CHAPTER 4

GEOLOGICAL BACKGROUND OF ORIGIN OF CBM

Depositional systems and structural features are the primary geological controls on Coal bed Methane resources and the recoverability. The depositional system controls the occurrence, geometry and the thickness of coal seams by building platforms for peat accumulation and by bounding the seams. Additionally, the framework sandstone and shale of the depositional system commonly are the conduit and seal for coal. Although the coal seams are the primary aquifer the producibility, coal beds and associated sandstones in many cases perform as a single regional aquifer. However, fluid migrates within coal seams and hence producibility of methane is locally enhanced by structural control. Thus integration of factors like sedimentology and structural control are also major factors for production of coal bed methane.

Coal seams have facies or subsets of genetically related called depositional system[Fisher et al,1969]. The depositional system controls the occurrence trend thickness and greatly influences the quality of coal. Therefore the relations between sediments and coal occurrence determine from maps and cross sections are predictive and are a useful tool in coal bed methane exploration which is dealt in this chapter.

4. 1 INTRODUCTION

The term "CBM" stands for "Coalbed Methane". During the coalification process(formation of coal from the plant remains)gases of biogenic and thermogenic origin was generated. Most of the biogenic gases generated in the early stages of coalification escaped due to low pressure. However, the gases generated in the later stages, mainly of thermogenic origin , were stored in the coal and could not escape due to higher pressure regimes. The dominant constituent of these gases is Methane. Therefore. Methane is an integral constituent of present day coals and hence the term –coal bed Methane.

4. 2 GEOLOGICAL CONTROL ON COAL BED METHANE

Coal bed have long been recognized as a larger, dynamic eco-system that reflects both interactions of chemical and biological processes in a peatland complex active in concert with the physical & geomorphological processes of an adjoining drainage complex. Each of the environmental complexes can be considered as an open and process-response system with its own sets of attributes related to these internal processes and external geologic, hydrologic and climatic processes. Each such ecosystem involves blending of detrital and organic sediments deposited in drainage and peatland systems respectively. Thus a steady balance of these system requires upholding hydrologic, climatic and geomorphic thresholds un-embarked by geologic overprints. There are different systems included which are described below.

4. 2.1 THE DRAINAGE SYSTEMS

Fluvial system is the commonly associated drainage system for declined peatland. The ideal integrated network of a modern fluvial system [Schumm,1977] includes a water shed zone or sediment source area that merges down stream into a transfer zone in which sediments equals input into output along channels and floodplains.

Further downstream, a sediment sink zone or a major area of deposition occurs in the fluvial system. Thus, a fluvial system may be thought of either as an erosional or depositional complex and it is the later depositional component. There are three zones of these depositional complexes which are alluvial fans, alluvial plains, delta 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 Alpren, 1989; McCabe and Panish. 1992].

4. 2. 2 THE ALLUVIAL FANS

Alluvial fans are morphologically cone shaped depositional complexes formed by ephemeral streams (dry fans) and perennial streams (wet fans). In arid climates dry alluvial fans are built mostly of mud and debris flows (Bull, 1964). Peatlands are generally associated with wet alluvial fans rather than with the dry alluvial fans. Peat preservation and accumulation related to alluvial fans may be aided by the downstream textural and compositional gradients of the sediments which enhance ground water to flow and carry nutrients to sustain the peatlands. For example, on the Rio Grande alluvial fans of Sun Luis Valley, Colorado (Emery et al., 1971) the topographically high proximal fan search as a recharged area for ground water that flows laterally because of the hydraulic gradient and discharges down-fan into shallow aquifers where peatland vegetation grows organic rich deposits and merges with distal fan deposits through time. Alluvial fans that prograde into a standing body of water (lake or sea) are termed as fan deltas (Westcott and Ethridge, 1980) and usually contain sediments as coarse as the alluvial fans.

4.2.3 THE ALLUVIAL PLAINS

Alluvial plains form flat areas of deposition that consist of fluvial channels separated by inter channel depressions commonly developed in the transfer and sediment sink zone. Fluvial channels in the alluvial plains contain either bedload, suspended load or mixed load and exhibit high to low sinuosity (Schumm 1960, 1972, 1981; Galloway, 1985). Low sinuosity channels are associated with net vertical aggradations or degradation of the valley floor, whereas high sinuosity channels reflect simultaneous lateral aggradations and erosion with negligible net erosion or deposition, as they transfer their sediments across the depositional surface. Fluvial channels also shift laterally by avulsion, producing abandoned alluvial ridges that become part of alluvial plain surface.

Sediments consist mainly of suspended load that is rapidly distributed and deposited during flood or peak flow events. Some inter-channel areas distant from fluvial pathways favor development of paleosols and peatlands. Paleosol development in the flood plain deposits represents sediment-starved areas subjected to pedogenic processes that can be maintained for prolonged periods of time.

Peatlands in inter-channel areas similarly represents sites of very slow deposition (average rate of peat accumulation between 20 and 80 cm in 1000 years (Walker, 1970; Moore and Bellamy, 1974) of organic matter. In most modem and ancient peatlands, peats typically overlie paleosol. Lifespan of these inter-channel peatlands is controlled partly by the processes of the adjoining channel hydrology, sediment influx via complex lateral channel migration.

4. 2. 4 THE DELTAIC COASTAL PLAINS

Delta plains are lowland areas where the fluvial system enters a body of water such as a lake or ocean and are commonly formed in the transfer and sediment sink zones. Delta plains consist of well-defined networks of channels (distributaries) separated by inter-channel areas (inter-distributaries) that include floodplains, bays, and wetlands. Delta plains are bounded distally by a sandy delta from where river mouth deposits are redistributed by waves and currents. The relative dominance of coastal processes (i.e., waves and tides) versus fluvial processes (i.e., river discharge and load) controls the types of deltas formed (Fisher et al., 1969; Galloway, 1975). Much like the buildup of the alluvial-fan and alluvial-plain surfaces, the delta plain is constructed by lateral crevassing of individual distributary channels that are superimposed on larger scale abandonment and shifting of the deltaic lobes that are web reward and transformed into destructive deltas landward of which are uninterrupted peatland. Autocyclic process in turn, is affected by fluctuations of sea level and lake level and by tectonism. Peatlands in delta plains that may be non-peat-fonning vegetated wetlands are formed in inter-distributary depressions and expanded laterally on to both abandoned delta· lobes and individual smaller crevasse deltas. Like peatlands in the alluvial plains they are affected by fluvial sediments from nearby distributaries. Abandoned distributary channel ridges and crevasse deltas provide short-lived platforms on which peatlands could form. On the other hand, abandoned sub-delta lobes or large crevasse deltas associated with channel shifting can serve as longer-lived platforms on which peat can accumulate without high frequencies of sediment influxes. Peats formed in some delta-plain peatlands are extremely sensitive to marine or lacustrine processes. Vegetal growth in the delta-plain peatland is directly influenced by their salinity tolerance and affects the types of peatland formed, which in turn controls the quality and quantity of peat deposit produced (Kosters, 1983). Mucks and peats formed in the delta setting particularly those affected by marine incursions, are degraded and produced biogenic gas that can be trapped elsewhere in the system.

4. 2. 5 NON DELTAIC COASTAL PLAINS

These are low lying areas that grade ocean ward into barred and non-barred shore lines (Elliott, 1986) and are drained by tidal inlets, estuaries and short headed streams into lagoons or estuaries. They are commonly formed in the sediment sink zone. Detritus supplied by short headed streams and coastal processes (i.e., long shore drips, rip currents, tidal currents, fair weather and storm waves) may range from pebbly sands to mud sizes. The coastal plain is sensitive to relative sea leave fluctuations that can produce alternations between regressive and transgressive and stationary condition. Detrital input, the types of shoreline and the extent of landward penetration of coastal waters all influenced the type of coastal plain peatland that is developed.

Peatland in the coastal plains form behind both barred and non-barred shore lines in estuaries, along lagoons and atop inter-fluvial lowlands. The peats of marine influence coastal plains are accumulated on raised platforms above and behind relict barrier terraces on abandoned estuaries and along abandoned fluvial channel ridges and on infilled lagoons. The preservation and accumulation of peat in such coastal plain peatland requires prolonged protection from marine processes. Topographic relieve in coastal plains also controls the peatland types and their evolution. Low lying areas prone to tidal inundation initially form brackish peatland which may be succeeded in turn by fresh water peatland that migrated from the margins of more elevated areas. The fresh water peatland thus established continues to form peat atop a slightly raised surface above the sediment-laden waters.

4. 2. 6 THE PEATLAND SYSTEMS

A peatland is an ecosystem where the ground water table is near (wetland) or slightly above the mineral soil and the associated vegetation produces organic matter (peat) at a rate faster than degradation processes can decompose it. The resultant bogs, fens, swamps and marshes are grouped as mires (Moore and Bellmy, 1974; Anderson, 1983). Peat generally accumulates in bogs, fens and swamps and to a lesser extent in marshes; such peatland may produce organic matter with a considerable rate.

4. 2. 7 THE BOGS

Bogs whose root systems do not reach mineral soil are exclusively sustained by recycled nutrients from decaying older organic debris as well as by nutrients supplied from rainfall. They are topographically raised above the adjacent drainage system and are morphologically domed (convex-upward surface) with steep margins to a flat central surface.

Doming of the peat bog deposits is more pronounced in the upstream portion of the valley. The bogs formed a single body bounded by adjoining channels of a trunk tributary fluvial system. The plant community adjacent to the bogged margin include taller trees with canopies. Towards tile central plains of the bog, the plant community is reduced to small trees.

Areal zonation of the floristic composition of the bog is duplicated in the vertical profile. The amount of decayed organic matter increases downward and towards the margin of the peat bog because a substantial part of this matter is derived from large woody trees.

Peat preservation is controlled by high water tables maintained by high rainfall in a tropical climate. Preservation is enhanced by acidity of water which inhibits microbial activity. Peat bogs are not restricted to only tropical climate but also occur in cool and temperate climates which are associated with an intermontane-fluvial coastal plain drainage system.

4. 2. 8 OTHER PEATLAND SYSTEMS

Swamps and marshes from the other group of peatland are sustained by nutrients from mineral soils and / or mineral-bearing sediments transported into the peatland by ground water and / or surface water (minerotropic). Ancient deposits containing abandoned high-ash coals are commonly related to these minerotrophic peatland. The marshes are intermittently flooded by fresh or salt water and mayor may not accumulate significant organic matter. Topographically such peatland display a topogenous or low-lying, flat to slightly convex upper surface and form thin. wide spread, blanket-shaped and lenticular deposit.

Unlike to dammed box which generally depict systematically lateral and vertical vegetational successions, fens, swamps and marshes display a less consistent pattern of vegetational succession in response to changing conditions (Cameron et al., 1989). Furthermore, these peatland comprise either mono-vegetational (i.e. Sphagnum, Grasses) or vari-vegetational communities.

In general, peats formed in the fens and swamps particularly those that are not evolved into raised bogs are very thin and are prone to destruction by decomposition, erosion and sediment burial. As such preservation potential of the peats is very low and a correspondingly inadequate source of coalbed methane gas. However, similar processes of degradation, erosion and aggradations yield dispersed organic detritus as well as deposition of mucks formed in marshes which altogether can serve as source of biogenic gas that may accumulate economically in associated sediments.

4. 2. 9 CHARACTERISTICS OF BOGS & OTHER PEATLAND SYSTEMS

The most important differences between deposits of bogs and other peatlands are their thickness, ash content and sulfur contents. Bog peat deposits are typically thick and contain lowest and low sulfur; thus, analogies are drawn to extremely thick coal deposits in the tertiary Powder River Basin. Vertical accretion of raised peat bogs well above the adjoining drainage levels combined with regional (tectonism) and local (auto-compactional) subsidence are believed to contribute to accumulation of these thick coals. Their low sulfur and ash content may result from upward accumulation of peat that is, buffered and far removed for sediment bearing flood waters. As a result, peat becomes extremely acidic and have decreased microbial activity de-compositional rate and sulfur reduction. Thus the nature of the topography and acidity of the dome peatland directly affects the ash and sulfur contents (Cameron et al., 1989).

In contrast, peat deposits of fens, swamps and marshes are thinner than those of bogs because their low-lying (topogenous) nature makes them vulnerable to premature destruction by sediment bearing flood waters. In addition, oxygenated flood water that episodically flows across peats in low-lying swamps fosters decomposition of at least the upper part of the peat bed and thus hinders its preservation and accumulation. The difference in topography and thickness of the peat deposits among the bogs and other peatland may influence their geometry as well. The shape and distribution of the peat deposits in bogs and other peatland reflect control by their bounding drainage system.

4.3 COALIFICATION-THE EVOLUTION OF COAL

The term coalification in broad sense refers to the diagenetic alteration of all sedimentary organic matter (OM) during burial, including tiny organic particles dispersed in an inorganic matrix. However, coalification here refers to the combine set of processes (physical, chemical, biological and rather biochemical) by which coal is formed from peat to anthracite via lignite, sub-bituminous and bituminous rank (where "coal" refers to rocks comprised of at least 50% by weight and 70% by volume carboniferous material).

Coalification can be viewed in a simplified fashion as comprising five successive but overlapping stages: 1) peatification, 2) dehydration, 3) bituminisation, 4) de-bituminisation and 5) graphitization. Each stage involves a combination of physico-chemical processes and there are no sharp division between stages. The major rank subdivision may be placed together into five groupings closely parallel to the five genetic stages described herein: 1) peat, 2) lignite and sub-bituminous, 3) high volatile bituminous, 4) medium and low volatile bituminous and 5) Semi-anthracite and anthracite.

These five stages correspond more or less to the evolutionary stages of maturation of coal where peatification and dehydration correspond to diagenesis bituminisation and de-bituminisation to catagenesis and graphitization to metagenesis. However, maturation pathways for different organic matter (OM) types differ substantially. Consequently, coalification processes must differ substantially as well. Therefore, it is to mention here that the five coalification stages pertain mostly to the humic (huminite and vitrinite) maceral, which are the predominant maceral component of most coal. It is notable in this regard that inertinite maceral undergo de-volatization and aromatization much earlier in their maturation history than the Vitrinite maceral. By anthracite rank however, the end product is virtually the same.

4.4 COAL RANK PARAMETERS AND CLASSIFICATION

In the most general sense, a "rank Parameter'" is a compositional variable that provides a measure of the degree to which organic metamorphism has progressed during coalification. As such, a rank parameter should have the following qualities: (l) Its magnitude must be reasonably precise and reproducible, (2) It should change significantly and measurably with increasing rank (3) Its magnitude should reflect only the diagenetic alteration of the coal and not differences in OM type and grade. In actuality, no known rank parameters satisfy all these criteria. All are at least partly influenced by differences in OM (organic matter) type. Moreover, many of the commonly used rank parameters, such as fixed carbon and gross calorific value, are routinely determined on whole coal samples, where the results represent the combined influence of all the type constituents present. This can completely mask their heterogeneous nature. Even vitrinite reflectance, which ostensibly measures a property of a single "class" of coal constituents, can be quite variable, depending on vitrinite type.

Moreover, each vitrinite reflectance reading represents the combined contribution of many component molecules-some aromatic, some aliphatic, etc. The use of molecular thermal maturity Indicators attempts to circumvent this problem with some success by tracing the compositional evolution of a particular group or class of molecular constituents (Curiale et al., 1989). Recognizing that no property of coal is universally applicable as a rank parameter, Hood et al (1975) proposed a synthetic rank scale termed Level of Organic Metamorphism ,or LOM. Although well conceived, the LOM scale has never been widely utilized in maturation studies, possibly because it does not represent a directly measurable property of coal (as does vitrinite reflectance, for example), combined with the fact that rank classes such as high volatile bituminous, etc., are already well entrenched in the literature. Also, LOM has never been adopted as a standard of reference by any national or international organization(s). Thus, coal researchers are effectively constrained to using well-established rank parameters (such as vitrinite reflectance) and rank classes.

4.5 PEATIFICATION

Peats are organic-rich sedimentary beds having in-ground moisture contents greater than 75 wt % and/or burial depths less than 1OO meter. [Stach et al., 1982; Suggate, 1990]. Peats consist of a wide variety of organic materials admixed with variable amounts of inorganic minerals and water, which form a loosely to moderately well compacted mass.

Compositional changes occurring during peat formation are so severe, and so fundamentally different from those occurring later in coalification, that a distinction is commonly drawn between "peatification." which represents the transformation of freshly deposited organic matter into peat, and "coalification" which represents the transformation of peat into coal [Teichmuller,1982].

Since most "peatigenic" processes occur within 1 m of the sediment surface, it is useful to further distinguish between "surface peat" and "burial peat" [Suggate,1990]. The principal processes affecting surface peats are oxidation and fermentation. Microbiota (both aerobic and anaerobic) appear to take an active role in catalyzing both types of reactions. The principal change occurring in burial peats is the progressive loss of moisture (dehydration), both through physical compaction and chemical transformations. Chemical changes in burial peats are believed to be facilitated by (anaerobic) bacteria, but to a lesser degree than in near-surface peats.

Although the temperature and pressure conditions of peatification are relatively benign in comparison with later stages of coalification, the compositional changes experienced by the organic matter in the peat-forming process are relatively severe, so much so that the vegetal origins of most peat constituents become very difficult to determine. Once the precursors of coal macerals are formed at the peat stage, however, they can be traced with more or less ease through the rest of the coal rank series. The degree of initial alteration of plant material is very strongly dependent on ambient conditions in the peat-forming environment, including pH, nutrient supply, temperature, and the types of plants present. Most of these variables are either directly or indirectly related to climate.

Two alternative views regarding the origin of humic substances are: (l) that they represent the variously degraded residue(s) of plant biopolymers (principally lignin) admixed and/or polymerized with varying amounts of N-bearing proteinaceous material derived from microorganisms (Waksman, 1938). The bulk of recent evidence suggests that selective preservation accounts for most of the humic materials in peat. Both selective degradation and de-polymerization/re-polymerization are thought to be brought about by fungi and aerobic bacteria, and take place for the most part at or near the sediment surface in the presence of free oxygen.

Depending on the composition of the starting material and conditions in the peat-forming swamp, very little of the carbohydrate-derived plant polymers (cellulose, etc.) survive the initial stages of coalification. Thus, vitrinite has been described as being essentially a lignin-derived material, with most of the less-resistant materials having been broken down through hydrolytic biodegradation (Hatcher, 1990). Selective preservation also accounts for an enrichment of certain paraffinic constituents as well (Zelibor et al., 1988; Tegelaar et al. 1989).

The formation of carboxylic acid (-COOH) structures at the peat stage provides evidence that oxidative processes have occurred. Subsequent decarboxylation and expulsion of humic acids at lignite through sub-bituminous rank may be important from the standpoint of diagenesis, in that it (hypothetically) contributes to development of secondary porosity in associated sediments (Surdam and Crossey. 1985). Decarboxylation continues up to approximately the boundary of sub-bituminous and bituminous coals, by which point carboxylic acid groups are essentially gone from the coal structure (Blom et al. 1961; Hatcher et al.. 1982).

Gelification, another process occurring during peat forrmation, describes a process by which a colloidal solution (hydrosol) is formed from the original organic precursors. This subsequently dehydrates to form a hydrogel (a network of hydrocarbons in a suspension of water. (Francis, 1954; Teichmilller ,1982). The physically altered gel formed by this process can be completely structure less or can contain a highly degraded, swollen remnant cell structure, derived from the original woody plant materials (Teichmilller, 1989). The importance of gelification is that water becomes an integral constituent of the structure of the coal at the lowest rank, and remains so (to a lesser degree) throughout coalification, but do not include physically bound water. This is partly a consequence of analyses being done for the most part on dried samples, from which most sorbed water has been removed.

During anaerobic bacterial degradation of peat, a portion of the oxygen from the organic matter is metabolized, leaving a product enriched in hydrogen. By-products of this process include hydrogen sulfide, methane, carbon dioxide, ammonia. water, and organic acids (Stach et al., 1982; Hsu-Giou et al., 1989). As there is no mechanism for retaining the gases so formed, they readily escape from the system. Tile composition of the residual mass, particularly in terms of its H/C ratio. will strongly influence the quantity and varieties of hydrocarbons generated during later stages of coalification. Thus, peatification is potentially important in determining whether a coal will eventually be oil-prone or gas-prone during later stages of coalification.

Peat-to-Lignite Transition

The transition from peat to lignite entails a number of significant physical changes to the coal. Many of these changes relate to the progressive loss of water from the coal structure. This represents the most important compositional change occurring in coals of this rank range.

As compared with peats, lignites are hard and well compacted. They are often dull and earthy in appearance, but may exhibit a vitreous luster in some cases. Microscopically, there is a darkening in color of the constituents, particularly of the huminite macerals accompanied by an increase in huminite reflectance to around 0.3-0.5% (Valceva,1979; Stach et al .,1982; Suggate, 1990). Although the carbon content of lignites can be quite variable (generally in the range of 60-80%). the changes in the optical characteristic of lignite indicate a higher degree of aromaticity of the product. Lignites have a higher specific gravity, lower porosity, and lower moisture content than peat. The loss of porosity at low rank is largely the result of physical compaction due to the weight of the overlying sediments (White and Thiessen. 1913; Ting, 1977;

Rollins et al., 1991). Individual cell lumens become collapsed and fragments of organic material are forced into closer proximity with one another.

Although the decrease in moisture content at low rank is partly related to physical compaction, it is also strongly influenced by changes in chemical composition, which are thermally controlled. Humic hydrosols present in peat contain abundant moisture both as free water in macropores and capillaries, and as sorbed water that is physically bound to the organic molecules (Francis. 1954; Ode, 1963; Camier and Sieman, 1978). Both forms of moisture are lost in the process of gelification.

The transition to hydrogel at the lignite stage is accompanied by a significant volumetric shrinkage of the coal matrix, which produces shrinkage cracks in gelified vitrain bands. This constitutes the earliest form of "cleat'" in coal. although in the absence of a tectonic stress field, there is no preferred orientation. In most cases, these early formed shrinkage cracks become resealed either by annealing or by repolymerization, during subsequent stages of coalification.

Bituminous Coals:

The bituminous coal rank series, encompassing the range from the high volatile C Bituminous through low-volatile bituminous involves a significant rearrangement of the molecular composition and structure of the coal.

The transition from lignite to bituminous coal entails a number of fundamental changes to coal composition and structure. From the standpoint of coal petrology, one of the most important of these is vitrinitization or the transformation from the huminite macerals into vitrinite macerals (Teichmuller,1989).During vitrinitization, the color of the coal changes from brown to black, its hardness and brightness increase and microscopic structure develops a more densely packed character. The remnant cellular structure present in huminite at lignite rank is rendered invisible during this process, termed as "geochemical gelification"(Teichmuller,1989).

An important aspect of vitrinitization is the continued decrease in macroporosity and moisture content. Loss of so called porosity has been interpreted as representing primarily a physical process (Teichmuller,1989; Cook and Struckmeyer,1986; Damberger 1991), but thermally driven geochemical transformation appear to play an important role as well. Specifically, loss of oxygen bearing functional groups diminishes the vitrinite's affinity for water. Simultaneously, bituminization further promotes the compositional transformation of the molecular phase from a water dominated (hydrogel) system to a bitumen dominated system(bituminogel).This process represents the third major stage in coalification.

Anthracites:

Whereas coalification in the bituminous rank range centres around changes to the molecular component, coalification at Anthracite and meta anthracite stages is principally related to structural rearrangement of the matrix component. At high coal ranks, the elemental composition of the coal changes very little and this primarily involves the loss of hydrogen. With most of the molecular fraction having been expelled or re-polymerized coalification at anthracite rank principally involves the growth and coalescence of aromatic carbon structure to form a two-dimensionally and ultimately three-dimensionally ordered structure(Oberlin et al.,1980).According to Bonioly et al(1982) adjustment to the coal structures at high rank involves first a coalescence of neighboring pores, followed by growth and alignment of aromatic layers. Accompanying this change are significant increases in vitrinite reflectance, density, structural anisotropy, and hardness. The coal also becomes stronger and more coherent through the re-healing of previously formed cleat fractures. Most of these changes are interpreted as a consequence of a substantial increase in the number of condensed rings per structural unit.

4.6 PETROLOGY OF COAL

The characterization of recognizable plant material in coal was first undertaken using transmitted white light microscopy (Thiessen,1912).The megascopic(macroscopic) components of coal are termed as ingredients (Stopes,1919) or lithotypes (Stach et al. 1992). The microscopic components are termed as macerals which are comparable to the mineral grains in other rock. According to its megascopically recognizable components(termed as lithotypes), coal is classified into two types: humic and sapropelic (Stach et al,1982) . Humic coal is generally banded and sapropelic coal is non-banded. The banded bituminous coal lithotypes classified as vitrain, clarain, durain and fusain. Vitrain is bright black, glassy, shiny and brittle. Clarain is semi bright, silky and a slightly duller than vitrain. Durain is dull, greasy , and blocky. Fusain is a fossil charcoal and is dull ,flaky or fibrous , and powdery. Bone coal , a term usually used by American miners to describe impure high ash coal is used in the lithotype classification. Hower et al.,1990 also pointed out the relationship between lithotype, micro-lithotype and percentage of macerals. In lignite, the diversities of plant components related to megascopic observation are more complex due to the lack of homogenization.

Coal is not a homogeneous substance but consists of various constituents . In the same way as inorganic rocks or composed of minerals- coal consists of macerals. Macerals are the microscopically recognizable constituents of coal that originate from the different organs or tissues of plants. The physical, chemical and technological properties of the macerals vary continuously with increasing rank but in different proportions. The three maceral groups are to a certain degree characterized by their chemical compositions. If one compares iso-metamorphic maceral groups i,e the groups of the same rank, the vitrinite contains relatively more oxygen, the liptinite more hydrogen and the inertinite more carbon. With the increasing rank the macerals varying their way their chemical, physical and technological properties alter. The rank of the coal can be determined exactly by measuring its reflectance on a polished surface with a increasing rank the individual maceral becomes less and less different in reflectance so that it becomes much more difficult to differentiate between them under the microscope. When examining a polished surface of an anthracite special techniques are required to differentiate between the individual macerals. The macerals may contain inorganic components of submicroscopic size which are already present in the original plant material or which formed during the first stage of coalification process. This inorganic admixtures are grouped under the term inherent ash . This inherent ash in coal ranges from fraction of 1% to several percent.

Macerals of one and the same maceral group differ from one another in morphology structures rather than in reflectance. This is to say that there are only slight differences in volatile matter yield, elementary composition and technological properties amongst macerals belonging to the same group. If certain forms or structures of macerals can be ascribed without any doubt to a certain plant organ or plant tissue i.e. to a woody or a parenchyma tissue as in the case of telenite, the term maceral variety is used . 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.

The name vitrinite is derived from their glassy appearance, liptinite is derived from lipid components of the plant and other substances, and inertinite is derived from the inertness of their components to chemical reaction. 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, fungi, lipid, and faunal remnants .

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 bituminisation (Stach et al., 1982; Stout and Spackman, 1987; Teichmuller, 1989; ASTM, 1991).

4.7 NATURAL FRACTURES IN COAL

The fractures in coal are of four distinct classes in descending order of magnitude: 1) faults and sheer zones, 2) extension and compression-related joint sets, 3) mining-induced fractures and 4) coal cleat. It is important to note that drilling, blasting and distressing effects associated with overburden (open-cut) or coal removal (underground) can produce fracture system that can be either miss-interpreted as part of the natural fracture system or effectively overprint the pre-existing network. Among the other four fracture systems mentioned above, cleat serves as the most important natural fracture system responsible for permeability avenues for fluid or gas flow.

Cleats in coal generally form an orthogonal set of fractures that are essentially perpendicular to the bedding surfaces. Face and butt cleats systems are the primary and secondary natural fractures in coal. They are commonly mutually orthogonal or nearly orthogonal and are essentially perpendicular to near perpendicular to bedding surfaces.

Joints on the other hand in coal refers to any other extensional fracture that is confined to or transects a coal seam. Although the definition of a joint automatically assumes an extensional origin no specific contemporaneous tectonic stress regime or structural mechanism is implied in the term. (Patterson et.al., 1996).

Cleats in coal

The use of the word cleat as a mining term dates back to the late 19th century (Kendall & Briggs 1933) and has since been adopted by miners, geologists and engineers to describe a variety of fractures commonly found in coal. Most workers regard cleats in coal as equivalents to joints in clastic rock(Ver Steeg,1942; Ramano & Moiz 1968.)

Consequently, cleats in coal have been variously described as being restricted to individual coal bands or in some mine exposures to encompass the vertical extent of the seam (Tremain et al., 1991).

Cleating was found to be well developed within bright coal bands, but was rarely well-developed in dull bands. Such a tendency has been noted previously by numerous workers (Ting,1977; Hucka 1989; Law 1991; 1993; Tremain et al., 1991; Close & Mavor 1991), and is regarded here as of fundamental significance.

It was also noted that cleats rarely crossed lithotype boundaries unless they were linked through the duller lithotypes by through-going fractures. Therefore, a cleat is defined as an extensional fracture occurring within coal that is confined to a particular lithotype or microlithotype. This definition may not be universally applicable, but it is interesting to note that lithotype controlled cleat height has also been described for coals of the Uinta (Bunnell 1987; Hucka. 1989; 1991) and Raton (Close 1988) basins in the USA.

Joints in coal:

Given that cleats are defined here as being lithotype-bound then the definition of a joint in coal refers to any other extensional fracture that is confined to or transects a coal scam. Although the definition of a joint automatically assumes an extensional origin, no specific contemporaneous tectonic stress regime or structural mechanism. The coal joints generally extended vertically through only a small number of lithotypes, but in some instances extended throughout the entire seam, this being especially notable in mine exposures of German Creek coals. This latter type of joint has been often referred to as master cleats (Henkle et al., 1978; Laubach et al,1991.)However, based on our field observations, it is likely that these seam-height joints represent late-stage tensile fractures associated with unloading and de-stressing and would not be present at any great depth. Primary evidence for this is the lack of any visible infilling mineralization associated with these major fractures, even when minerals are evident within the cleat system, and the noted lack of vertically extensive fractures found in coal cores derived from depths greater than 300 m. Although not entirely conclusive, it does agree with the interpretation forwarded by Tremain et al. (1991) that so-called 'cleats' found in some immature Tertiary coals in the USA are nothing more than recently developed joints.

Mineralization in cleats and joints

Cleats examined were typically filled by one or more mineral species, whereas joints in coal and clastic rocks showed more erratic mineralization. Butt cleats and joints on the other hand, were dominated by Calcite and other carbonate minerals.In all instances noted, carbonates were clearly formed after the clay minerals and occupied the centres of cleat and joint apertures.

Fracture Geometrics: cleats in coal generally form an orthogonal set of fractures that arc essentially perpendicular to bedding surfaces. These cleat sets are well developed and continuous in bright coal bands and poorly developed and discontinuous in the dull bands. For historic reasons the predominant or primary cleat is referred to as the face cleat and the secondary or end cleat is known as the butt cleat. In plan view, face cleat geometries typically range from linear to curvilinear and form parallel to sub-parallel sets that can be continuous beyond the "open cut pit "scale (approx 50m). Butt cleats generally form parallel sets that are aligned normal to the face cleats. However, there are many exceptions to this idealized geometry. In some areas the face and butt cleat are largely indistinguishable or similar in appearance, whereas-in other areas the cleat pattern is chaotic or resembles that of polygonal shrinkage cracks.

Cleat spacings were generally found to show similar lateral consistency to orientation with similar degrees of variation adjacent to zones of structural disturbance. Cleat frequency was not typically found to increase near fault zones, although the incidence of pervasive fractures (joints) within coal seams and overburden strata did . Cleat frequency also varied systematically with lithotype, the highest frequency being associated with vitrain layers. Joints in overburden strata tended to show more complex patterns than those shown by cleats. However, in areas of faulting joints through both coal and overburden were often aligned with and perpendicular to the fault trend, and showed a good match with cleat directions.

Cleat formation

Theories proposed to explain the formation of cleats in coal have been categorized by Close (1993) into three groups: (1) endogenetic, involving soft sediment deformation processes such as differential compaction and shrinkage during coalification; (2) exogenetie, related to tectonic stresses imposed during burial and/or uplift; and (3) duogenetic, involving some combination of the preceding. Various workers have pointed to the regional consistency in cleat orientation and relationship with dip and strike as evidence of a tectonic origin. Close (1991) and Close & Mavor (1991) concluded from structural and other data that cleat formation in Cretaceous coals of the San Juan and Raton basins (USA) occurred during burial and before folding of the strata and occurred within a few million years of surface peat accumulation.

In a similar manner to Close (1991), the perpendicular nature of cleats with respect to bedding in Bowen Basin coals interpreted as evidence that cleats were formed before folding. Equally, the parallelism with strike trends suggests a relationship with the burial process, as discussed earlier, whereas modifications to the regional pattern suggest that cleats were modified by pre-existing structures, or in some instances overprinted by later structural events. The generally recognized orthogonal geometry of cleats strongly indicate that they formed by brittle failure of lithified material. Consequently, the evidence suggests that most cleats arc of tectonic origin and formed under the influence of a regional stress pattern. However, as cleat geometries can be variable ,it is likely that their orientation was controlled to some degree by local stress fields, reflecting differing degrees of stress anisotropy.