Thermal history and geological controls on the distribution of coal seam gases in the southern Sydney Basin, Australia

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CHAPTER 1. INTRODUCTION

The Sydney Basin is one of the most important coal mining regions in Australia. The basin forms the southern-most element of the major structural unit, the Sydney-Bowen Basin, which extends for approximately 1,500 km, from Batemans Bay in southeastern NSW to the central part of Queensland (Fig. 1.1). The Sydney Basin represents a retro-arc foreland basin with the New England Orogen on the north east representing the magmatic arc (Scheibner, 1976; Herbert, 1980; Jones et al., 1984).

The Sydney Basin consists of four coalfields of which Southern Coalfield, embodying the southern Sydney Basin, is the southern-most which extends from south of Sydney to Bateman's Bay and inland to the Burragorang Valley. This coalfield is centred around the city of Wollongong and covers an area of approximately 8,600 km.

1.1 GENERAL BACKGROUND

The rank of coal in the Southern Coalfield ranges from high volatile bituminous in the southern and western parts to low volatile bituminous in the northeastern part of the coalfield. These coals contain variable amounts of gas, mainly methane and carbon dioxide. Locations of coal mines, for which data were used in this study, are shown in Figure 1.2.
Figure 1.1 Location of the Sydney Basin and its coalfields.
Figure 1.2 Location of mine leases in the study area.
During 1991-92 fifteen mines operated in the region and produced 17.35 million tonnes of raw coal of which the Bulli seam accounted for over 75% of the production. Coal mining in this region is exclusively by underground methods at depths varying from 150 m to greater than 550 m. The occurrence of large amounts of gas causes numerous problems during coal mining, especially in the deeper mines. The two major hazards are ventilation problems and gas outbursts.

The coal-mining industry of the region has a long history of gas outbursts dating back to the 1920s and possibly earlier as explosions were recorded in mines in the latter part of last century but the causes were not documented. The first documented incident of this kind in the region was in 1925 at the Metropolitan Mine, where an instantaneous outburst of gas and coal caused two fatalities. Since then such outbursts have occurred in various other mines with or without fatalities. The most recently recorded major outburst occurred in 1991 at the South Bulli Colliery causing two fatalities. Besides these major outbursts, other relatively small scale outbursts have caused frequent stoppages of mining operations. It is estimated that such stoppages as well as other gas-related problems cost the Australian underground longwall operations approximately 50 million dollars annually (Lama, 1991).

In order to control the problems caused by high gas contents in coal mines techniques for gas removal before and during mining (that is pre-drainage and post-drainage) have been successfully employed. Pre-drainage of gas greatly reduces high gas emissions and permits faster rates of mining. Post-drainage which involves draining of gas during and after mining removes the gas from strata and goaf whilst reducing the air ventilation
requirements of panels. This method also controls gas inflow from the adjoining seams.

Gas removed by pre-drainage and post-drainage methods are utilised for local power generation at West Cliff and Appin Collieries. In other parts of the coalfield, however, gas drained from the coal mines is not utilised and is exhausted to the atmosphere. Calculations by the author prior to this study indicated that during the production of 17.35 million tonnes of coal from the Southern Coalfield the approximate volume of gas (methane and carbon dioxide) produced is over 15 million cubic metres. Most of this gas is released to the environment which is unfortunately an environmentally unfriendly process, especially in view of the greenhouse problems. An understanding of the origin and occurrence of seam gases will allow more efficient utilisation of them.

Methane extracted from coal seams is one of the significant energy sources of North America. United States Bureau of Mines (USBM) estimates that the coal gas resources of the United States of America (U.S.A) is over 18 trillion cubic metres and this resource has the potential to double the proven gas reserves of that country (Waller, 1992). Coal seam gas is not commercially exploited from the Sydney Basin. Australian Gas and Light Petroleum Ltd (AGL) conducted some early studies including a series of bore holes (Bootleg and Moonshine series) to evaluate the coal and hydrocarbon potential of southern Sydney Basin. Besides these efforts systematic and comprehensive evaluation of these data together with other geological factors is lacking.

In addition to the work of AGL, other institutions such as British Petroleum Pty Limited (BP), Broken Hill Proprietary Ltd (BHP), Kembla Coal and Coke Proprietary Limited
(KCC) and the Department of Minerals and Energy have made routine gas measurements in their coal exploration boreholes. Gas measurements are also conducted routinely during coal mining by many of the mines in the region.

1.2 PREVIOUS WORK

The frequent occurrence of outbursts in coal mines of Queensland and New South Wales in the late 1950s prompted mining companies to investigate the causes of these outbursts. Alan Hargraves could be considered the pioneer of gas outburst studies in New South Wales and Queensland coal mines. As early as 1958, Hargraves published a paper entitled 'Instantaneous outbursts of coal and gas', in which he described numerous occurrences of outbursts in Australia and other parts of the world. The paper discussed the gas properties of some Australian coal seams, gas compositions of coals of the Metropolitan (Southern Coalfield, N.S.W.) and Collinsville Mines (Bowen Basin, Queensland) and the major factors contributing to gas outbursts.

It has been known for many decades that coal seam gases of the Illawarra Coal Measures comprise a mixture of \( \text{CO}_2 \) and \( \text{CH}_4 \). Hargraves (1963) produced a map showing the variations in gas composition of the Bulli seam using data from underground coal mines; this was the first of its kind. Later, the same author (1984; 1986) published further updated versions of this map showing iso-methane lines for the Bulli seam. These maps were based primarily on gas analyses data obtained from underground mine samples and thus most of the data points tend to be clustered around the then mined regions. These
early works, however, were of immense value for the region’s coal mining activity because they presented very useful information on gas composition of the coal seam.

During the early days of gas studies main concern was on the occurrence of CO$_2$ and its significance to gas and coal outbursts. The gas composition maps of Hargraves indicated a relationship between isolines of CO$_2$ percentage in seam gas and the pattern of igneous sill in the Bulli seam at the Bulli Colliery. Gas distribution patterns in the Metropolitan Colliery showed that the CO$_2$ iso-lines are closely related to the occurrence of igneous bodies, mainly dykes. From these observations at the Bulli and Metropolitan mines Hargraves suggested that anomalous amounts of CO$_2$ in seam gas had been caused by the introduction of this gas from magmatic sources such as dykes and sills.

A series of studies as to the chemical and isotopic composition of Australian coal seam gases have been published over the past decade (Gould and Smith, 1980; Smith and Gould, 1980; Gould et al., 1981; Smith et al., 1982; 1984; 1985). Smith and Gould (1980) studied the isotopic composition of CO$_2$, calcite and bi-carbonates in seam water to determine the origin of CO$_2$ and the occurrence of outbursts. Their work indicated that where the CO$_2$ content of seam gas is high, $^{13}$C values of CO$_2$ are relatively low and hence indicated a magmatic origin. However, the close association of high CO$_2$ seam gas and the occurrence of major igneous bodies was found in a few areas only (for example Metropolitan and Bulli Collieries). In other parts of the coalfield, where considerably large areas with high CO$_2$ contents are found, the contiguous occurrence of major igneous bodies has not been indicated by these authors and thus their conclusions are at best tentative. Furthermore, in other parts of the Sydney Basin (for example Newcastle area in
the northern part of the basin) where igneous bodies are prevalent no significant occurrences of CO₂ are known.

By studying the gas composition of a few boreholes in the north-central part of the southern Sydney Basin, Smith et al. (1985) noted that there is considerable inter-seam variation in the gas composition. Where the largest variations in gas composition occur they observed that the highest CO₂ concentrations are found in the shallowest Bulli seam. They believed that this feature was a result of the rise of magmatic CO₂, through faults, and the subsequent migration laterally along seams of differing permeabilities. In this context the Bulli seam, which has a high proportion of inertodetrinite, may be more permeable than the other seams and this was thought to be a factor causing the high concentration of magmatic CO₂ relative to the other seams (Smyth cited in Smith et al., 1985). However, no supporting evidence for this hypothesis was given and a large set of geological and petrological data, coupled with a clear understanding of the diffusion and migratory properties of gases, is needed to test that hypothesis.

Few detailed studies relating the variations in the coal seam gas contents with coal petrology, stratigraphy, structural geology, thermal history and tectonic history of the Illawarra Coal Measures have been undertaken. This is mostly because mining companies have been concerned only with outburst problems and until recently it was widely believed that the high concentration of CO₂ was the main cause for these gas outbursts. Therefore, most of the published and unpublished work dealt with the problem of CO₂ and gas outbursts. Work done in other parts of the world, for example, British and North American Coalfields (Creedy, 1985; 1988; Meissner 1984; Rightmire et al., 1984; Ulery
1984; Levine, 1987; Close and Erwin, 1989) exemplifies the importance of geology when determining the gas distribution in coal measure sequences.

Several laboratory investigations on the gas sorption capacity of Bulli seam, taken from different mines, have been reported in the literature (Hargraves, 1963; Lama and Bartosiewicz, 1982; Bartosiewicz and Hargraves, 1985; Siahaan, 1990). The investigations measured the quantity of gas sorbed onto a known weight of coal at different pressures and clearly revealed that the gas sorption capacity of Bulli seam increases with increased pressure in a curvilinear pattern. These studies also indicated that at constant temperature the gas sorption capacity generally increases with decreasing moisture and volatile matter content of the coals. In addition, Bartosiewicz and Hargraves (1985) suggested that an increase in in-situ stress could reduce the gas sorption capacity of coals.

Similar experiments conducted in other parts of the world have also indicated comparable results. Kim (1977; 1978) produced a report on estimating CH₄ content of bituminous coals from adsorption data. By combining information from various isotherms, she computed a general equation for sorbed gas volume as a function of temperature, pressure and moisture content. Using the equation, she proposed a graphical model representing the amount of gas adsorbed by a bituminous coals as a function of rank. The diagram of Kim has been commonly used by many later workers as representing the methane sorption capacity of coals of different rank as a function of pressure.

In other parts of the world some work has been documented regarding the variations in
gas sorption capacity with the maceral composition of coal. These works, however, do not show any definite agreement as summarized by Ettinger et al. (1966a, 1966b). Ettinger et al. (1966a) reported on a study relating petrography to the sorption properties of coals from the Pechora and Kuznetsk Basins in the U.S.S.R. and concluded that at pressures over 2000 kPa, fusinite sorbs more methane than vitrinite for medium rank coals. The study also indicated that for lower and higher rank coal, no significant difference in the methane sorption capacity between these macerals was evident. This conclusion contradicts the observation of earlier workers such as Patteisky (1961; cited in Ettinger et al., 1966a) and Coppens (1936; cited in Ettinger et al., 1966a) who observed that vitrains (coals with abundant vitrinite) sorbed much greater amounts of gas than fusains and durains (coals with less vitrinite). Later studies of Creedy (1988) suggested that in British coals, liptinite has the greatest gas sorption capacity while fusinite has the lowest. Lamberson and Bustin (1992; cited in Levine, 1992b) also indicated that in some Western Canadian medium volatile bituminous coals, the CH₄ sorption capacity of coals increases with increasing vitrinite content. In another study, Schwarzer and Byrer (1983) studied a set of American coals and observed no systematic difference in the sorption capacity between different macerals. Such detailed studies examining the relationship between gas sorption capacity and maceral composition of Sydney Basin coals have not been conducted.
1.3 AIMS OF THE STUDY

The major factors that control variations in gas content and composition of coal seams are reported to be coal type, rank, thermal history, tectonic history and geological structure of the region. This thesis investigates the influence of these and other geological factors on seam gas distribution in the Illawarra Coal Measures. Apart from original data obtained by the author, other data were taken from exploration boreholes and underground mines. The locations of boreholes, from which data were used, are shown in Map 1 (in pocket).

The principal aims of the study are to:

1. examine the rank and compositional variations of coal seams in the Illawarra Coal Measures of the Southern Coalfield;
2. model the thermal and gas generation histories;
3. investigate the porosity, pore size distribution, gas sorption and desorption properties of a selected suite of coals under controlled laboratory conditions;
4. compile a database of gas content and gas composition in coals of the Illawarra Coal Measures;
5. establish the spatial and stratigraphic variations in the gas content and composition of the coal seams;
6. investigate the role of coal type, rank, stratigraphy, geological structure, tectonic and thermal histories on the distribution of seam gases.

An understanding of the major geological factors controlling the distribution of coal seam
gases in the Illawarra Coal Measures will lead to more efficient mine planning and better methods for controlling gas-related problems during coal mining. Furthermore, it will identify prospective areas for CH₄ exploration.