.0% vitrinite reflectance. Peak maturity for CSM is around 1.2%.

To summarise, permeability, gas content and gas saturation are the most important parameters controlling the production of CSM. As such, exploration programs, as those in the Gunnedah Basin, are designed to locate “sweet spots” where there is an overlap of good gas content and favourable permeability characteristics. Extensive seismic and drilling coverage is required to properly delineate these trends.

7.2 TARGETS

Two coal bearing sequences constituting the CSM resource within the Pilliga region are contained within the Early Permian Bellata Group - Maules Creek, Leard and Goonbri formations (depth 700-900 metres) - and the Late Permian Black Jack Group coals (depth 500-600 metres). The Maules Creek Formation contain thick coals that are gas saturated and highly permeable. The Late Permian Black Jack Group coals include a widespread and thick development of the main basal seam known as the Hoskissons Coal Member. The Black Jack Group is laterally equivalent to the Late Permian Bowen Basin coal measures that are commercially productive in both the Peat and Fairview Fields in Queensland and also in the Sydney Basin, NSW.

Coal seams of the Bellata and Black Jack Groups in the Mullaley/West Gunnedah Sub-basin, the Maules Creek and Hoskisson coals, are the main target seams for the Gunnedah Basin. Although the Huskisson’s seam extends across much of the Basin, the majority of coal seams are confined to the southern to south-eastern corner. With the exception of the Huskisson’s seam, which attains a maximum thickness of 16m and averages 10 m across the southern area of the Basin, seams of the Black Jack Group average between 2 m and 6 m in thickness. The very high ash composition of these coals decreases the total net clean coal component. Despite this, there is a large potential resource (Brown et al., 1996) with much of the southern Gunnedah Basin possessing an average thickness of 20 m of total clean coal over a consistent 250 to 300m pay interval.

To the west of the Boggabri Anticline (Ridge) the coal seams of the Late Permian Black Jack Group (formerly Black Jack Formation) are seen to have widespread distribution and lateral continuity. In particular, the Hoskisson’s seam

presents as a prospective CSM target. The sedimentary thickness of 50 m to 100 m in the northern extent of the Mullaley or West Gunnedah Sub-basin, contains a coal reservoir thickness typically of 5m to 10 m total net clean coal. To the south, total sedimentary thickness increases to 300m, and contains a coal reservoir thickness of 10m to 20m total net clean coal. To the southeast, total coal reservoir thickness increases to a maximum of 30 m total net clean coal in the area of Breeza, where formation (Black Jack Group) thickness approaches 500m.

In the Mullaley/West Gunnedah Sub-basin mean maximum vitrinite reflectance values range from 0.65% along the eastern extent of the Black Jack Group (Hoskisson's coal seam) to 0.8% in the southwestern margin of the Gunnedah Basin. The coal seams of the Gunnedah Basin are generally high in ash, values ranging most commonly from 15% to 30% raw ash.

The Maules Creek Formation, prominent to the north in the Maules Creek Sub-basin, contains some 11 distinct coal seams which range from 1.5 metres to 3.5 metres in thickness (Tadros, et al., 1993, *their Figure 12.6).* An extensive borehole coring program has established that coaly facies associated with the Lower Permian, and particularly the Maules Creek Formation, extend through the Sub-basin and this has been well documented and discussed in a number of publications (eg. DMR 1992; Pratt, 1998; Tadros et al., 1993; Tadros, 1999).

Aggregate or net coal thicknesses are very substantial. **Figure 9** (from Forcenergy, 1999) summarises lithological data from a number of boreholes within the Mullaley Sub-basin. Contoured, these data confirm the presence of a depocentre axis running in a roughly north-south direction through the Bellata, Bohena and Bando Troughs. Calculated net coal thicknesses of up to 37.6 m are recorded in Wilga Park 3 and 5 wells. Characteristics of these coals are pictorially summarised in **Figure 10**. In the Bohena and Wilga Park areas the coals are described as clean or boney depending upon their ash content. Wilga Park coals are significantly cleaner with about 20% of the coals being described as boney. At Bohena, the boney component is more variable, ranging from around 20% at Bohena-3 to more than 60% at Bohena-5. Weighted average gas contents for both clean and boney coals are about 400 SCF/ton (Forcenergy, 1999). In Wilga Park the calculated gas contents range from 433 to 453 SCF/ton for the clean coals and 176 to 214 SCF/ton for the boney coals (**Figure 10**). Higher gas contents are associated with the clean coals in the Bohena area. These are typical values for high volatile bituminous coals (Gas Research Institute, 1994).

These data confirm the presence of a significant gas bearing coaly sequence associated with the Maules Creek Formation in this area. Although quantitative gas content analysis is largely restricted to PEL 238, earlier regional studies confirm that the same coaly facies are present within the Mullaley Sub-basin, coincident with the area in which Lower Permian sedimentation is development.

Notwithstanding the large amount of monies spent to-date, the PEL 238 Joint Venture has evaluated only a portion of the Permit, mainly to the north of the East Pilliga Forest. Further work is, and will, continue in order to identify the optimum sweet spots within this permit. Other industry groups will concentrate on establishing how far these trends continue outside of this Permit. Results in PEL 238 indicate the CSM potential increases southwards beneath the East Pilliga Forest. Consequently, exploration is likely to proceed southwards within the eastern two-thirds of the East Pilliga Forest underlain by Permian coals. The distribution of both Early and Late Permian coals is shown on **Maps 5** and **6**.

7.3 EVALUATION PROGRAM & ECONOMIC SIGNIFICANCE

As a measure of the potential economic benefits that might flow from this exploration, one estimate of the natural gas resources for Petroleum Exploration Licence 238 (covering approximately 9,500 km^2) has been put at over 35 trillion cubic feet (TCF) (Morton, 2000). Although this is not yet at a status of producible reserves, just 1TFC of gas reserves would supply, at current consumption levels, the entire Newcastle-Sydney-Wollongong gas market for approximately 10 years. Pilot plants at Bohena and Wilga Park, just to the north of the East Pilliga Forest, are currently producing CSM, and between March 1998 and February 1999 the PEL 238 joint venture expended some $30 million on the drilling of 15 wells, the acquisition of 484 km of seismic data, two cavity completions and 7 hydraulic fracture stimulations (Morton, 2000). Significant exploration activity has occurred elsewhere within the region targeting equivalent, or similar, geological units. For example, in PEL's 1, 10, 12 and 286, Pacific Power is coventuring with Australian coalbed Methane Pty Limited (Weber, 2000) within the Gloucester Coal Measures. Current exploration is concentrating on proving the resource characteristics of the Stratford Prospect which is thought to contain some 50 PJ (petajoules) of methane in-place. This and other prospects indicate that Gloucester Basin might contain some 200 PJ of methane (Weber, 2000).

Gas reserve forecasts for CSM are established in the same analytical style as conventional reserves with input of all critical data into a reservoir simulator that forecasts gas rates and reserves over time. The "Comet II" reservoir simulator was developed specifically for CSM reserve forecasts and it is the industry standard. Utilising the measured reservoir parameters in the Bohena Project area the "Comet II" reservoir simulation forecast reserves of 5-12BCF/well on a 240 acre (1 square kilometre) well spacing. Reserve variability reflects variations in coal thickness, permeability and completion effectiveness.

Future programs will include drilling additional wells in the Bohena Project area and also focusing on the 15 anticlinal structures identified on the recently acquired seismic data as sites for conventional oil and gas exploration. These newly identified anticlines may have coal seams with free gas caps and so provide both CSM and conventional targets.

The value of a CSM project is determined by both the size of the gas-in-place and the potential reserves (Mavor & Nelson, 1997). The Late Permian Black Jack

Group and the Early Permian Bellata Group contain sizeable coal reserves. The size of the resource within the Pilliga region of the South Brigalow Bioregion is extremely large. However, caution needs to be exercised because at this stage of exploration and production assessment it is not yet possible to quantify what percentage of the ultimate resource is recoverable. As stated in Section 7.1 recoverable quantities, constituting reserves, are controlled by many factors and it is first necessary to quantify the critical coal reservoir properties; coal thickness, gas contents, permeability and reservoir pressure. In the Bohena Sub-basin the Maules Creek Formation coals are thick, very gassy, highly fractured with little or no mineralisation, highly permeable and over-pressured. Reservoir testing of Maules Creek Formation coal seams indicates gas reserves of 5-12 BCF/well at depths less than 1,000 metres (Morton, 2000). Reservoir characterisation projects are being undertaken at both Bohena and Wilga Park areas.

Bohena Project:

Forcenergy (1999) reported that the Bohena Project area contains an average 16.2-21.6 metres of coal over a stratigraphic interval ranging between 36.6-45.7 metres in thickness. The basal seam varies between 4.6-12.2 metres thick. Thirty-three gas content measurements have been performed on Maules Creek Formation coals with analytical techniques rigidly adhering to protocol requirements as recommended by the USA Gas Research Institute ("GRI").

Gas content measurements are high with an average of 474 SCF/ton on a clean coal basis and 540 SCF/ton on a Dry-Ash Free basis (Morton, 2000). Bohena Project area gas-in-place calculated using these gas content measurements is 29-40 BCF/square mile (2.56 sq kms).

Maules Creek Formation coals were isolated for drillstem testing ("DST") during the recent drilling program. DST analysis calculated permeability of 18md in Bohena-2 at a depth of 920 metres and 36md in Bohena-3 at a depth of 887 metres. The high measured permeability is consistent with the highly fractured nature of coals that were recovered by coring and the high fracture intensity mapped with borehole images. Both wells were over-pressured with a pressure gradient of 0.48psi/ft.

Five widely spaced wells were drilled and stimulated using different stimulation technologies. Two wells were completed open hole and treated using the dynamic cavitation method. Two wells were stimulated using a nitrogen foam hydraulic stimulation and two wells were hydraulically stimulated using a borate cross-linked gel. Post stimulation production varied between 200MCF/D and 100BWPD to 1.2MMCF/D and 350BWPD (Morton, 2000). Wells have been undergoing production testing and applications for the drilling of additional production wells are currently before the Department for approval.

Wilga Park Project:

Wilga Park wells encountered clean coal in the Maules Creek Formation ranging in thickness from 20.9-30.7 metres. Gas content measurements of Black Jack Group coal yielded 292 SCF/ton on a clean coal basis and 341 SCF/ton on a

Dry-Ash Free basis – there is no gas content data available for the coals of the Maules Creek Formation (Morton, 2000). Wilga Park Project area gas in place estimates quoted by Morton (2000) range between 12-19 BCF/square mile. Four CSM wells have been drilled at Wilga Park and two of these wells have been hydraulically stimulated using water and one well with nitrogen foam. The wells are currently undergoing production testing.

8. PROSPECTIVITY OF CONVENTIONAL OIL & GAS

8.1 PRINCIPLES

Most sedimentary rocks contain some organic material, although not all rocks are capable of generating hydrocarbons. Typically, rocks capable of generating conventional hydrocarbons have at least 0.5 % and preferably more than 1.0%, total organic carbon content. Coals and fine grained sedimentary rocks, such as shales and siltstones, are the most common rock types containing adequate organic material to constitute potential hydrocarbon source rocks.

When subjected to sufficient depths of burial (associated with increased temperature), and for sufficient time, source rocks will generate and expel liquid or gaseous hydrocarbons. These hydrocarbons move through the microscopic voids in rocks under the influence of buoyancy and congregate in traps where their further movement is impeded by permeability barriers. Structural traps typically are associated with anticlines or faulting. The most prospective traps involve very porous and permeable rock types - reservoirs, such as sandstone in which significant quantities of hydrocarbons may be contained. Seismic reflection surveys are used by explorationists to image potential traps in the subsurface so that they may subsequently be drilled to test whether they contain hydrocarbon bearing reservoirs.

Unlike CSM, expelled conventional oil and gas may move tens of kilometres under the influence of buoyancy (a process of migration) out of the deep basinal areas in which they were generated and across the flanks of adjoining structural highs.

The pod of actively generating source rock (kitchen area) and all related oil and gas, together with all of the essential elements and processes needed for oil and gas accumulations are referred to as a petroleum system (Magoon & Dow, 1994; Magoon, 1997). The occurrence of genetically related oil and gas accumulations implies that migration pathways must exist, either now or in the past, connecting the kitchen with the accumulations. Using the principles of petroleum geochemistry and geology this fluid system can be mapped in order to better understand how it evolved. The goal of the explorationist is to use seismic data, well data and other geophysical data to map and delineate specific petroleum systems in order to locate undiscovered hydrocarbons. This approach can be applied at both the basinal and continental-wide scale (eg. Bradshaw 1993; Bradshaw et al., 1994; Boreham & Summons, 1999).

Traps are described as prospects or leads depending upon the degree of confidence of their delineation. Typically the play fairway comprises a group of areally defined prospects and leads which share similar or

common trap types, seal, reservoir, and hydrocarbon source within a petroleum system. Thus they share common elements of exploration risk relating to the possible occurrence of oil and gas (Baker et al., 1986). Exploration strategies are geared to targeting specific traps in a play fairway and previous exploration results in a specific fairway reflect the geological risk associated with that play type. That is, within the same fairway sourcing, migration and entrapment are similar, whereas they are to some degree different to those of adjacent fairways.

On **Maps 5** and **6** a number of fairways have been defined, based on the regional geology and exploration results to date. The plays within these fairways are described in Section 8.3 and the volumetric capacity of a number of traps already identified by seismic coverage north of the East Pilliga Forest are outlined in Section 8.4.

8.2 OCCURRENCE OF CONVENTIONAL HYDROCARBONS

There have been two significant gas discoveries in the Pilliga region, at Wilga Park-1 and Coonarah-1/1A. Numerous gas and one oil show have also been reported in other wells drilled throughout the region (DMR, 1992; Tadros 1993).

A DST of sands within the Late Permian Porcupine Formation at Wilga Park-1 flowed gas at a rate of 1.0 MMCFD (Morton, 1995). The gas is dry and this may reflect local conditions of the main gas reservoir having been intruded by a 6m thick diorite sill. Conventional gas was discovered within Early Triassic clastics of the Digby Formation at a depth of 473 m by the Coonarah-1 and 1A wells. A minimum 37 m gas column was intersected with no gas-water contact encountered. Seismic mapping indicates a maximum vertical closure of 47 metres. Coonarah-2, located 1.8 km northeast of Coonarah-1 and 1A, intersected a gas filled but tight Digby Formation and recovered a small amount of gas from the underlying Late Permian Black Jack Group. Post-Coonarah-2 reserve estimates indicate potential for sufficient gas in both the Black Jack Group and Digby Formation to be economic (Forcenergy, 1999). High helium and nitrogen contents are also of commercial interest.

The Department of Mineral Resources drilled Bellata-1 in 1986 and intersected a gas sand within the Jurassic Purlawaugh Formation. Wireline logs indicate the sand is gas saturated (Morton, 1995) but it was not tested. Numerous small gas shows have been recorded in a number of coal exploration boreholes (Beckett et al., 1983; Pratt, 1998). The majority of these gas flows emanate from porous and permeable sandstones interbedded with coal seams of the Permian Black Jack Group. An oil show was reported from the Early Permian Boggabri Volcanics in Amoseas Bohena-1 well.

One of the key factors that has emerged with respect to conventional oil and gas exploration in the Gunnedah Basin is recognition of the importance of sediment provenance in controlling reservoir potential. Previous drilling established that sediments derived from the east, sourced from the New England hinterland, tend to be labile rich resulting in poor reservoir

potential – a product of clays derived from the volcanically dominated constituent rocks of that terrane. In contrast, sediments shed from westerly provenances tend to be quartz rich and generally display good reservoir quality (Stewart & Alder, 1995; Morton, 1995; Pratt, 1998). Sandstones within the Late Permian "western bed load fluvial system" (Brigalow Formation) and early Triassic "quartz sand facies" (Ulinda Sandstone Member of the Digby Formation) are considered the most prospective (Pratt, 1998). Reservoir potential of easterly derived sandstones is usually associated with sediments that have been cleaned by reworking in a marine environment, such as a delta front facies (upper Watermark Formation) or shallow marine facies (lower Black Jack Group) (Pratt, 1998).

Forcenergy provided seismic lines from the FSG 98 survey in order to verify the prospects and leads they had identified. The FSG 98 data reveal a highly reflective sequence, consistent with extensive coal measures development. (Coals are particularly strong reflectors of seismic energy). Numerous undulating structures, folds, can be interpreted, such as the one shown on Line FSG98-AAG (**Figure 11**). This feature has an amplitude of about 60 milli-seconds, or 100m, making it quite a robust feature. It correlates with one of the targets listed in **Table 3**, mapped at the Black Jack level. There may be minor faulting on the eastern flank, although rollover is almost exclusively fault independent. Rollover diminishes up through the section but is present within the Surat Basin sequences. This suggests that the folding mechanism is relatively old, probably pre-dating any initial generation of hydrocarbons. Interestingly, there is a small horizontal reflector evident at ~ 500 msec and a slight phase reversal at ~400 msec levels. Both of these features are anomalous to the overall fold envelope geometry of adjacent and bounding reflectors. Such reflections are typically attributed to emanations from fluid boundaries – such as a gas water or gas oil interface. For this reason these reflections are referred to direct hydrocarbon indicators or DHI's, in that they may represent manifestations of the presence of hydrocarbons within the section. Currently, there is no technology which allows the remote, surface detection of commercial quantities of hydrocarbons in the sub-surface.

Lack of faulting, the magnitude of the rollover and associated closure, its "palaeo" time of formation, its position within the depocentre, and the possible presence of DHI's make this an attractive conventional oil and gas target. Drilling however, would be contingent upon further seismic delineation in order to select an optimum well location.

Adjoining lines of this survey show similar anticlinal structures within the Bohena Trough as well as a variety of fault related anticlines and tilted basement blocks, confirming the presence of targets itemized in **Table 3**. A number of smaller, fault related structures are also observed, although data density does not enable these to be mapped as prospects at this stage.

In addition to the structural targets, the seismic data also show the potential for stratigraphic and combinational traps for conventional hydrocarbons. These are

particularly developed across the western flank of the Bellata Trough where the available seismic coverage shows the sediment thicknesses to rapidly thin, over a depositional "hinge-line". An example is shown as **Figure 12**, portion of Line FSG98-AAC. Truncation of the strongly reflective, coaly, sequences provide so-called up-dip pinchout potential immediately below the Triassic – Permian Unconformity. Unconformity traps such as this are a well recognised type of conventional oil and gas trap, but their veracity would need much more seismic control in order to confirm that permeability barriers exist both at the unconformity surface and structurally to the north and south of the illustrated section before a well would be drilled. Nevertheless, the severity of truncation suggests that this trapping mechanism might exist along the entire margin of the Beheno Trough, and adjacent Bando and Bellata Troughs, in a zone roughly coincident with the truncation of the coaly facies.

8.3 PLAY DELINEATION

For practical purposes the play fairways were defined on the basis of seismic maps showing structuring and the distribution of drainage catchment areas. The distribution of fairways and associated play types are illustrated on **Map 6.**

8.3.1 Tooraweenah Trough

This fairway encompasses the northern and eastern flank of the Tooraweenah Trough together with the southern flank of the Baradine High. The prospectivity here is predicated on the presence of an active petroleum system within the Tooraweenah Trough. North of the synclinal axis, generated hydrocarbons would migrate up-dip northwards under the influence of buoyancy into the surrounding highs. Traps are envisaged to involve southern plunging noses, and drape over undulations along the flank of the Baradine High. A stratigraphic component, with pinchouts onto shallowing basement, is envisaged, similar to that illustrated in **Figure 12**. Target reservoirs are anticipated within the Black Jack and Digby units, this fairway being well positioned to receive quartz rich sediments derived from the adjacent western Lachlan Fold Belt provenances.

8.3.2 Bando Trough West Flank

This fairway encompasses the western flank of the Bando Trough and includes the eastern projection of the Baradine High. It is the counter-part to the Bando Trough East Flank fairway. The prospectivity here is predicated on the presence of an active petroleum system within the Bando Trough. West of the synclinal axis generated hydrocarbons would migrate into anticlinal folds and fault related anticlines such as observed on **Figure 11** within the depocentre. Objectives would be sought within the Porcupine, Black Jack (western bed load fluvial system) and Digby Formation, especially those quartz rich units derived from the west. Beyond the western margin hinge-line hydrocarbons may accumulate within the unconformity traps and structural traps associated with eastern plunging noses, involving the Digby Formation. Unconformity traps would be best developed where Lower Permian sediments rapidly thin across the hinge line, in a setting similar to that shown in **Figure 12**.

8.3.3 Bando Trough East Flank

This fairway encompasses the eastern flank of the Bando Trough and includes the southwestern flank of the Boggabri Ridge. It is the counter-part to the Bando Trough West Flank fairway. The prospectivity here is predicated on the presence of an active petroleum system within the Bando Trough. East of the synclinal axis generated hydrocarbons would migrate up-dip to the east under the influence of buoyancy. Again faulted anticlines and folds such as observed on **Figure 11** within the depocentre would be the primary exploration targets. Further out of the basin faulted basement blocks and drape over westerly plunging structural noses may be the principal targets in that area. Objectives would be sought within the Porcupine, Black Jack and Digby units, although the latter, being more distal to the provenance is likely to be less developed than its equivalents on the western flank.

8.3.4 Pilliga Trough East Flank

This fairway encompasses the eastern flank of the Pilliga Trough and the western flank of the Rocky Glen Ridge, west of the north-south trending structural axis. Regional geological cross-sections, based on existing drilling, confirm that Permian sediments thin onto the flank of this Ridge and as such provide regional potential stratigraphic traps within sands of the Black Jack and Digby units. This play type is predicated upon a petroleum system located within the Pilliga Trough. Both stratigraphic traps and structural traps located on shallowing basement across the northern flank of the Baradine High and western flank of the Rocky Glen Ridge would be sourced by such a petroleum system, the hydrocarbons moving up-dip into these structurally shallower sites under the influence of buoyancy. The extent of the associated fairway is controlled by the position of regional structural (anticlinal) axes to the south (along the Baradine High), north and east (along the Rocky Glen Ridge) (**Map 6**). Being the most westerly located, this fairway is anticipated to have the greatest proportion of quartz-rich facies capable of providing potential reservoir sequences, particularly within equivalents of the Digby Formation. These would constitute the principal reservoir targets.

8.3.5 Bohena Trough West Flank

This fairway encompasses the western flank of the Bohena Trough and the eastern flank of the Rocky Glen Ridge, east of the north-south trending structural (anticlinal) axis. Regional geological cross-sections, and seismic traverses such as FSG98-AAG (**Figure 11**) confirm that the Maules Creek Formation (Lower Permian) and Upper Permian (Back Jack) thin towards the west onto the Rocky Glen Ridge. As shown on **Figure 11** and illustrated on **Maps 5** and **6**, numerous anticlinal structures have been identified within the main depocentre. These appear to involve compactional drape as well as some possible late compressional reactivation. Some structures have both fault dependent and independent closures evident. Having palaeo-closure components, being located within the depocentre and being relatively robust, these are considered excellent targets for conventional gas and oil exploration. Several appear to have possible DHI's suggestive of effective trapping. Reservoir objectives for these targets would be sought within the Porcupine, Black Jack and Digby units. The Digby Formation flowed at a rate of approximately 2 million cubic

feet of gas per day (2MMCFPD) during a drill stem test in 1998.

Further out of the Trough, across the hinge-line, unconformity related pinchout traps are anticipated involving the coal measure sequences. West of this Digby Formation reservoirs would be sought in easterly plunging structural noses, and fault related tilted basement blocks. In addition, an east-west trending high, the Culgoora High (**Map 2**), forms a major focal point for hydrocarbons migrating northwards out of the Bohena Trough proper. This high encompasses the Wilga Park and Coonarah hydrocarbon accumulations. The occurrence of gas at these localities attests to the presence of an active petroleum system within the Bohena Trough. In addition to sourcing hydrocarbons along the Culgoora High, traps to the west across shallowing basement onto the flanks of the Rocky Glen Ridge are also likely to be sourced by migrating hydrocarbons sourced from this kitchen area. Westerly derived quartz rich sandstones within the Brigalow Foratmion, Clare Sandstone and Upper Digby Formation are anticipated to provide the principal reservoir targets.

8.3.6 Bohena Trough East Flank

This fairway encompasses the eastern flank of the Bohena Trough and western side of the Boggabri Ridge, including the Culgoora High east of the Bohena Trough synclinal axis. This fairway is a counterpart to the West Flank, being distinguished by the easterly movement (charge) of hydrocarbons out of the Bohena Trough, under the influence of buoyancy. Similar traps to those described on the West Flank counterpart are envisaged across this fairway, although it is likely that some coals here may be adversely affected by igneous activity associated with the Garrawillia Volcanics, and again the Digby Formation may been less well developed because of its more distal setting.

8.3.7 Bellata Trough West Flank

This fairway encompasses the western flank of the Bellata Trough and the northern extension of the Rocky Glen Ridge. It is the northern equivalent of the Bohena Trough West Flank fairway, being distinguished by hydrocarbon charge sourcing the Bellata, rather than the Bohena, Trough because of the structural barrier created by the east-west trending Culgoora High. Otherwise, similar trapping mechanisms and exploration objectives are envisaged to that described for the Bohena West Flank fairway.

8.3.8 Bellata Trough East Flank

This fairway encompasses the eastern flank of the Bellata Trough and the western side of the Boggabri Ridge (locally referred to as the Moema High), north of the Culgoora High. This fairway is the counterpart to that of the West Flank, being distinguished from the Bohena Trough East Flank fairway because of the Culgoora High, which effectively compartmentalises the petroleum system active within it. East of the synclinal axis, hydrocarbons generated within this Trough would migrate under the influence of buoyancy into either folds and anticlines within the depocentres or more easterly located, westerly plunging noses and tilted basement fault blocks on the shallowing basement to the east. Southerly migrating hydrocarbons may also charge structures on the eastern

portion of the Culgoora High. Portions of this fairway may be adversely impacted by shallow intrusives.

8.4 Volumetrics

As an indicator of the potential of structures identified by the detailed seismic coverage in the Bohena Trough "theoretical" volumetrics for oil and gas were calculated. These were derived either by use of the fundamental volumetric equations (eg. Webber 1961) or by industry accepted rules of thumb, such as barrels recoverable per acre-ft or cubic feet of gas/acre-ft. In each case reserves were estimated for each reservoir horizon taking into account known drilling results.

Volumetrics for oil and gas were determined as described below using standard industry formulae (eg., Webber, 1961).

Volumetric Oil Reserves

Volumetric estimates of oil reserves can be established by the following industry applied formula.

$$\mathbf{V} = \mathbf{G} \times \mathbf{A} \times \mathbf{H} \times \mathbf{Geof}$$

where

$\mathbf{G} = 7758 \times \phi \times (1-\mathbf{S_w}) \times \mathbf{B_o}$

where $\mathbf{B_o}$ is the hydrocarbon volume factor, $\mathbf{S_w}$ is the water saturation, ϕ is the porosity, **A** is the area of the trap in acres, **H** is the net thickness in feet and **Geof** is a geometric factor of the reservoir.

Volumetric Gas Reserves

Volumetric estimates of gas reserves can be established by the following industry applied formula.

$$\mathbf{V} = \mathbf{G} \times \mathbf{A} \times \mathbf{h}$$

where

$\mathbf{G} = 43560 \times \phi \times (1-\mathbf{S_w}) \times \mathbf{B_g}$

and $\mathbf{B_g} = \mathbf{P_{res}} \times \mathbf{T_{surf}} (1-\mathbf{Z}) / \mathbf{P_{std}} \times \mathbf{T_{res}}$

V is the volume of gas reserves in place at 14.7 psia and 60^o F (standard atmospheric pressure and standard surface temperature), **G** is the volume of gas reserves in place per acre-foot (SCF/acre-ft), **A** is the area in acres defined by structural mapping and **H** is the net pay in feet, ϕ is the porosity, $\mathbf{S_w}$ the water saturation, $\mathbf{B_g}$ the gas volume factor applied assuming ideal gas law conditions expressed as reservoir cubic feet per standard cubic feet, $\mathbf{P_{res}}$ is the reservoir pressure in psia and $\mathbf{T_{res}}$ is the reservoir temperature (^{o} R), and **Z** is the gas deviation factor.

Table-3 shows indicative volumetrics for targets identified to date at the Black Jack Group coal measures level, on a structure map interpreted by Forcenergy using their seismic coverage. Assuming a 300,000 SCF/Acre-FT recovery factor for conventional gas and adopting a 20ft thick net pay interval (within the combined Porcupine, Black Jack and Digby units) this equates to a 4,000,000 SCF per acre of net pay. At 250 acres km^2. This equates to 1.5 BCF of gas per sq km of trap. For oil using standard parameters, a conservative recovery of 150 barrels equivalent per acre-ft is anticipated. Assuming a 20ft net pay interval this equates to 3000 barrels per acre of trap, or ~750,000 barrels per sq km. Individual volumetrics will obviously vary depending upon specific reservoir parameters. For example at Coonarah a thicker pay (a 37 metre gross gas column is indicated to have a 80% net/gross ratio -

Morton, 1995) is indicated and reserves have been estimated at between 15 and 40 BCF (Mullard, 1999).

Table 3 : Volumetrics for Identified targets at Black Jack level.

Structure	Area(KM^2)	Gas Recoverable (BCF)	Oil Recoverable Millions of barrels
Burrawarni	21.75	32.6	16.31
Bibblewindo	9.0	13.5	6.750
Jack Creek North	9.0	13.5	6.750
Jack Creek South	18.0	27.0	13.5
Wilga Park	12.0	18.0	9.0
Goona Creek	7.0	10.5	5.25
Newell Highway	13.0	19.5	9.75
Lynwood	10.0	15.0	7.5
Coonarah	9.0	13.5	6.75

9. CONCLUSIONS

CSM gas occurrences and pilot testing at Coonarah, Bohena and Wilga Park establish the Permian coal seams of the Pilliga region of the Gunnedah Basin as having the potential to be a signficiant gas resource. Likewise, the occurrence of gas within sandstone reservoirs at Coonarah and Wilga Park attest to the Bellata and Bohena Troughs containing active petroleum systems capable of conventional gas generation. Similarities of the geology and burial depths and minor occurrences of gas in coal-bores imply that the neighouring, but the less well explored, Bando, Pilliga, and Tooraweenah Troughs are also likely to be sites for generation for both conventional and CSM associated hydrocarbons. Using standard industry accepted techiques, regions of both CSM and conventional oil and gas related prospectivity have been identified. These cover much of the Pilliga region of the Southern Brigalow bioregion.

The East Pilliga Forest and Pilliga Nature Reserve lie within a roughly north-south corridor, centred on the Bellata, Bohena and Bando Troughs, a geological area considered to be the most prospective portion of the Pilliga region for both CSM and conventional oil and gas. Enhanced conventional oil and gas prospectivity is recognised around the northern and eastern margins of the Tooraweenah and Pilliga Troughs, respectively, and across the adjacent bounding highs. With the current state of knowledge, the least prospective areas for both conventional oil and gas and CSM is coincident with the structural axis of the Baradine High, which lies immediately to the south of the Pilliga Nature Reserve and West Pilliga Forest. This area has no coal measure cover and is probably too remote from known, or anticipated, petroleum kitchen areas, to have received any significant hydrocarbon charge to have significant conventional oil and gas prospectivity.

Put within the context of hydrocarbon exploration generally, the Pilliga region represents the most prospective portion of the State yet identified. In terms of current knowledge, and ranked on a state-wide basis, its prospectivity is outstanding. There are no other basins in the State in which have two conventional hydrocarbon accumulations has been discovered, let alone be under evaluation. Moreover, CSM evaluation in the Gunnedah Basin is to be favourably distinguished from that in the Sydney Basin because of its more advanced stage of assessment.

That is, this assessment of the prospectivity of the Gunnedah Basin is based not only on perceptions of exploration potential but on actual production testing and exploration (drilling) results to-date. Although it is too early to quantify actual recovery rates and quantities, the CSM and conventional gas accumulations may have the potential to provide the Newcastle-Sydney-Wollongong market for several years and so be of comparative size to the Cooper Basin

reserves. Industry assessment is on-going and although the commercial viability will depend ultimately upon the outcome of these, and future production tests, there is a reasonable expectation that the exploration in this portion of the Gunnedah Basin will yield results that could be significant at three levels :

- At a regional level, by providing gas related energy to the regional community based around Narrabri.

- At a State level, by providing gas feed-stock to the state-wide pipeline system, enabling greater diversification and stability of supply and first significant domestic production of gas within New South Wales.

- At a national level, by reducing the reliance upon black coal fired power within the State and so impacting upon Australia's greenhouse targets and the diversity and stability of gas supply throughout Eastern Australia

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GLOSSARY

BFC - billion cubic feet (x 10^9)

BSL - below sea level

MBBLS - thousands of barrels

MCF - thousand cubic feet (x 10^3)

Msec – Milliseconds (1/1000^{th} of a second), units of seismic reflection travel time, as displayed on vertical scale of seismic section.

MMBBLS - millions of barrels

MMCF - million cubic feet (x 10^6)

MSL - mean sea level

psi - pounds per square inch

SCF - standard cubic feet (as opposed to volumes at reservoir temperatures and pressures)

TCF - trillion cubic feet (x 10^{12})

TD - total depth (of petroleum well or coal bore hole)

APPENDIX - META FILE DESCRIPTION

The following meta-files pertaining to the Maps included in this report are described:

Wilga Park Production Area

Top Digby Formation – Structure contours across Coonarah Field.

Pilliga Play Map

Petroleum Bore Hole Locations

Permian Edge Pinchout – western margin

Seismic Line Location Map – open file data only

Seismic Line Location Map for FSG 1998 Survey

Black Jack Level Exploration Targets

Bohema Production Area

Coal Seam Methane Potential

Coal Bores

Depth Contours

Maules Creek Formation

Shot Point Location Data

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Wilga Park pilot area well testing and production area map. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
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METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	Polygon delineating the extent of the Wilga Park production testing facility / development of coal seam methane as defined by Forcenergy 1999. This area contains several gas testing wells linked to a central connection point as part of a long term testing program to establish gas production characteristics from coal seam methane.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas, coal seam methane, production facility.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Location name of feature
	Scale/Resolution	Boundary defined from 1:30,000 scale hardcopy.
DATASET CURRENCY	**Beginning date**	1999
	Ending date	1999
DATASET STATUS	**Progress**	Boundaries to testing area will alter over time as exploration and testing proceed.
	Maintenance and update frequency	Complete
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	12 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Derived from hardcopy map showing location of production test wells. Sourced from Forcenergy 1999 documents.
	Positional accuracy	Indicative to 200m
	Attribute accuracy	100%
	Logical consistency	100%
	Completeness	Complete
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	Coal Petrosys
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
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	Suburb/place/locality	Armidale
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	Country	Australia
	Postcode	2350
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	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Extent of structural closure as defined by Top of the Digby Formation depth mapping for the Coonarah gas field. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
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METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	Polygon delineating the extent of structural closure based on depth mapping of the top of the Digby Formation around the Coonarah gas field as defined by Morton (1995)-figure 13. This defines the extent of the known conventional gas occurrences encountered in the Coonarah 1A and 2 wells.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Location name of feature
	Scale/Resolution	Boundary defined from 1:40,000 scale hardcopy.
DATASET CURRENCY	**Beginning date**	1995
	Ending date	1995
DATASET STATUS	**Progress**	Boundaries to known gas occurrences will alter over time as exploration and production proceed.
	Maintenance and update frequency	Complete
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	12 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Derived from hardcopy map showing location of production test wells. Sourced from Morton (1995) see Shaw (2000).
	Positional accuracy	Indicative to 250m
	Attribute accuracy	100%
	Logical consistency	100%
	Completeness	Complete
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	Coal Petrosys
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Pilliga Play Map Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This is an interpretative map based on accepted petroleum industry constructs. This map shows tracts in which conventional oil and gas exploration plays are identified. That is, tracts in which exploration risk for targets is likely to be similar because the geological controls governing oil and gas accumulations are similar. In each tract – or fairway there are similar reservoirs, seals, traps, migration pathways and source rocks, and burial history. These are the principal elements controlling the formation of conventional oil and gas. Fairways provide a convenient way of categorising exploration targets into “play types”.-
	Search Word	Geoscience, geology, faults, mineral exploration, conventional petroleum, gas. prospectivity
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Name – refer to Shaw (2000) for full details of each polygon attribute.
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	2000
	Ending date	2000
DATASET STATUS	**Progress**	Completed.
	Maintenance and update frequency	May be revised as further exploration and development drilling results emerge.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	50kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Interpretative Shaw (2000)
	Positional accuracy	1 or 2 km. The boundaries are indicative and may be gradational over several kms especially in areas where geoscientific data coverage is pauce.
	Attribute accuracy	High
	Logical consistency	High
	Completeness	Complete
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Petroleum bore hole locations for the Pilliga region. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/1029
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This coverage shows the location and name of petroleum bore holes in the Pilliga region. This does not include all gas testing wells or coal bore holes. The set only includes holes drilled for conventional gas or petroleum targets.
	Search Word	Geoscience, geology, mineral exploration, petroleum bore holes.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Point
	Attribute/Field List	Name
	Attribute/Field Description	Name
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent. Some parts are 1:100,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1965?
	Ending date	2000
DATASET STATUS	**Progress**	Upgrades will continue.
	Maintenance and update frequency	As resources are available.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	10 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	The location of petroleum bore holes have been recorded progressively in Departmental databases over several decades. This data set is indicative only and does not necessarily show all holes. Attribute data is minimal in this data set.
	Positional accuracy	Various, some holes are located with high accuracy, others to several hundred metres.
	Attribute accuracy	Name only, accurate.
	Logical consistency	100%
	Completeness	Indicative only. The data set does not necessarily show all holes. This data set is not fully validated.
NOTES	**Notes**	The Department of Mineral Resources holds additional data on drill holes such as total depth of wells and formation types and tops.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Permian Edge pinchout edge of Permian aged sediments maps. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This map shows the western extent of interpreted Permian aged sediments within the project area. The significance of this boundary is that it defines the western limit of areas prospective for coal seam methane potential. It also defines the western extent of sediments likely to have source potential for generating conventional oil and gas. The boundary is truncated both north and south for convenience. Conventional oil and gas targets exist on either side of this boundary, although it is implicit that those to the west are more hydrocarbon migration dependent.
	Search Word	Geoscience, geology, faults, mineral exploration ,coal seam methane petroleum, gas.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Line
	Attribute/Field List	Level – not meaningful in this context
	Attribute/Field Description	
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1992
	Ending date	2000
DATASET STATUS	**Progress**	Complete
	Maintenance and update frequency	May be updated with newer interpretations.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	8 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Sourced from DMR (1992).
	Positional accuracy	500m
	Attribute accuracy	High
	Logical consistency	High
	Completeness	Complete. However boundary extends to north and south beyond line ends.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Seismic line locations map- open file data only. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This coverage shows the distribution of seismic reflection data recorded to image the sub-surface for both conventional oil and gas as well as coal seam methane targets. The data set consists of individual shot points, or vibration points, which mark the position where seismic energy has been introduced into the ground. Typically has required truck access but with regrowth there may be no physical evidence of the location of these lines. More recent lines are delineated with permanent markers, usually at the end of the line and at line intersections. These consist of surveyed steel star pickets, identifying the line number, survey name and year of acquisition.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas, seismic.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Point
	Attribute/Field List	Line name, shot number, grid reference
	Attribute/Field Description	Line name, shot number, grid reference
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent. Some parts are 1:100,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1963?
	Ending date	2000
DATASET STATUS	**Progress**	Additional points will be added over time from new surveys.
	Maintenance and update frequency	As required
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	7 Mb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Data have been progressively acquired from surveyed shot point locations provided in reports to the Department of Mineral Resources since exploration in this area began. Prior to ~1985 data points were digitized from shot point location maps typically at a scale of 1:50,000 or 1:100,000. More recent data are provided directly in surveyed digital form by the seismic contractor. There appear to be alternate positional data for some lines.
	Positional accuracy	Highly accurate but older surveys may be mis-located by up to 200m due to digitizing errors or mis-registration.
	Attribute accuracy	High, but some lines appear to be duplicates.
	Logical consistency	High
	Completeness	Complete for open file data only.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	FSG (First Source Group / Forcenergy) Seismic line locations map- 1998. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/1029
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This coverage shows the distribution of seismic reflection data recorded to image the sub-surface for both conventional oil and gas as well as coal seam methane targets. The data set consists of individual vibration points, which mark the position where seismic energy has been introduced into the ground. Typically has required truck access but with regrowth there may be no physical evidence of the location of these lines. Lines are delineated with permanent markers, usually at the end of the line and at line intersections. These consist of surveyed steel star pickets, identifying the line number, survey name and year of acquisition.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas, seismic.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Point
	Attribute/Field List	Line name, shot number, grid reference
	Attribute/Field Description	Line name, shot number, grid reference
	Scale/Resolution	Highly accurate +/- 5 m.
DATASET CURRENCY	**Beginning date**	1998
	Ending date	1998
DATASET STATUS	**Progress**	Complete.
	Maintenance and update frequency	Not applicable.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	10 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Data have been provided from First Source Energy from recent survey. Data provided in digital form.
	Positional accuracy	Highly accurate GPS survey points.
	Attribute accuracy	High
	Logical consistency	High
	Completeness	Complete.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Black Jack Formation - structural targets for conventional oil and gas. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	Structural targets are areas identified on the basis of mapping of the top of the Black Jack Formation which are considered to coincide with conventional oil and gas traps. These are typically the crests of anticlines or tilted fault block structures. The mapping is derived from seismic data coverage sets. These targets are described as either prospects or leads depending upon the degree of reliability. They have not yet been drilled but represent an inventory of targets that may be drilled in the future. Some will require further seismic delineation prior to drilling.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas, seismic.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Name
	Scale/Resolution	Digitized from 1:50,000 hardcopy interpretative map
DATASET CURRENCY	**Beginning date**	1999
	Ending date	1999
DATASET STATUS	**Progress**	Prospect boundaries will alter with the acquisition of further seismic data and exploration drilling.
	Maintenance and update frequency	
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	30 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Based on interpretation of maps provided by First Source Energy to the Department of Mineral Resources.
	Positional accuracy	Indicative to 200m
	Attribute accuracy	100%
	Logical consistency	High
	Completeness	High, but does not include stratigraphic or combination structural / stratigraphic traps.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Bohena pilot well testing and production area map. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	Polygon delineating the extent of the Bohena production testing facility / development of coal seam methane as defined by Forcenergy 1999. This area contains several gas testing wells linked to a central connection point as part of a long term testing program to establish gas production characteristics from coal seam methane.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas, coal seam methane, production facility.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Location name of feature
	Scale/Resolution	Boundary defined from 1:30,000 scale hardcopy.
DATASET CURRENCY	**Beginning date**	1999
	Ending date	1999
DATASET STATUS	**Progress**	Boundaries to testing area will alter over time as exploration and testing proceed.
	Maintenance and update frequency	Complete
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	12 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Derived from hardcopy map showing location of production test wells. Sourced from Forcenergy 1999 documents.
	Positional accuracy	Indicative to 200m
	Attribute accuracy	100%
	Logical consistency	100%
	Completeness	Complete
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	Coal Petrosys
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Coal Seam Methane potential distribution map. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
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	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This map shows the extent of interpreted coal seam methane potential. It coincides in the east with the distribution of the Lower Permian Maules Creek Formation and in the west with the extent of known Late Permian coaly facies sediments (Permian edge). Within this defined polygon there is potential for coal seam methane. As such it includes those areas currently under pilot production testing at Wilga Park and Bohena. Conventional oil and gas targets exist both inside and outside this defined polygon.
	Search Word	Geoscience, geology, faults, mineral exploration,coal seam methane petroleum, gas.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Name
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1992
	Ending date	2000
DATASET STATUS	**Progress**	Complete
	Maintenance and update frequency	May be updated with newer interpretations.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	8 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Sourced from DMR (1992) and Forcenergy (1998)
	Positional accuracy	500m
	Attribute accuracy	High
	Logical consistency	High
	Completeness	Complete within boundaries – units extends beyond polygon to north and south.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Coal bore hole locations for the Pilliga region. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/1029
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This coverage shows the location and name of coal bore holes in the Pilliga region.
	Search Word	Geoscience, geology, mineral exploration, coal bore holes.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Point
	Attribute/Field List	Name
	Attribute/Field Description	Name
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent. Some parts are 1:100,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1970
	Ending date	2000
DATASET STATUS	**Progress**	Upgrades will continue.
	Maintenance and update frequency	As resources are available.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	10 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	The location of coal bore holes have been recorded progressively in Departmental databases over several decades. This data set is indicative only and does not necessarily show all holes. Attribute data is minimal in this data set.
	Positional accuracy	Various, some holes are located with high accuracy, others to several hundred metres.
	Attribute accuracy	Name only, accurate.
	Logical consistency	100%
	Completeness	Indicative only. The data set does not necessarily show all holes. This data set is not fully validated.
NOTES	**Notes**	The Department of Mineral Resources holds additional data on drill holes, such as coal seam thicknesses and depth of holes.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
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	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Depth to basement contours. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
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	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	Depth to basement contours derived from bore and petroleum well and interpreted depth conversion of seismic data. Contours are relative to mean sea level and are indicative outside of the basin proper due to paucity of data. . Basement in this context refers to the top of indurated rock layers (either metamorphic or igneous rocks) that do not contain any significant oil or gas or coal seam methane potential. Depth contours are indicative of the overlying thickness of sediments- relative to datum.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Line
	Attribute/Field List	Level
	Attribute/Field Description	Depth to basement relative to sea level in metres.
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1995
	Ending date	2000
DATASET STATUS	**Progress**	Complete
	Maintenance and update frequency	Complete
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	300 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Data set represents a compilation of two sources. Firstly, Encom (1995) – based on borehole information, and secondly, First Source Energy (1999) based on depth conversion of seismic data.
	Positional accuracy	250m
	Attribute accuracy	High, but interpretative
	Logical consistency	High
	Completeness	Complete
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
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	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Maules Creek Formation – distribution map. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	C00/0129
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
	Mail Address 2	(PO Box 536)
	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This map shows the distribution of the Lower Permian Maules Creek Formation. The formation is contained within the defined polygon, being truncated onto the adjacent structural highs. This distribution is based on seismic imaging and intersections of the formation by coal bore holes. The formation continues to the north and south and polygon boundaries in these directions are arbitrary for the purposes of this project. The Maules Creek Formation distribution approximately coincides with the extent of Lower Permian coal seam methane potential.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Polygon
	Attribute/Field List	Name
	Attribute/Field Description	Name
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1998
	Ending date	2000
DATASET STATUS	**Progress**	Complete
	Maintenance and update frequency	May be updated with newer interpretations.
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	10 kb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Sourced from Tadros et al. (1993) and Forcenergy (1998)
	Positional accuracy	500m
	Attribute accuracy	High
	Logical consistency	High
	Completeness	Complete within boundaries – units extends beyond polygon to north and south.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET	**Title**	Seismic line locations map- open file data only. Geoscience Resource Audit – Western Region South Brigalow Belt -(Pilliga State Forest).
	Custodian	NSW Department of Mineral Resources
	Jurisdiction	New South Wales, Australia
	Project Name	South Brigalow belt (Pilliga forest) – geoscience data
	Project Number	
CONTACT ADDRESS	**Contact organisation**	NSW Department of Mineral Resources Geological Survey of New South Wales Minerals Assessment Program Coal and Petroleum
	Contact position	Brad Mullard, Assistant Director, Coal and Petroleum or Robert G Barnes, Senior Geologist, Resource Information, Integration and Analysis.
	Mail Address 1	29-57 Christie Street
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	Suburb/Place/Locality	St Leonards
	State/Locality 2	NSW
	Country	Australia
	Postcode	1590
	Telephone	02 9901 8888
	Facsimile	02 9901 8783
	Electronic mail address	barnesr@minerals.nsw.gov.au or mullardb@minerals.nsw.gov.au

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DESCRIPTION	**Abstract**	This coverage shows the distribution of seismic reflection data recorded to image the sub-surface for both conventional oil and gas as well as coal seam methane targets. The data set consists of individual shot points, or vibration points, which mark the position where seismic energy has been introduced into the ground. Typically has required truck access but with regrowth there may be no physical evidence of the location of these lines. More recent lines are delineated with permanent markers, usually at the end of the line and at line intersections. These consist of surveyed steel star pickets, identifying the line number, survey name and year of acquisition.
	Search Word	Geoscience, geology, faults, mineral exploration, petroleum, gas, seismic.
	Geographic Extent Name(s)	This data set is one of several which cover the Pilliga forest and surrounds only.
	Geographic Extent Polygon(s)	The data set covers an area included in the polygon – southwestern corner 640,000e, 6,520,000N, northwest corner 640,000E, 6,700,000N, northeast corner 780,000E, 6,700,000N and southeast corner 780,000E, 6,520,000N. Although data may extend beyond these boundaries it may not be complete.
	Type of feature	Point
	Attribute/Field List	Line name, shot number, grid reference
	Attribute/Field Description	Line name, shot number, grid reference
	Scale/Resolution	The data is presented as 1:250,000 scale equivalent. Some parts are 1:100,000 scale equivalent.
DATASET CURRENCY	**Beginning date**	1963?
	Ending date	2000
DATASET STATUS	**Progress**	Additional points will be added over time from new surveys.
	Maintenance and update frequency	As required
DATASET ENVIRONMENT	**Software**	ArcInfo, ArcView
	Computer Operating System	UNIX, Windows NT
	Dataset Size	7 Mb

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
ACCESS	**Stored Data Format**	Data are presented as ArcView shape files but are derived from source data held in a PetroSys database.
	Available format types	ArcView
	Access constraints	Publicly available provided that reference to data source is made. Any re-distribution of the data in any form must be licensed by the NSW Department of Mineral Resources.
DATA QUALITY	**Lineage**	Data have been progressively acquired from surveyed shot point locations provided in reports to the Department of Mineral Resources since exploration in this area began. Prior to ~1985 data points were digitized from shot point location maps typically at a scale of 1:50,000 or 1:100,000. More recent data are provided directly in surveyed digital form by the seismic contractor. There appear to be alternate positional data for some lines.
	Positional accuracy	Highly accurate but older surveys may be mis-located by up to 200m due to digitizing errors or mis-registration.
	Attribute accuracy	High, but some lines appear to be duplicates.
	Logical consistency	High
	Completeness	Complete for open file data only.
NOTES	**Notes**	Further detail refer to Shaw, R. (2000). Assessment of hydrocarbon potential, Pilliga region, New South Wales. Prepared for Department of Mineral Resources.
METADATA DATE	**Metadata date**	February 2000.
METADATA COMPLETED BY	**Metadata sheet compiled by**	Robert G Barnes, Ray Shaw
FURTHER INFORMATION	**Further information**	The reference source data is stored on servers in the Department of Mineral Resources.

METADATA CATEGORY	CORE METADATA ELEMENT	DESCRIPTION
DATASET ENVIRONMENT	**Name of System:**	
	Contact organisation	NSW Department of Mineral Resources
	Contact position	Senior Geologist, Resource Information Integration and Analysis, Geological Survey of NSW
	Mail address	PO Box 65, Armidale, NSW, 2350
	Suburb/place/locality	Armidale
	State	NSW.
	Country	Australia
	Postcode	2350
	Telephone	02 67702118
	Facsimile	02 67702121
	Electronic mail address	barnesr@minerals.nsw.gov.au
	Description	ArcView / ArcInfo GIS
	Availability	
	Miniumum Hardware Requirements	PC Pentium
	Miniumum Software Requirements	ArcView 3.1
	Input Format/Type	ArcView shape file
	Output Format/Type	Various exchange formats available through ArcView
	References	