Introduction

Canada has vast coal resources, most of which are found in the Western Canada Sedimentary Basin, where they are being mined and used extensively for the generation of electricity. Considerable tonnage is shipped abroad for use mainly in the production of metallurgical coke.

At various times during the Late Jurassic to Paleocene, tectonic, sedimentological and ecological factors combined to provide favourable coal-forming environments in the foreland basin along the eastern flank of the Cordillera, resulting in major deposits of thermal and metallurgical coals. These coals are widespread and have diverse characteristics with regard to their composition, physical properties, maturity (rank), and stratigraphic and structural framework.

The term "coal" is used for a rock that comprises mainly plant-derived carbonaceous material. The term is generic and is applied to rocks having significantly different properties. These differences have profound implications on the potential utility of a coal. Most coals are consumed either by combustion to raise steam for electric power generation, or by carbonization to produce metallurgical coke. Coals that are used to fuel electric power generating plants are referred to as thermal coals. Coals that are suitable for the production of metallurgical coke are referred to as metallurgical coals.

In addition to their commercial applications, coals are useful indicators of environments of deposition within sedimentary basins, and of the thermal histories of the basins. The present distribution and character of coals in the Western Canada Sedimentary Basin reflect mainly regional variations in environments of deposition and post-depositional development of the foreland basin during the Cretaceous and Laramide orogenies.

The composition of coals in the basin is controlled mainly by depositional environment and climate. These factors influenced the types and proliferation of coal-forming flora, and conditions of early diagenesis of accumulated plant debris. Post-depositional tectonic and thermal history of the basin, mineralization within the fractures and pores of coal beds, and oxidation have modified the composition and properties of the coals.

Coal maturation is characterized by a progressive loss of volatile matter and increase in carbon content, an increase in latent heat value, and a decrease in porosity and inherent moisture content. Increasing maturation, which changes the basic properties of coal, is commonly expressed in terms of coal rank in the continuous series that ranges from lignite through subbituminous, high volatile A, high volatile B, bituminous and meta-anthracite (Fig. 33.1). Metallurgical coals in the Western Canada Sedimentary Basin range in rank from high volatile A bituminous to low volatile B coals. All of these ranks are classified as thermal coals.

The variation of coal rank in the Western Canada Sedimentary Basin closely reflects the maximum depth of burial of the coal measures, which was related to burial beneath a thick Tertiary molasse, much of it subsequently eroded during the latter stages of the Laramide Orogeny (Nairn, 1980), and to tectonic burial below stacked thrust sheets (Hughes and Cameron, 1985; England and Bustin, 1986; Bustin and England, 1989). Variations in paleo-geothermal conditions also have left an imprint on coal rank patterns.

Variations in the patterns of subsidence, orogenesis and stratigraphic fill in the Cordilleran foreland basin resulted in the development of distinct regions between which coal properties and deposits differ fundamentally. These differences are a major consideration in coal exploration, evaluation, development and resource management.

<table>
<thead>
<tr>
<th>Class</th>
<th>Group</th>
<th>White reflection</th>
<th>Black reflectance</th>
<th>Volatile matter</th>
<th>Band reflectance (reflectance</th>
<th>Carbon content (vol. %, dry basis)</th>
<th>Moisture content</th>
<th>Calorific value (megajoules/kg, air dry basis)</th>
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<tr>
<td>Anthracite</td>
<td>Meta-anthracite</td>
<td>Anthracite</td>
<td>2.50</td>
<td>0.82</td>
<td>22.5</td>
<td>92</td>
<td>10</td>
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<td></td>
<td></td>
<td>Semi-anthracite</td>
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<td>1.33</td>
<td>23</td>
<td>87</td>
<td>15</td>
<td>35.5</td>
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<td></td>
<td>Low volatile</td>
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<td>0.75</td>
<td>31</td>
<td>36</td>
<td>80</td>
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<td>High volatile B</td>
<td>0.60</td>
<td>0.75</td>
<td>30</td>
<td>36</td>
<td>80</td>
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<td>High volatile C</td>
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<td>0.75</td>
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<td>36</td>
<td>80</td>
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1) Brown Dry, mineral matter free; 2) Non-agglomerating, agglomerating, classified as low-volatile bituminous; 3) If agglomerating, classified as high-volatile C bituminous.

Figure 33.1 Classification of coals by rank and indices of organic maturity. The draft is a composite modified from ASTM (1981), Teichmüller and Teichmüller (in Stach et al., 1982), Dow (1977) and Cameron (1988).

Within the southern Canadian Rocky Mountains major coal deposits occur in the Front Ranges, inner foothills and outer foothills (Mackay, 1947; Smith, 1986; Bustin and Smith, in press). Middle and upper Paleozoic carbonates and Mississippian clastics of the Front Ranges are characterized by major east-westing thrust faults with up to tens of kilometres displacement and cove fold. Deposits of high to low volatile bituminous metallurgical coals and rare serpentinite occur in the Jurassic-Cretaceous strata of the Mount Mountain Formation (Fig. 33.2a). The Rocky Mountain Foothills, which lie between the Front Ranges and the western Interior Plains, comprise mainly deformed Mesoic and Cenoseic clastics. The inner foothills, immediately east of the Front Ranges, embrace a high-relief area of mainly Lower Cretaceous coal-bearing strata. In the inner foothills of northeastern British Columbia and west-central Alberta, significant resources of medium to low volatile bituminous metallurgical coals occur in the Lower Cretaceous Gething (Aptian to Lower Albian) and Gates (Albian) formations (Fig. 33.2b). The topography of the outer foothills is more subdued and Liassic lower rock of the Cretaceous Upper Cretaceous Tertiary coal-bearing strata. In the outer foothills of western Alberta, resources of high-volatile bituminous thermal coals occur mainly in the Coalbase Formation (Maastrichtian-Paleocene), with minor amounts in the Belly River (Campanian) and upper Beausoleil (Maastrichtian) formations (Fig. 33.2a).
Figure 31.2 Coalfields of the Western Canada Sedimentary Basin, coded according to the stratigraphic group or formation within which they occur. The stratigraphic columns highlight the major coal-bearing units by region in the lithostratigraphic context of: a. the Rocky Mountain Front Ranges and Foothills of southwestern Alberta and southeastern British Columbia, b. the Rocky Mountain Foothills of northeastern British Columbia, c. the Rocky Mountain Foothills of west-central Alberta, d. the Interior Plains of south-central Alberta, and e. the Interior Plains of southern Alberta and Saskatchewan.
Between the mid-Jurassic and Late Cretaceous (Maastrichtian) the eastern basins of the Cordillera Orogen were flooded by the eastward-flowing seas (Williams and Stelck, 1975; Kele and Stelck, 1984). The paleogeography and major transgressive-regressive cycles in the subsiding foreland basins were controlled mainly by the Cordillera and Laramide orogenies, together with global sea-level changes (Stott, 1984). Major coal deposits originated during long periods of autochthonous (in situ) and parautochthonous (nearly simultaneous) coal accumulation in the swampy and marshy areas that developed in deltaic, alluvial and lacustrine environments near the margins of the seas and between their shorelines and uplifted areas to the west (Smith, 1989b).

Gething Formation (Bullhead Group) The Gething Formation (Bullhead Group) is a predominantly non-marine deposit, at least 1,150 m thick, which locally includes up to 100 seams of high to low volatile bituminous coal, with seams up to 4.3 m thick (Gibson, 1980b, 1991). The Gething Formation is a record of the development of a major deltaic coastal plain in Southwestern British Columbia during the Aptian and early Albian. A progressive decrease in peat accumulation during the Aptian, north of the Peace River, is attributed to deposition toward the fringe of the Gething Delta where inflows of large amounts of clastic sediments and repeatedly flooded by marine waters did not favor peat accumulation (Stott, 1972). To the north, the delta deposits grade to marine shales and siltstones assigned to the Moosecar and Backinger formations and, to the south, to alluvial-plain deposits of the Gladstone Formation.

Jurassic-Cretaceous Mit Mountain Formation (Kootenay Group) The Jurassic-Cretaceous Mit Mountain Formation (Kootenay Group), which contains the major coal deposits in the Frontier Ranges of southeastern British Columbia and southwestern Alberta (Fig. 33.5a), was deposited within a broad coastal plain environment as part of a north-to-northeast-prograding clastic wedge along the western margin of the Jurassic epicontinental Ferrerie Sea during the first of two major episodes of the Columbian Orogeny (Stott, 1984; Gibson, 1980a,b). The Mit Mountain Formation contains interbedded sandstone, siltstone, mudstone and coal up to 1,000 m thick, interpreted as deltaic and/or fluvial-alluvial plain deposits (Gib- son, 1980a,b; Dubson and Bustin, 1987). Economically important coal seams occur throughout the succession. The seams are up to 18 m thick and vary in rank from south to north, from high volatile bituminous to semianthracite. Progressive south to north changes in depositional environments, from Late Jurassic to the Early Cretaceous time, resulted in deposits, north of about latitude 52° north (Clearwater River), of the mainly coal-bearing, marine to marginal marine Niakanase Formation, which is correlative with the coal-bearing Kootenay Group to the south (Fig. 33.3).

Lower Cretaceous Lower Cretaceous coal-bearing strata extend for 800 km from near the Clearwater River in Alberta, northwest along the inner foothills to north of the Peace River. The coal-bearing Bullhead, Bullhead and Fort St. John groups in north-central Alberta and northeastern British Columbia were deposited during a second pulse of the Columbian Orogeny (Stott, 1984). Throughout the central and southern Canadian Rocky Mountains, the base of the second wedge is marked by the widespread and conspicuous Cadomin Formation, a resistant, chest-pit coal complex up to about 100 m thick (although generally much thinner; Fig. 33.5). In the central and southern Front Ranges and foothills, the Cadomin Formation is overlain by continental deposits consisting of interbedded dark mudstone, siltstone and sandstone of the Gladstone Formation (Bclairmore Group). In the northern foothills it is overlain by Aptian to lowermost Albian coal-bearing faces of the Gladstone Formation (Fig. 33.2b; Stott, 1984). North of Sukakwa River the primary coal exploration target is the Gething Formation, whereas to the south it is the Gladstone Formation (Fig. 33.2b). Several coal beds occur below the Cadomin Formations in the Blackdon and Gormann Creek formations of the Minnes Group (Stott, 1981), and above the Gladstone Formation in the Boulder Creek Formation (Fig. 33.3). They appear to have limited areal extent and are generally thin, although they may be structurally thickened to commercial-grade deposits in some areas.

Gates Formation (Luscar and Fort St. John groups) The upper Luscar-Minecup-Fort St. John succession and Dysvengen Formation record four major transgressive-regressive cycles, of which only the first led to deposition of major coal deposits (Fig. 33.3). Although thin coal seams and carbonaceous partings occur throughout most of the regressive successions, economically important coal seams are restricted to the Gates Formation. The general absence of coal development in the Blairemore Group in this area suggests that it is relatively thin, as well as the presence of red shales, could have resulted from more arid and climatic conditions than those that prevailed farther north, where coal development in Luscar strata was significant. A northward change from arid to humid climatic conditions, with similar rami- fications for coal development, has been postulated for the Upper Cretaceous and Paleocene deposits that overlie the Blairemore and Luscar groups, respectively (Jerykiewicz and Sweet, 1988). The Gates Formation comprises an assemblage of about 300 m thick succession of non-marine to marginal marine sandstone, conglomerates, and shales/mudstones, and up to 11 major coal seams. The coal measures of the Gates Formation have been interpreted as the deposits of a storm- and wave-dominated delta and strand plain (Kalker and Leech, 1989). The coal seams are high to low volatile bituminous, and are up to 10 m thick.

Mannville Group During deposition of the Luscar and Blairemore groups in the area now occupied by the foothills, the Lower Cretaceous Mannville Group continued to develop to the north and west. The Mannville Group is a non-marine deposit with a middle interval of marine shale and limestone, and limnic sandstone of the Oyen Member and Glacial Lake, respectively. Although only thin beds of coal originated in alluvial-plain and deltaic environments during deposition of the Lower Mannville, several coal beds in the Upper Mannville originated during the withdrawal of the sea.
Figure 3.34 Schematic cross-section illustrating the correlation and stratigraphic relations of major coal-bearing units in the Interior Plains.

Upper Cretaceous

The major coal-bearing units of the outer foothills occur within the non-marine Storms and Mannishatan and Paskapoo formations that overlie the Upper Cretaceous nearshore strata and the marine Waspi formation. Deposition of post-Waspis strata began during the late Cretaceous early phase of the Laramide Orogeny (Stott, 1984). Of the five formations that constitute post-Waspis strata in the outer foothills of southern Alberta, including the Belly River, Bearpaw, St. Mary River, Willow Creek and Pocpine Hills, only the Belly River Formation contains appreciable amounts of coal (Figs. 33.2a, 33.3) (Jerczykiewicz, 1992). The non-marine post-Waspis succession in west-central Alberta is assigned to the Saunders Group, which includes the Brazeau, Coalpits and Paskapoo formations (Fig. 33.2d).

North of Athabasca River, Upper Cretaceous and Paleocene strata that are correlative with the pre-Paskapoo strata of the Saunders Group are assigned to the coal-bearing Wapiti Group and Scollard Formation of the Interior Plains region (Fig. 33.2d).

Belly River Formation

The Belly River Formation comprises an eastward-thinning wedge of sandstones, siltstones, shales and minor coals, up to 900 m thick, which extends from the southern foothills to Snaskatchewan, where correlative strata are assigned to the Judith River Formation. In the outer foothills, the upper part of the Belly River Formation consists of a sequence of sandstone beds that extend from the United States border north to the Bow River, where correlative strata are assigned to the Brazeau Formation of the Saunders Group. Few significant coal seams are present in the Belly River Formation in the outer foothills. This is probably attributable to unfavourable synorogenic climatic conditions indicated by the presence of well-developed calcite deposits (Jerczykiewicz and Sweet, 1988). An anoxic tectonic environment also could have produced fluctuating conditions of subsidence and uplift not conducive to the extensive accumulation of peat deposits.

Foremost and Oldman Formations (Belly River Group)

In the Interior Plains, two distinct coal-bearing stratigraphic units can be recognized in the Belly River succession: the Foremost and Oldman formations of the Belly River Group. Deposition of the Foremost and Oldman formations, and correlative strata of the undifferentiated Belly River Formation to the west, took place within an early-stage prograding coastal plain during withdrawal of the ancestral Bow Basin in Cretaceous time. In late Cretaceous time a major transgression occurred in southern Alberta leading to deposition of carbonaceous material in the Bearpaw Formation. The transgression did not extend into the central or northern foothills, where strata correlatives to the Belly River and Bearpaw formations are assigned to the predominantly continental Saunders Group (Fig. 33.3).

Extensive Upt Cretaceous coal deposits in the Interior Plains originated mainly in deltaic environments, near the shores of the epipaleotrophic Palaeo Bow (CAMPIGNON) and Bearpaw (Mannishatan) seas, and in alluvial plain environments between the shorelines and uplifted areas to the west. The Foremost Formation is a transitional sequence between the underlying marine deposits of the Packersky Formation and correlative units, and overlying, predominantly non-marine, deposits of the Oldman Formation (Fig. 33.4). The most significant coal development in the Foremost Formation is near the base (MacKay Coal Zone) and at the top (Taber Coal Zone) of the formation.

The Oldman Formation is characterized by reworked flanking-upwelling environments that indicate a dominance of alluvial deposition. The best coal development is in the upper part of the formation (Lethbridge Coal Zone). The coal zone persists over a large part of the southern interior Alberta, but within it individual coal beds are relatively thin and laterally discontinuous.

Horseshoe Canyon Formation (Edmonton Group)

The favourable peat-forming conditions that prevailed during deposition of the Oldman Formation were terminated when the epipaleotrophic Bow Basin inundated the southern and central Interior Plains. Sedimentation during this last major Cretaceous transgressive-regressive cycle was characterized by a series of coarsening-upward cycles that have been interpreted as representing repeated delta construction cycles following transgressive cycles. A series of minor transgression events produced the Bearpaw Formation and continental sediments of the overlying Horseshoe Canyon Formation. The withdrawal of marine influence followed the last major transgressive pulse (Shepherd and Hills, 1979). Major coal beds were deposited toward the top of this transgressive system (lower Horseshoe Canyon Formation), and within fluvial deltaic and alluvial plain deposits throughout the remainder of the Horseshoe Canyon Formation. The coal-bearing Horseshoe Canyon Formation is overlain by the autochthonous Whitemud and Battle formations. These latter formations contain high proportions of altered volcanic ash, including distinct white-weathering montmorillonite-rich sediments (shales, till). Repeated deposition of volcanic ash and/or a more arid climate within the depositional region may have been the main factors that militated against the formation of coal.

Wapiti Group

In the west-central Interior Plains, strata correlatives with the Belly River-Bearpaw Edmontonian successions are assigned to the Wapiti Group (Allan and Carr, 1946; Kramers and Mellon, 1972). Recently, the Upper Cretaceous-Paleocene Scollard formation has been differentiated in this region and assigned to the Wapiti Group (Fig. 33.2d; Dawson et al., this volume, Chapter 24). The Wapiti Group comprises interbedded sandstones, siltstones and mudstones, containing interbeds of bone-grained sandstones of fluvial channel origin. The general depositional environment appears to have been mainly alluvial, with evidence of some lacustrine deposition (Dawson and Kalkreuth, 1989). A maximum of six coal zones, up to 6 m thick, have been reported within a 100 m thick stratigraphic interval of about 1300 m above the base of the Bearpaw Formation (Dawson and Kalkreuth, op. cit.). These coal-bearing strata may be correlated with similar coal-bearing strata of the Brazeau Formation (Saunders Group) in west-central Alberta and to the Carbon-impregnated Coal Zone in the Horseshoe Canyon Formation (Edmonton Group) in the west-central Interior Plains.

Scollard Formation (Edmonton Group)

The Scollard Formation, which is coeval with the Coalpits Formation, is the youngest formation in the Edmonton Group (Fig. 33.4). It contains the commercially important Ardley coal beds that are associated with clastic, shallow-water lacustrine sediments (Gibson, 1977). The Ardley Coal Zone, within which coal beds attain thicknesses in excess of 7 m, occurs, in general, continuously close to the surface along several hundreds of kilometres in central Alberta, in a north-south direction parallel to its outcrop/subcrop trend (Fig. 33.2d).

Paleocene

Paskapoo Formation

The youngest coal-bearing stratigraphic units in the Western Canada Sedimentary Basin are the Paskapoo, Ravenscrag and Turtle Mountain Formations of Palaeocene age (Fig. 33.4). The Paskapoo Formation overlies the Coalpits Formation in the central and northern outer foothills and the Scollard Formation in the Interior Plains. Correlative strata of the Paskapoo Formation unconformably overlie the Willow Creek Formation in the southern outer foothills (Jerczykiewicz and Sweet, 1988). Both the Paskapoo and Pocpine Hill formations are continental alluvial plain deposits and include thick successions of poorly indurated mudstones and sandstones. Economically important coal is restricted to the Paskapoo Formation north of Hinlon, Alberta (Obed Mountain coalfield), where a coal-bearing interval about 140 m thick contains up to six seams of high volatile bimineral coal, with individual seams up to 5 m thick (Horachek, 1985).

The absence of coal deposits in the Pocpine Hill Formation is probably a result of more arid synclinal climatic conditions than those that prevailed farther north. A southward palaeoclimatic variation has been recognized in the Willow Creek and Coalpits formations that underlie the Pocpine Hill and Paskapoo formations, respectively (Jerczykiewicz and Sweet, 1988).

Ravenscrag Formation

The southeastern Interior Plains, from about the Alberta-Saskatchewan border to the northwestern Montana boundary, is characterized by the coeval coal-bearing Ravenscrag Formation and correlative Turtle Mountain Formation. The Ravenscrag Formation is an eastward-thickening wedge with relatively few coal beds, and it overlies the Coalpits Formation of the Upper Cretaceous-Paleocene Scollard Formation of the Interior Plains. The number of seams increases with progressive increase in formation thickness to the east. Coal zones occur at approximately the same stratigraphic position throughout the extent of the formation. The lateral extent, thickness, geometry and splitting of and coalescing of the coal beds that occurs within relatively close stratigraphic proximity, were apparently controlled by the underlying deltaic deposits of the Frenchman Formation, as well as by depositional features in response to crustal subsidence and by varying subsidence caused by regional dissolution of Devonian salt beds (Broughton, 1985).

Structure

As a result of the Laramide Orogeny (Late Cretaceous-Sub-Tertiary), coal measures in the Rocky Mountains were faulted and folded to a varying extent (Price, 1984). Structural style has had a marked effect on the mineability and quality of the coal, and in many areas the structure is the principal controlling factor in resource development (Bustin, 1982a; 1989).

COAL RESOURCES
Front Ranges

In the Front Ranges of southeastern British Columbia and adjacent parts of Alberta, coal measures of the Mist Mountain Formation are characterized by broad uplift to overturned concentric folds, cut and repeated by major to minor thrust and tear faults, and late extensional faults. Extensive shearing and structural thickening, and thinning of coal beds in the cores of flexures are common in highly deformed regions. Deformation has resulted, in many instances, in the destruction of the primary depositional fabric of coal beds. Faulting and folding has segmented coal deposits into discrete structural domains of varying styles and complexities.

Major faults have resulted in repetition of the Kootenay Group and have brought coal measures of the Mist Mountain Formation to depths accessible to modern mining methods. Although extensive deformation of coal-bearing strata has enhanced the economic potential of the region, it has also complicated mining and exploration. Bedding dip surfaces, joints and cleats, and extension, contraction and wrench faults have been recognized as the fundamental fabric elements within many of the major coal beds of the Kootenay Group (Norris, 1971).

Inner Foothills

The structural style of coal measures of the inner foothills, which include those of the Gething and Gates formations, is for the most part similar to that of the Front Ranges, being dominated by concentric folds and southwest-dipping thrust faults. The surface structural expression in the inner foothills tends to be folded dominated in the northwest (south eastern British Columbia) and fault dominated toward the southeast (west central Alberta) (McMechan, 1985; Langenberg et al., 1987). As in the Front Ranges, structural deformation in the inner foothills has, in some areas, enhanced the mineability of the coal, whereas in other areas it has complicated mining and lowered coal quality. The coal measures are commonly steeply dipping and extensively sheared, although nearly flat-lying strata associated with box folds occur in some areas.

Coal Composition and Rank

Coal is a heterogeneous material that comprises an organic component and mineral matter. Composition and physical properties can vary widely.

The organic component consists of the coalified remains of a variety of plant tissues and products originating from different floral types and different plant parts such as cuticles, wood, spores, resin, etc. The types and relative abundance of coal-forming flora during any specific time period were influenced by climate and depositional environment. As plant remains underwent saprogenesis and catagenesis (petrification and coalification), they were continuously altered, both physically and chemically.

The inorganic component of coal (mineral matter) originates mainly from the introduction of non-organic detritus into post-depositional sediments, commonly as a result of flooding, but also from volcanic ash falls. Additionally, minerals can be introduced diagenetically into fractures and pores in coal, mainly by groundwater. The composition and properties of mineral matter within a coal deposit and between different deposits can vary significantly. Most mineral matter yields ash when coal is incinerated.

Microscopically recognizable constituents, referred to as "macerals", define the organic component of a coal. All coals consist of a variable proportion of the three main maceral groups, namely vitrinite, inertinite and liptinite. These constituents are commonly designated as reactive or inert, to reflect their contribution to processes such as carbonization, combustion, gasification and liquefaction. Vitrinite, inertinite and part of the semifusinite constituents are considered reactive, whereas the remainder of the semifusinite and other inertinite macerals are considered inert.

The optical reflectance of vitrinite, measured in oil at a wavelength of 546nm, is commonly used to express the level of organic maturity or coal rank. Vitrinite reflectance values can be related directly to ASTM (1985) coal ranks (Fig. 33.1; Camero, 1989). Coals of different rank have different properties and, therefore, can have different uses (Fig. 33.1).

For coal rank in the Western Canada Sedimentary Basin increases for all stratigraphic horizons from east to west, reflecting either deeper pre-tectonic or syntectonic burial (Hacquebard and Donaldson, 1974; Pearson and Greaves, 1985). A notable exception to this pattern is in southeastern British Columbia and adjacent west-central Alberta, where the maximum depth of burial and thus vitrinite reflectance (coal rank) of the Gething and Gates coal measures is considerably increased towards the west due to reflect- ing the pre-tectonic depth of burial (Figs. 33.11 - 33.14; Kurst and White, 1980; Kalkreuth and McMechan, 1984). Superimposed on variations in coal rank resulting from depth of burial are differences resulting from variations in paleogeothermal conditions. One example is the progressive increase in coal rank in the Mist Mountain Formation from the Cowesness Pass area north to Cam- more (Cascade Coal Basin), which has been interpreted as reflect- ing higher paleo-heatflow to the north (England and Bustin, 1986).

Coal rank distribution in the Interior Plains was controlled pre- dominantly by maximum depth of burial, which increased in the western Interior Plains toward the axis of the Alberta Syncline. Isorematn contours across the Interior Plains of Alberta approxi- mately parallel the eastern margin of the deformed belt (Figs. 33.11 - 33.16; Niewiorki, 1984; Bustin, 1991).

Mist Mountain Formation (Kootenay Group)

The composition of coals in the Mist Mountain Formation is highly variable (Pearson, 1980). In general, however, these coals have a sulphur content of less than 1% and an ash yield ranging from 5 to 30%. They are comprised mainly of vitrinite, semifusinite and other inertinite. For the most part the coal rank is too high for recognition of lignite group macerals (Fig. 33.10a). The ratio of vitrinite to semifusinite plus other inertinite group macerals increases toward the top of the formation (Cameron, 1972; Grieve, 1985; Bustin and Durdorp, 1992). Coals near the base of the succession average about 50 to 65% vitrinite and 30% semifusinite, whereas toward the top, the coals average 70 to 85% vitrinite and 10 to 15% semifusinite. This compositional trend has been interpreted by Cameron (1972) and Durdorp and Bustin (1987) to reflect systematic variation in plant types with increasing aromatic vegetation in younger sediments in response to varying depositional conditions.
Although much of the coal maturation in the Front Ranges appears to have taken place prior to tectonic deformation, coalification levels were probably influenced by additional burial caused by numerous overlying thrust faults. Coal rank distribution patterns, therefore, are related to geological structures. In some cases increased burial of coal under overriding thrust plates appears to have produced significantly higher coal ranks than would otherwise be expected (Bustin and England, 1989).

Coal in the Mist Mountain Formation vary in rank mainly between medium and low volatile bituminous (Fig. 33.10a), and generally yield firm, coherent coke, although non-cooking (or weakly coking) high volatile bituminous and semianthracite coals also occur in notable quantities in some areas. The local occurrence of relatively high ranks, such as in the vicinity of Cominco and Ianall, might have resulted from anomalously high geothermal conditions caused by intrusive activity (Macquarrie and Donaldson, 1974).

Metallurgical (coking) coals are being mined extensively in southeastern British Columbia, and shipped to steel mills abroad.

Gething and Gates Formations

Although coals in the Gething and Gates formations can vary significantly in composition throughout the inner foothills and within individual stratigraphic sections, they can be characterized generally as inertinite-rich, with low sulphur content (usually less than 1%), although values up to 7.2% occur; Gibson, 1985b) and ash yield between 10 and 30%. The coals have good coking properties except where oxidized, in which case they are used as thermal coals.

Coal of the Gething Formation are commonly composed of 50 to 90% vitrinite with highly variable amounts of inertinite (up to 75%). In most cases semianthracite is the major inertinite maceral (Fig. 33.10b). Liptinite is rare and generally constitutes less than 5% of the macerals.

Maceral distribution in coals of the Gates Formation is quite variable. Many of these coals are characterized by relatively low vitrinite content (45-75%), high inertinite content (25-50%) and negligible amounts of liptinite (Fig. 33.10c; Kalkreuth and McMechan, 1989; Lamberton et al., 1989).

The commercially significant coals of the Gething and Gates formations range in rank between high and low volatile bituminous (Fig. 33.10d) and generally yield firm, coherent coke. These metallurgical coals are being mined extensively in northeastern British Columbia and west-central Alberta, and shipped to steel mills abroad.
Mannville Group

Substantial quantities of coal occur in the Lower Cretaceous Mannville Group and its correlatives beneath the Interior Plains (Williams and Murphy, 1981). Little is known of the distribution and character of these coals because they generally occur at depths beyond that of current conventional mining capabilities. Beds of lignitic to subbituminous coal up to 1.5 m thick occur in the McMurray and Grand Rapids formations near the Athabasca River, in the Firbag Coalfield. Coals with similar characteristics occur in the Swan River Formation, south of Lac La Ronge, in the Wapowitch Coalfield. Some coal resources of immediate interest occur in these coalfields (Fig. 33.1b; Smith, 1989a).

Belly River Formation/Group

The few analyses of coals in the Belly River Formation in the outer foothills of southwestern Alberta suggest they are rich in vitrinite (75-90%) with minor amounts of inertinite (5-15%), most of which is semi-inertinite and inertinite (5-10%). These coals are generally high volatile bituminous to rank and as such are classed as thermal coal. Belly River coals that occur in the Foremost and Oldman formations in the Interior Plains of southern Alberta generally range in rank between subbituminous A and high volatile C bituminous. They are rich in reactive components, averaging about 85% vitrinite, 10% inertinite and very minor liptinite (Fig. 33.1a). Sulphur content is characteristically less than 0.5%.

Horseshoe Canyon Formation (Edmonton Group)

Coal in the Horseshoe Canyon Formation, like the Belly River coals, are also rich in vitrinite (Fig. 33.1b) and low in sulphur content. These coals, however, are commonly of subbituminous C rank, although some of the more deeply buried coals have achieved bituminous rank (Fig. 33.1e). Horseshoe Canyon coals are mined extensively in central Alberta to fuel mine-mouth electric power generating stations.

Wapiti Group

Little is known about the composition of coals in the Wapiti Group of central Alberta because of lack of exposure and the absence of mining operations. Recent analyses (Dawson and Kalkreuth, 1989) indicate that they characteristically have high vitrinite content (75-90%), moderate inertinite content (4-25%), and low liptinite content (2-8%). Coal ranks ranging between lignite A and high volatile B bituminous have been reported. They have highly variable ash yield (typically 5-25%) and low sulphur content (0.1-0.4%).
**Coalspur Formation (Saunders Group)**

Coals of the Saunders Group in the upper foothills contain, on average, about 80% reactive and 20% inert components (Fig. 33.10). The Upper Cretaceous-Paleocene Coalspurs Formation includes the majority of coal resources in the upper foothills. Coals of the Coalspurs Formation have low sulphur content (5%) and ash yields that average about 15% (Icely-kiewicz and McLean, 1989). The petrographic composition of the coals is known mainly for the Val d’Or and Myshera seams from the Coalspurs Coalfield. These thermal coals are generally high volatile C bituminous (Fig. 33.10d). They are being mined, processed to reduce ash and moisture content, and shipped to electric power generating stations in Canada and abroad.

**Scollard Formation (Edmonton Group)**

Coals of the Upper Cretaceous-Paleocene Scollard Formation are generally less rich in reactivity than the Bell River, Horsehoe Canyon coals, with vitrinite content averaging about 75% (Fig. 33.10g). Average sulphur content is in the range of 0.5%. These subbituminous B to C thermal coals are being mined extensively in the southeast of Stormont, Ionah, Saskatchewan, and probable to attributing to geothermal patterns similar to east-west paterns (Cameron, 1991). These coals characteristic feature includes high sulphur content and relatively lower ash yields (Fig. 33.10b). Sulphur content averages about 0.5%. The Scollard lignite is being mined in several localities in the southeastern and south-central parts of Saskatchewan to fuel mine-mouth electric power generating stations.

**Paskapoo Formation**

Economically important coals in the Paleocene Paskapoo Formation are restricted to the Obed Mountain and Harminilngton coal fields north of Hinton, Alberta, at the western edge of the Interior Plains. These coals have a low sulphur content (about 0.5%) and a variable ash yield (Maclennan, 1989). The petrographic composition of these subbituminous A to high volatile C bituminous coals is poorly known but they are generally the most reactive-rich coals within the Interior Plains region (Cantzi et al., 1989). The thermal coals near Obed Mountain are being mined and processed for shipment to markets in eastern Canada and the Pacific Rim.

**Ravenscrag Formation**

Coals of the Paleocene Ravenscrag Formation in southern Saskatchewan are lignitic. A subtle but consistent west to east increase of rank in these coals, from Cypress Hills to Estevan, Saskatchewan is probably attributable to geothermal patterns similar to east-west patterns (Cameron, 1991). These coals characteristic feature includes sulphur content in the range of 0.5%. These subbituminous B to C thermal coals are being mined extensively in the southeast of Stormont, Ionah, Saskatchewan, and probable to attributing to geothermal patterns similar to east-west paterns (Cameron, 1991). These coals characteristic feature includes high sulphur content and relatively lower ash yields (Fig. 33.10b). Sulphur content averages about 0.5%. The Ravenscrag lignite is being mined in several localities in the southeastern and south-central parts of Saskatchewan to fuel mine-mouth electric power generating stations.

**Organic Maturity in the Western Canada Sedimentary Basin**

Variation in patterns of organic maturity in the Western Canada Sedimentary Basin occurs in three levels: basin wide (1st order), regional (2nd order), and local (3rd order) (Buttin, 1993). First-order patterns are manifested by an overall increase in maturity of strata of the same age from east to west, from the Interior Plains to the Rocky Mountain foothills and Front Ranges, in response to progressively deeper burial and higher paleogeothermal gradients. Superimposed on this first-order variation is second- and third-order variations, which are interpreted as reflecting local differences in depth of burial, conductive and advective heat transport, or affects of thrust faulting. Fig. 33.13 shows patterns of maturation for various chronostratigraphic units (in some cases regionally restricted) in the Western Canada Sedimentary Basin. Figs. 33.16 and 33.17 show isomaturity lines and the approximate position of the oil window on two west-to-east cross sections within the basin.

Maturation gradients in the axis of the basin are exceedingly low, averaging 0.18 log%Ro/km, whereas in the Front Ranges and foothills the gradients are substantially greater, averaging 0.25 log%Ro/km. Variations in maturation gradients are interpreted as reflecting lower paleogeothermal gradients resulting from rapid sediment loading and subsequent unloading in the Interior Plains, and higher advective heat transport in the deformed belt of the foothills and Front Ranges.

Maturation of Phaneranitic strata occurred mostly during deep burial by Upper Cretaceous and/or Paleogene sediments in foredeeps that developed in response to crustal loading during the eastern migration of the foreland fold and thrust belt. As a result of the west-to-east propagation of deformation during the Laramide Orogeny, deep burial, maturation, hydrocarbon generation, and uplift occurred earlier in the foreland belt (Late Cretaceous) than in the Interior Plains to the east, where most maturation and hydrocarbon generation occurred as late as Eocene. A thick succession of strata currently are within the oil window in the Interior Plains because of the low maturation gradients. In the deformed belt, however, because of the higher maturation gradients, the thickness of strata within the oil window is correspondingly less. In response to higher paleogeothermal gradients, strata in the deformed belt matured more quickly, leading to more rapid hydrocarbon generation and migration than in areas to the east.

In the southern part of the Cordilleran, significant maturation post-dates structural deformation of the strata, whereas in northern British Columbia and adjacent parts of Alberta, maturation primarily precedes structural deformation. Data from some deep boreholes and surface samples in the southern part of the Cordilleran provide evidence for maturation postdating or accompanying replacement of major overthrust sheets (isotonic burial). In most areas, however, there is no clear evidence for the timing of maturation relative to faulting, nor is there evidence of frictional heating.
Coal Resources

Coal beds are relatively common in Mesozoic and Cenozoic rocks of the Western Canada Sedimentary Basin. To contribute to the resource base, however, the coals must have potential for endowing wealth to the nation. Therefore, the term "coal resource" is constrained to coal deposits within specified limits of seam thickness and depth from surface, which are intended to reflect limits of economic and/or technological feasibility for exploiting the coals. In this report, assumptions related to these economic and technological factors pertain to conventional coal extraction (mining) methods only. Therefore, all coal deposits occurring at depths below 300 m in the Interior Plains and 750 m in the Rocky Mountain Front Ranges and Foothills have been excluded from resource estimates. Also, all coal beds less than 0.6 m thick have been excluded from estimates. Vast quantities of coal exist beyond the limits of depth and thickness applied in this report. These could become commercially significant if viable in situ recovery methods (e.g., in situ gasification) are developed. Also, deep coal beds may host coalified methane resources.

Coal resource quantities are estimated and categorized with respect to relative exploitative potential and age of occurrence (Smith, 1989b). Exploitative potential is expressed according to the notion of immediate interest and future interest, whereby resources of immediate interest for continuing exploration and possible development have currently favourable combinations of thickness, depth, location, and suitability. Coal deposits having lower favourable combinations of these factors contribute to resources of future interest, if they might reasonably be considered for possible exploitation in the future, given moderate improvements to economic and/or technological conditions.

Assessments of the relative assurance of the existence of estimated resource quantities are made on the basis of spatial distribution of available data. It is assumed that resource definition near points of observation is more reliable than that which is more remote. Resource quantities are classified as measured, indicated, inferred, and speculative based on the notion of decreasing confidence of the estimates according to distance from control data. The term "coal reserve" refers to that portion of the resource that is anticipated to be mineable under technological and economic conditions prescribed by a feasibility study, and that has no legal impediment to exploitation. Coal reserves that form a portion of measured and/or indicated coal resources of immediate interest are not discussed in this volume.

A common method of aggregating or comparing quantities of different coal types involves converting tonnages to tonnes coal equivalent (tce), which refers unit heat values to a standard 29.3 megajoules per kilogram (MJ/kg). On this basis, coal resources of immediate interest in the Western Canada Sedimentary Basin include about 14,000 measured megatons (i.e., million metric tonnes), 10,000 indicated megatones and 28,000 inferred megatones (Fig. 33.16). Coal resources of future interest in the basin comprise about 6,000 measured megatones, 5,000 indicated megatones, 46,000 inferred megatones and 55,000 speculative megatones on a tonnes coal equivalent basis (Fig. 33.18). The following approximations illustrate the energy equivalence of one tonne of total (coal basis) in terms of volume of crude petroleum and natural gas:

- 1 tce = 28,300 MJ
- 1 tce = 4.75 barrels of crude petroleum
- 1 tce = 0.75 cubic metres of crude petroleum
- 1 tce = 730 cubic metres of natural gas

Estimated coal resource tonnages in the Western Canada Sedimentary Basin are summarized in Figure 33.18. These estimates are based mainly (with minor revisions) on information published recently by the Geological Survey of Canada (Smith, 1989a). They are subject to ongoing change as new information is acquired through continuing exploration and geological surveys.

In addition to their suitability as conventional thermal or metallurgical coals in present coal markets, many coals in the Western Canada Sedimentary Basin have characteristics that are favourable for their conversion to liquid and gaseous hydrocarbons using hydrogenation or vacuum pyrolysis processes (Chakrabarty and du Plessis, 1985; Alberta Research Council, 1998; Kalkreuth et al., 1989).

Hydrocarbon gases are produced during all phases of coal maturation. Large volumes of these gases (mainly methane) remain trapped or sealed in the coal beds and adjacent strata in the Western Canada Sedimentary Basin (Wymann, 1984). Additionally, large volumes of coalified gases are adsorbed on the surfaces of the coals. Coal-generated gases, a viable fuel in many parts of the world, might constitute a very substantial energy resource in the Western Canada Sedimentary Basin.
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References


Figure 31.18 Summary of estimated coal resource quantities in the Western Canada Sedimentary Basin. All figures are in billion metric tonnes (megatonnes). Figures in brackets are calculations on a tonnes coal-equivalent basis, which relates unit heat values of different coals to a standard 7.93 MJ/kg.

General coal classes: lkg = lignite, llg = subbituminous B/C; sub-lbg = subbituminous A and high volatile B/C; bituminous, hkg = medium and low volatile bituminous; lvb = low volatile bituminous and anthracite.


