CHAPTER 2
LITERATURE REVIEW

This Chapter reviews the literature relevant to this research. The emergence of coal bed methane gas as a major hydrocarbon resource has resulted in establishment of integrated exploration and development concepts. Literature review is focused on the contemporary work being done towards convergence of the disciplines of applied Geophysics and Petroleum Engineering. Relevant literature on related domain has also been reviewed, in particular, those areas that are relevant to the research being envisaged. Literature on the Geophysical applications of various methods including Well-logging processes and other geological processes has also be studied to identify gaps in existing knowledge in the field.

2.1 INTRODUCTION

Coal has been recognized for thousands of years as a natural rock material with qualities beneficial to the economic well-being of man. Recognition of the wide range of chemical and physical properties of coal and the relationship of these properties to a great variety of uses is relatively recent.

The emergence of coal bed methane gas as a major hydrocarbon resource has resulted in establishment of integrated exploration and development concepts. One of these concepts utilizes knowledge of depositional environment of coal beds to predict their continuity, thickness, geometry and distribution. Understanding coal bed depositional environments originates from information of their modern physical, biological and chemical processes. [*Landis et al.,1993*].

Natural gas is generated in coal by two distinct processes: biogenic and thermogenic. Biogenic gas , primarily methane and carbon dioxide is produced by decomposition of organic matter by micro-organisms and is commonly generated in peat swamps.[*Kim and Douglas,1972*].The breakdown of organic matter leading to methanogenesis is performed in a complex series of processes by a diverse population of microbes ,each of which contributes to the partial oxidation of organic matter [*Woese et al.,1990*]. The generation and accumulation of biogenic gas in ancient sequences is described by *Rice and Claypool(1981),Zhang and Chen(1985) and Rice(1992).*

Valuable geologic information can be obtained by utilizing wireline conveyed measurements. Most tools are made up of sensing section called sonde and signal amplification and processing unit called cartridge. Among different well logs, clay will cause resistivity logs to read low .[*Johnston,1990,Mullen ,1988,and*

Mavor, 1991].For sonic logs, they generally read high porosity in coals[*Johnston, 1990, Ellis et al., 1988*].Because of low matrix density of coals, density logs will read low density . [*Johnston et al., 1990*].

2.2 CBM AND RELATED DEPOSITIONAL ENVIRONMENT:

Coal beds have long been recognized as the products of a larger dynamic ecosystem that reflects both interactions of chemical and biological processes in a peatland complex acting in concert with the physical and geo-morphological processes of an adjoining drainage complex . Depositional environments of coal beds despite the various works on this topic, remain elusive and difficult to prove[*Dapples and Hopkins, 1969; Ferm et al., 1979*]. Factors and control coal accumulation are as varied as the many disciplines(Sedimentology, Petrology, Geochemistry, Paleobotany etc).However, attempts to bridge the disciplinary gap during the past few decades have induced new insights on the nature and origin of coal associated sedimentary rocks[*Raistrick and Marshall et al, 1989; Pocknall and Flores, 1987*].

The economic potential of Coal bed Methane gas has renewed study of Coal resources, Coal rank, geochemistry and physical properties of coal.[*Fassett et al, 1988*]. Although coal beds often serve as source and reservoir rocks of Methane gas ,it has been said that adjoining sandstones can also serve as reservoir rocks.[*Rice and Flores, 1990; Flores et al., 1991; Law et al; Pashin et al., 1991*]. Thus knowledge of the origin and the properties of the sedimentary rocks lateral to, above and below coal beds is vital to a successful recovery of coal bed Methane resources. An integrated approach of the above provides an advantageous strategy to resource assessment, exploration and exploitation of coal bed methane.

The drainage system most commonly associated with the peatland system is a fluvial system. The idealized integrated network of a modern fluvial system [*Schumm, 1977*] includes a watershed zone of sediment source area that merges downstream into a transfer zone in which sediment input equals output along stable channels and floodplains. Thus a fluvial system may be thought of either as an erosional or depositional complex and it is later proved by Schumm(1977) that depositional component is a critical aspect in CBM. In the zones of Schumm(1977) the depositional complexes are alluvial fans, alluvial plains, delta plains, coastal plains and deeper water settings. Peatland systems can occur in association with and can be equally common in all these depositional complexes except the deep water area[*Rahmani and Flores, 1984; Lyons and Alpern, 1989; Macabe and Parrish, 1992*].

Alluvial fans that prograde into a standing body of water are termed as fan deltas[*Westcott and Ethridge, 1980*] and usually contains sediments as coarse as alluvial fans. Unlike continental alluvial fans, the peatlands associated may occur along the marginal flanks because their distal part is partially submerged and reworked by lacustrine or marine processes.[*Nemec and Sreel, 1983; Colella and Prior, 1990*].

A peatland is an ecosystem where the ground water table is near or slightly above the mineral soil and the associated vegetation produces organic matter(peat) at a rate faster than degradation processes can decompose it.[*Moore and Bellamy, 1974; Anderson, 1983; Martini and Glooschenko, 1985*].

Selected ancient environmental paradigms are important in coal bearing sequences in order to develop a guideline to exploitation of coal bed Methane gas. The zones are areas with established coal bed Methane production in US such as Powder river basin,Wyoming; Sun Juan basin,New Mexico and Black Warrior basin, Alabama. These areas have in common large coal resources that range from Pennsylvanian to Tertiary in age .

Biogenic coal bed Methane in Powder River basin is produced from the Upper Paleocene Tongue River member of the Fort Union formation. The Tongue River member contains extremely thick discontinuous coal beds as much as 210 ft thick[*Warwick and Stanton,1988*].Potential coal bed Methane exists in the overlying Upper Paleocene and Eocene Wasatch Formation where coals are as much as 250ft thick. Fort Union and Wasatch coals vary from lignite to sub-bituminous and contain 3-34% ash and 1-2% Sulfur. Coals in this formations are interbedded with lacustrine deposits [*Ethridge et al,1981;Flores 1981,1986*]. In addition to coal gas is also produced from associated channel sandstones. Although relative gas content of the coals in the Powder River basin is low, the large amount of the coal resources (1.3 trillion tons) [*Choates et al .,1984*] guarantees economic accumulation of Coal bed Methane gas. Resources for the Powder River basin are estimated to be as much as 30TCF. [*Choates et al .,1984*]

2.3 COALIFICATION-THE EVOLUTION OF COAL

From the standpoint of Petrogenesis, coalification refers to the combined set of processes by which the sedimentary rock coal is formed[*Schopt,1956; Bates and Jackson,1980*].The rank related compositional parameters may be used to classify coal into different rank categories, such as peat,sub-bituminous, bituminous and anthracite.[*Stach et al.,1982; Teichmuller, 1987*]. The term maturation is commonly used synonymously with coalification[*Suggate,1990*].Gondwana coals are abnormally low at low rank , giving them the appearance of a higher rak coal as compared with vitrinite rich Euro-American Carboniferous age coals[*Alpern et al.,1989*].

Coalification begins at the sediment surface and continues through out burial history encompassing a diverse set of physical, chemical and biological processes. [*Dulhunty,1954*]. The nature of coalification processes changes significantly at different stages of coalification.[*Hood et al.,1975*]. The earlier stages of coalification(termed peatification) are dominated by microbially metabolized biochemical reactions.[*Teichmuller,1969*]. Peats are organic rich sedimentary beds having in ground moisture contents greater than 75wt%and/orburial depths less than 100m[*Stach et al,1982; Robert,1988*].Early field based studies led researchers to conclude erroneously that burial and tectonic pressure enhances coalification[*White,1925*]. More recent field and laboratory based studies have relegated pressure to the lesser role of influencing mostly the physical structure of the coal while having little impact on the chemical composition.[*Ehrlich,1981*].

2.4 PETROLOGY OF COAL

The characterization of recognizable plant material in coal was first undertaken using transmitted white light microscopy[*Thiessen,1912; Thiessen and White,1913*] and subsequently elaborated upon by megascopic[*Stopes,1919*].

The megascopic (macroscopic) components of coal are termed ingredients[*Stopes,1919*] or lithotypes [*Stach et al,1992*]. The microscopic components are termed macerals which are comparable to the mineral grains in other rocks[*Stopes,1935*]. The natural association of various bituminous macerals or macerals and minerals under reflected light microscopy is called a microlithotype.

Since 1936, the understanding of the composition of the coal has been greatly enhanced by the application of the incident light fluorescence microscopy[*Schohardt,1936;Jacob,1984; Van Gijzel,1967; Ottenmjann et al.,1974].* Coal is classified into two type as humic and sapropelic according to its megascopically recognizable components[*Stach et al.,1982].*The physical, chemical and technological properties of the macerals vary continuously with increasing rank but in different proportions. All macerals contain the suffix"inite"[*Stopes Heerlen System,1971].*

Macerals of one and the same maceral group differ from one another in morphology structures rather than in reflectance[*Stach et al,1982*] The three maceral groups are huminite /vitrinite, liptinite (exinite) and inertinite. Liptinite macerals have the lowest reflectance, vitrinite macerals are of intermediate reflectance and inertinite macerals show the highest reflectance under oil immersion. Vitrinites originate from the lingo-cellulosic parts of plants; liptinites come from the exine and lipid substances of plants; and inertinites represent the oxidized components of plant lignin,cellulose and faunal remnants.[*Stout and Spackman,1987*].

The maceral and maceral types from the huminite/vitrinite group are evolved through several physical and chemical processes of homogenization known as humification, gelification and bituminization[*Stach et al,1982; Teichmuller,1989*].

2.5 NATURAL FRACTURES IN COAL

Cleats in coal generally form an orthogonal set of fractures that are essentially perpendicular to the bedding surfaces.[*Patterson et al.,1996*]. The use of the "cleat" as a mining term dates back to the late thirties. [*Kendall and Briggs,1933*] and has since been adopted by miners, geologists and engineers to describe a variety of fractures commonly found in coal. Most workers regards cleats in coal as equivalents to joints in clastic rocks.[*Ver Steeg,1942; Ramano & Moiz,1968; Diamond et al.,1976*]. Consequently, cleats in coals have been variously described as being restricted to individual coal bands or in some mine exposure to encompass the vertical extent of the seam[*Tremain et al.,1991*].

In all instances , cleating was found to be well developed within bright coal bands, but was rarely well developed in dull bands. Such a tendency have been noted previously by numerous workers[*Ting,1977; Hucka ,1989 ; Law 1993; Tremain et al.,1991*] and is regarded here as of fundamental significance. It was also noted that cleats rarely crossed lithotype boundaries.[*Close & Mavor,1991*]. Generally a cleat is defined as an extensional fracture occurring within coal that is confined to a particular lithotype or microlithotype.[*Close,1988*].Formation of cleats in coals have been categorized by Close(1993). Various workers have pointed to the regional consistency in cleat orientation and relationship with dip and strike as evidence of a tectonic origin[*Close and Mavor,1991*]. As recognized during previous studies, butt cleats were always confined between face cleats, which has in the past been used as evidence to suggest that face cleats were the first to form. However, the presence of polygonal cleat geometrics and the similar mineral assemblages infilling face and some butt cleats suggests that the two cleat sets may have formed contemporaneously or butt cleat initiation closely followed face cleat generation.[*Baker and Caritat,1992*]. Cleat orientation were largely dictated by the prevailing regional stress pattern with face cleats aligned parallel to the principal maximum horizontal compressive stress.

2.6 GLOBAL SCENARIO IN CBM

In North America, the recent success in CBM scenario has put this nation as the role model world-wide. Strong demand for natural gas is pushing the rest of the world to speed up the CBM developments. Apart from North America, Australia has the most commercially advanced CBM Industry. The proven resources have been estimated in Australia approximately as 9tcf in their thirty coal bearing basin of Mesozoic and Permian in age. The majority of Australia's CBM resources occur in the eastern coast of Australia, primarily in the Australian states of Queensland and New South Wales. The Australian Gas Association[*Gas statistics Australia,2002*] estimates the total Australian resource. Most of the CBM reserves (about 7 tcf) have been discovered in Bowen-Surat basin followed by Galilee-Eromanga, Sydney, Otway onshore and Gunnedah Basin respectively. [*Alex Chakhmakhchev et al,2007*]. In Australia, a joint venture test project for Methane drainage conducted in 1981 in Appin colliery, New South Wales produced gas at a maximum rate 17,000m3/day.

In China, CBM resources has been estimated with an very high figure of 1200tcf.Key international CBM players are Chevron, BP, Greka, ConocoPhilips and other Canadian companies. In northern province of China called Shanxi, CNPC invested 28 millions US dollars last year in China's largest CBM project in Qinshi basin . According to the CNPC company report, they drilled 230 coal-bed gas wells in 2006 and 55 of them have been put into operation. Recovering vented methane in order to augment local supplies of natural gas is commonly adopted in several European countries notably Great Britain, Germany, France and Belgium.

CBM activities are on in West European Countries including France, Italy, Germany, Spain and Swizetzland. In UK, exploration efforts resulted in the discovery of 15 fields with total reserve size of 120 bcf [IHS Data].Two of them are producing in the Midland Valley Graben. From a commercial standpoint, West Europe is favorable for CBM developments; however environmental issues and lack of gas saturated coal seams extended over large areas may slow down full scale production.

United Kingdom has applied the first controlled drainage system in Ruhr and Mansfield mines in the Rottersbank seam in 1943.This proved very successful and was quickly introduced to the gassy seams in all the major European coal fields in the 1950's. The largest utilization has been at Harworth Colliery, the surface Methane extraction plant was commissioned in February,1970.[*Tremain et al,1990*].

In Germany, some of the collieries are operating with this technology. One of the collieries are operating of Ruhrkohle working at present with2.6m average thickness. The working depth varies from 1000 to 1150m with an average seam thickness of 2m in South-Western Germany bordering France and Belgium. Rhineland Colliery, situated at the heart of Ruhr Colliery has emitted gas at 10m3/min. There are two coal fields in Belgium, the southern one which is entirely closed, and the northern one(Campine) which is still in operation.Belgium has applied fire damp drainage since 1949 in very gassy mines and even in mines with gas outbursts in south basin.

The extracted gas from gassy Sunagawa mine in Japan is used for power generation. The operation of power plant is completely automatic and centralized. The amount of gas burnt is 76m3/min.[*Metcalfe et al.,1991*].

In Canada, development for extracting methane from coal seams began in 1977 with a surface demethanation project in the Rocky Mountains, Canmore,Albarta. Another same type of project was implemented in the New Glassgow-Stellarton region of Nova Scotia.[*Tremain et al.,1990*].

2.7 INDIAN SCENARIO IN CBM

In India, economically exploitable coal resources occur in two stratigraphic horizons viz the Lower Gondwana and Tertiary. Lower Gondwana coals are extensively developed in the south-eastern quadrant of the country while the Tertiary coal occurrences are found on either extremities of the extra peninsular India. However, major deposits of Tertiary coals are located in the north-eastern and the western region. The Gondwana usually relates to the deposits of Upper Carboniferous to Lower Cretaceous age. The Lower Gondwana coals are the most important both as regards their wide distribution as well as their quality and their presence.[*Patra et al.,1994*].

Spurred by the commercial success of coal bed Methane activity in USA, India initiated evaluating its coal bearing basins for their CBM potential in 1992. Estimated coal resources of Indian basins is 211 billion metric tons. Indian coal deposits occur in two stratigraphic groups viz Gondwana (mainly Permian) and Tertiary(Eocene and Oligocene).

India, which has the 6th largest coal reserves in the world is expected to have potential for Coal bed Methane. About 99% of the coal reserves of India are found in the Gondwana basin while 1% lies within the Tertiary basins.[*Mandal & Ghosh,1997*].

Several workers [*Sharma & Singh et al.,2003*]have also estimated lignite resources in the deeper Tertiary basins to be of the order of 254 BT. Coals in the Gondwana Grabens with suitable rank have indicated CBM prospectivity. Gondwana grabens occur in aborted rift graben along Rajmahal-Damodar,Son-Mahanadi,Wardha-Godavari and satpura-Narmada river valleys from satpura in the West to the Raniganj in the east.Substantial amount of surface and shallow depth coal characteristics data is available for the coal fields occurring in the Gondwana grabens while data in the Tertiary basins are usually lacking on account of greater depths of occurrence and lack of exploration for methane in the lignites.[*Singh et al,2002*].The workable Gondwana coal seams are confined to the Damuda group of the Lower Gondwana's, wherein they occur in two main horizons-the Lower of Barakar measures of Lower Permian age and the Upper or Raniganj measures of Upper Permian age. The Indian coal deposits are confined to 59 coal basins.

Some of the Gondwana basins have been prioritized for evaluating the coal bed Methane plays. Through R&D activities and exploratory work, considerable development had been made on understanding of Methane plays in Damodar Valley Gondwana coalfield. Based on large national resource base, CBM has been projected as a viable major energy source of future. High CBM resource does not necessarily mean high production potential, since successful CBM production depends on three most critical parameters viz gas content, saturation and permeability. Careful examination and comparison of above critical parameters of Indian coal basins with the producing basins of the world indicate that the prospective CBM play is likely to be confined to the four major Damodar valley Gondwana coalfields viz Jharia, Bokaro, North Karanpura and Raniganj.[*Hajra & Chaudhury,2003*].

It has been inferred by many geologists[*Biswas et al,1995*] that the range of CBM gas resource of the gondwana coals in India may be of the order of 1-2 TCM(most likely 1.5 TCM). The maximum density of gas resource is expected in the Eastern Coalfields. Moderate density is expected in the North-Eastern Coalfields as also in the coalfields of Madhya Pradesh, judging from the chemical and petrographic composition, rank and maturity of the coal.[*Prasad et al,2003*]. The coal bearing Indian basins have been subdivided into four categories [*James Peters et al, 2001*] on the basis of rank, physicochemical characteristics, prospective area available, depth of occurrence of coal seams, geological age and present level of knowledge. The category I coalfields viz Jharia, Bokaro, North Karanpura and Raniganj with huge coal thickness, high rank and maturity compares well with global CBM producing coalfields in terms of Gas content and adsorptive capacity[*Hajra et al,2003*]. Category II and III coalfields predominantly occur in the Damodar and Mahanadi Valley but have a progressively lower rank of coal .Coals of Ib river, Talcher and Korba coalfields, though are quality wise inferior but possess extensive thickness and occur at shallower depth, which may provide better hydro-dynamic condition than some of the category II basins. The CBM potential of Tertiary coal/lignite under normal circumstances should be rated as category IV. [*Sen et al.,2003*].However, certain geological factors which have contributed in making Powder River Basin, USA with lignite a producing prospect may be present in some basins under category III & IV. Tertiary coal occurrences in India are known from Cambay basin, Bikaner-Nagaur and Barmer Basins, Assam-Arakan basin, Foothills of J&K and Neyveli in Cauvery basin. Their CBM prospectivity have put them in category IV.

It is thus evident that a majority of proven coal resources lie in mineable depths and since India is not presently practicing Coal Mine Methane(CMM) and Abandoned Mine Methane(AMM) activities, the coal quality available for Virgin Coal Bed Methane(VCBM) projects lie in the inferred and indicated category coal resources. Therefore, it becomes imperative for CBM operators to first prove the existence of coal in the category of I-IV before carrying out a full-fledged CBM project. Ample scope exists for exploring and proving/upgrading the lower categories of coal and lignites in the future in the interest of CBM exploration.[*Bastia et al.,1995*].

Considering the type of coal in the Upper, Middle and Lower Barakar Formation, it is felt that both the generative and adsorptive capacity of these particular type of coals of Jharia basin is high and a potential good source for future CBM Exploitation program.

2.8 APPLICATION OF GEOPHYSICAL METHODS IN CBM

The applicability of Seismic method has been discussed and experimented outside India. Vertical seismic profiles of a coal-bed methane test well near Red Deer, Alberta provide useful data regarding the physical properties of the coal and its suitability for development. [*Richardson, S.E., Lawton D.C., 2002, Deffenbaugh, M., Shatilo, A., Schneider, B., and Zhang, M., 2000.*]

Valuable geologic information can be obtained by utilizing wireline conveyed measurements. Most tools are made up of sensing section called sonde and signal amplification and processing unit called cartridge. Among different well logs, clay will

cause resistivity logs to read low [*Johnston,1990,Mullen ,1988,and Mavor,1991*].For sonic logs, they generally read high porosity in coals[*Johnston,1990,Ellis et al.,1988*].Because of low matrix density of coals, density logs will read low density . [*Johnston et al.,1990*].