Authors:
G.G. Smith - Geological Survey of Canada, Calgary
A.R. Cameron - Geological Survey of Canada, Calgary
R.M. Bustin - University of British Columbia, Vancouver

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 Columbian and Laramide orogenies.

The composition of coals in the basin was 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, medium volatile and low volatile bituminous ranks, to anthracite 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 bituminous. Coals of all other ranks are classed as thermal coals.

Coal rank: Class	Coal rank: Group	Vitrinite reflectance (random)	Volatile matter (wt.% dmmf)[1]	Bed moisture (wt %)	Calorific value MJ/kg (moist,mmf)	Hydro-carbon generation	Principal uses
Anthracitic[2]	Meta-anthracite		2			Dry Gas	Space heating Chemical production
	Anthracite	2.50	8				
	Semianthracite	1.92	14				
Bituminous	Low volatile bituminous	1.51	22			Wet Gas	Metallurgical coke production Cement production Thermal electric power generation
	Medium volatile bituminous	1.12	31				
	High volatile A bituminous	0.75			32.6	Oil and Gas	
	High volatile B bituminous	0.50-0.75			30.2		
	High volatile C bituminous	0.50 ?		8-10	26.8		
Subbituminous	Subbituminous A[3]				24.4	Early Gas	Thermal electric power generation Conversion to liquid and gaseous petroleum substitutes
	Subbituminous B			25	22.1		
	Subbituminous C	0.42			19.3		
Lignitic	Lignite A			35	14.7		Thermal electric power generation Char production Space heating
	Lignite B			75			
	Peat						

1) dmmf - Dry, mineral matter free
2) Non-agglomerating; if 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 chart is a composite modified from ASTM (1981), Teichmüller and Teichmüller (*in* Stach et al., 1982), Dow (1977) and Cameron (1989).

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 (Nurkowski, 1984), and/or tectonic burial below stacked thrust sheets (Hughes and Cameron, 1985; England and Bustin, 1986; Bustin and England, 1989). Variations in paleogeothermal 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 geologically, geographically and physiographically distinct regions between which coal properties and deposits differ fundamentally. These differences are a major consideration in coal exploration, evaluation, development and resource management.

Within the southern Canadian Rocky Mountains major coal deposits occur in the Front Ranges, inner foothills and outer foothills (MacKay, 1947; Smith, 1989a; Bustin and Smith, *in press*). Middle and upper Paleozoic carbonates and Mesozoic clastics of the Front Ranges are characterized by major east-verging thrust faults with up to tens of kilometres displacement and coeval folds. Deposits of high to low volatile bituminous metallurgical coals and rare semianthracite occur in the Jurassic-Cretaceous strata of the Mist Mountain Formation (Fig. 33.2a). The Rocky Mountain Foothills, which lie between the Front Ranges and the western Interior Plains, comprise mainly deformed Mesozoic and Cenozoic clastic rocks. 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 underlain by more recessive-weathering Upper Cretaceous and Tertiary coal-bearing strata. In the outer foothills of western Alberta, resources of high-volatile bituminous thermal coals occur mainly in the Coalspur Formation (Maastrichtian-Paleocene), with minor amounts in the Belly River (Campanian) and upper Brazeau (Maastrichtian) formations (Fig. 33.2a,c).

East of the Cordilleran deformed belt, relatively undeformed Upper Cretaceous and Paleocene coal-bearing strata occur near the surface within the region of the Interior Plains. In the Interior Plains, resources of thermal, mainly subbituminous and lignite coals occur in: 1) Upper Cretaceous strata of the Foremost, Oldman and Horseshoe Canyon formations, and the Wapiti Group; 2) Upper Cretaceous-Paleocene strata of the Scollard Formation; and 3) Paleocene strata of the Paskapoo and Ravenscrag formations (Fig. 33.2d,e). Coal beds also occur in the Lower Cretaceous Mannville Group and correlative strata (e.g., Swan River Formation) that underlie the Interior Plains. With the exception of the lignitic to subbituminous coals in the Firebag and Wapawekka coalfields (Fig. 33.2d,e), these Lower Cretaceous coal deposits occur at depths beyond current conventional coal mining capabilities.

In the Front Ranges and inner foothills, tectonic deformation of coal measures is commonly the major factor that controls the present areal extent, thickness variability, lateral continuity, and geometry of coal beds. Both sedimentological factors and tectonic deformation have left a significant impression on the present distribution and geometry of coal beds in the outer foothills. In the Interior Plains, sedimentological factors have been the major control on the present distribution of coal beds. Variable coal accumulation in areas within each region, in addition to the truncation of coal deposits by erosion and/or faulting, has resulted in the formation of discrete coalfields (Fig. 33.2).

Stratigraphy and Depositional History of the Coal Measures

Coal is formed from peat which, in turn, is formed from vegetal debris that accumulates and decomposes in the stagnant waters of swamps and marshes. The formation, accumulation, preservation and alteration of peat relate to geological, biological, ecological, and geochemical factors associated with environments of deposition. In the Western Canada Sedimentary Basin, peat-forming swamp/marsh environments were controlled by: 1) regional variation in rate of basin subsidence; 2) downwarping caused by reactivation of Precambrian basement blocks; 3) climate; 4) facies disposition and compaction relief in underlying deposits; and, in some areas, 5) subsidence related to dissolution of Devonian salt beds.

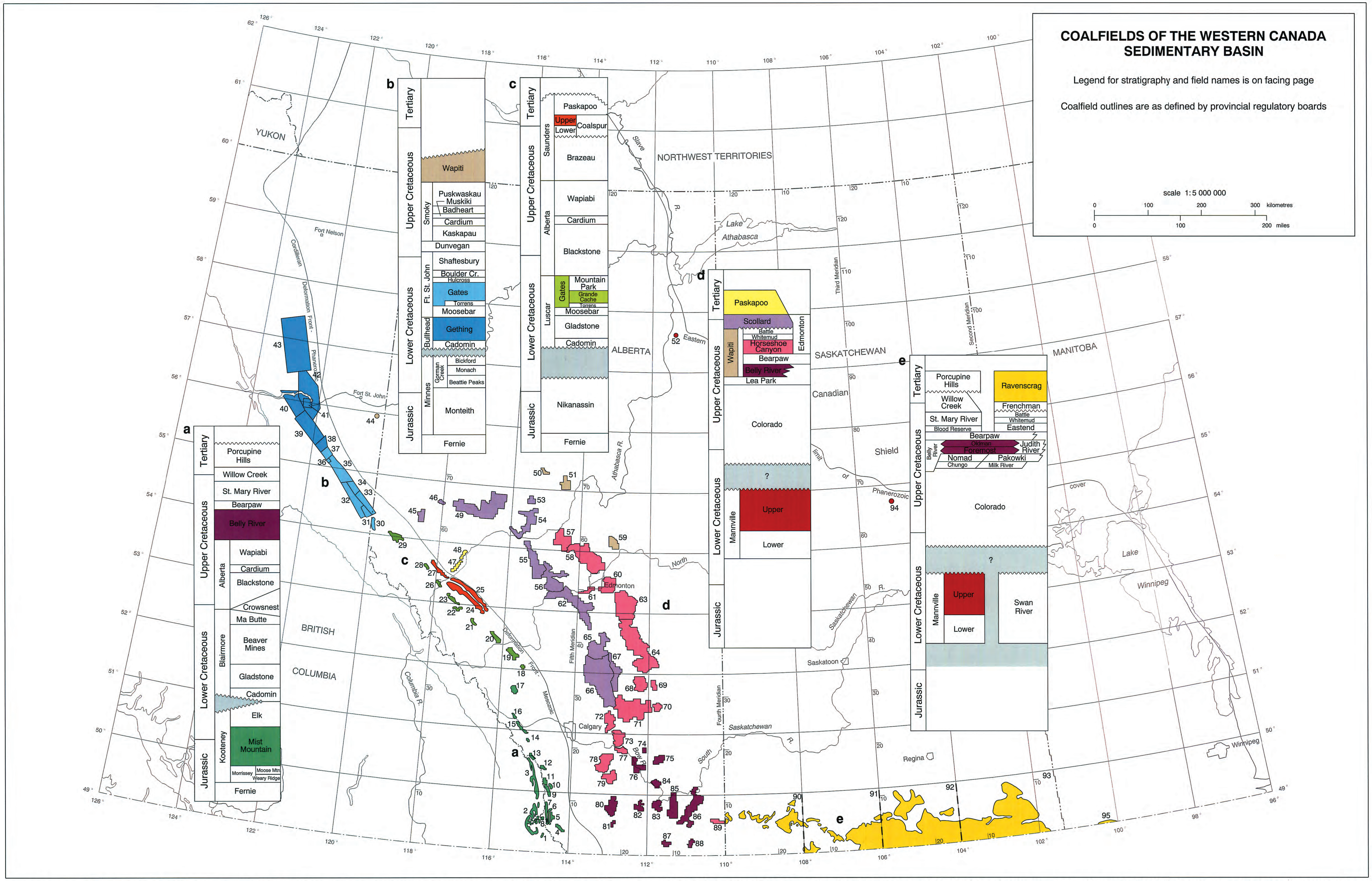

Figure 33.2 Coalfields of the Western Canada Sedimentary Basin coded according to the lithostratigraphic group or formation within which they occur. The stratigraphic columns highlight the major coal-bearing units by region in the lithostratigraphic context of: **a.** the Rocky Mountain Front Ranges 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.

Paleocene

Paskapoo Formation
- 47 Hannington
- 48 Obed Mountain

Ravenscrag Formation
- 90 Cypress
- 91 Wood Mountain
- 92 Willow Bunch
- 93 Estevan
- 95 Turtle Mountain

Upper Cretaceous-Paleocene

Coalspur Formation
- 24 Coalspur
- 25 McLeod River
- 27 Jarvis Lake

Upper Cretaceous

Edmonton Group

Scollard Fm
- 45 Musreau Lake
- 46 Simonette
- 49 Fox Creek
- 53 Swan Hills
- 54 South Swan Hills
- 55 Mayerthorpe
- 56 Wabamun
- 62 Wetaskiwin
- 65 Alix
- 66 Ardley
- 67 Scollard

Edmonton Group (cont'd)

Horseshoe Canyon Fm
- 57 Barrhead
- 58 Morinville
- 60 East Edmonton
- 61 Devon
- 63 Tofield-Dodds
- 64 Battle River
- 68 Chain Lakes
- 69 Garden Plain
- 70 Sheerness
- 71 Drumheller
- 72 Strathmore
- 73 Hussar
- 77 Blackfoot
- 78 Buffalo Hill
- 79 McGregor
- 89 Cypress Hills

Wapiti Group
- 44 Wapiti
- 50 Sawridge Hill
- 51 Lesser Slave Lake
- 59 Thorhild-Abee

Belly River Group
- 74 North Brooks
- 75 East Brooks
- 76 Brooks
- 80 Lethbridge
- 81 Pothole
- 82 Taber
- 83 Rolling Hills
- 84 Grassy Lake
- 85 Bow Island
- 86 Medicine Hat
- 87 Lucky Strike
- 88 Comrey

Lower Cretaceous

Luscar Group
- 18 Seven Mile Creek
- 19 Ram River
- 20 Nordegg
- 21 Southesk River
- 22 Mountain Park
- 23 Cadomin-Luscar
- 26 Brule
- 28 Moberly Creek
- 29 Smoky River

Ft. St. John Group
- 30 Kakwa River
- 31 Saxon
- 32 Belcourt East
- 33 Belcourt West
- 34 Monkman
- 35 Quintette
- 36 Mt. Spieker
- 37 Bullmoose

Bullhead Group
- 38 Sukunka
- 39 Pine River
- 40 Carbon Creek
- 41 Peace River
- 42 Butler Ridge
- 43 Halfway River

Mannville Group
- 52 Firebag
- 94 Wapawekka

Lower Cretaceous/Jurassic

Kootenay Group
- 1 Flathead
- 2 Fernie
- 3 Elk Valley
- 4 Beaver Mines

Kootenay Group (cont'd)
- 5 Bellevue
- 6 Blairmore
- 7 Coleman
- 8 Tent Mountain
- 9 Oldman River
- 10 Beaver Creek
- 11 Savanna Creek
- 12 Highwood Ford
- 13 Kananaskis
- 14 Pocaterra
- 15 Canmore
- 16 Bankhead
- 17 Costigan

Figure 33.2 *Continued*

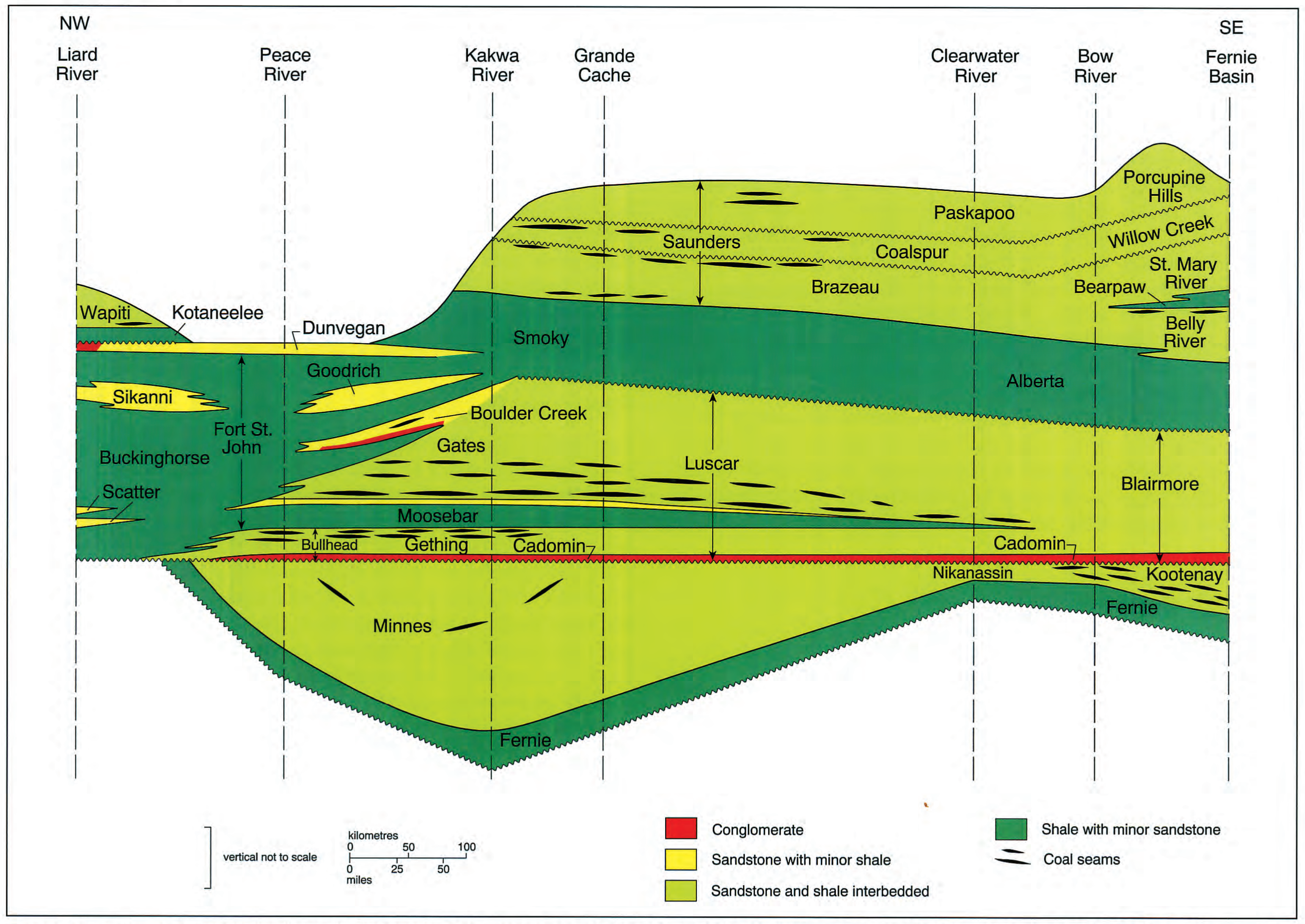

Figure 33.3 Schematic cross section illustrating the stratigraphic relations of coal-bearing units in the Rocky Mountain Front Ranges and Foothills (after Stott, 1984; Langenberg and McMechan, 1985).

Between the mid-Jurassic and Late Cretaceous (Maastrichtian) the emerging landmass of the Cordilleran Orogen was flanked to the east by seas (Williams and Stelck, 1975; Koke and Stelck, 1984). The paleogeography and major transgressive-regressive cycles in the subsiding foreland basin were controlled mainly by the Columbian and Laramide orogenies, together with global sea-level changes (Stott, 1984). Major coal deposits originated during long periods of autochthonous (in situ) and hypautochthonous (nearly in situ) peat accumulation in the swamps and marshes 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).

Jurassic-Cretaceous

Mist Mountain Formation (Kootenay Group)

The Jurassic-Cretaceous Mist Mountain Formation (Kootenay Group), which contains the major coal deposits in the Front Ranges of southeastern British Columbia and southwestern Alberta (Fig. 33.2a), 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 Fernie Sea during the first of two major episodes of the Columbian Orogeny (Stott, 1984; Gibson, 1985a). The Mist Mountain Formation consists of interbedded sandstone, siltstone, mudstone and coal up to 1000 m thick, interpreted as deltaic and/or fluvial-alluvial-plain deposits (Gibson, 1985a; Dunlop 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 at least Early Cretaceous time, resulted in deposition, north of about latitude 52° north (Clearwater River), of the mainly coal-barren, marine to marginal marine Nikanassin 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 Luscar, Bullhead and Fort St. John groups of west-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, chert-pebble conglomerate up to about 100 m thick (although generally much thinner; Fig. 33.3). 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 (Blairmore Group). In the northern foothills it is overlain by Aptian to lowermost Albian coal-bearing facies of the Gething Formation (Fig. 33.2b; Stott, 1984). North of Sukunka River the primary coal exploration target is the Gething Formation, whereas to the south it is the Gates Formation (Fig. 33.2b). Several coal beds occur below the Cadomin Formation in the Bickford and Gorman Creek formations of the Minnes Group (Stott, 1981), and above the Gates 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.

Gething Formation (Bullhead Group)

The Gething Formation (Bullhead Group) is a predominantly non-marine succession, at least 1050 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, 1985b; 1991). The Gething Formation is the record of a major deltaic coastal plain system in northeastern British Columbia during the Aptian and earliest 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 influx of large amounts of clastic sediment and repeated flooding by marine waters did not favour peat accumulation (Stott, 1972). To the north, the delta deposits grade to marine shales and siltstones assigned to the Moosebar and Buckinghorse formations and, to the south, to alluvial-plain deposits of the Gladstone Formation.

Gates Formation (Luscar and Fort St. John groups)

The upper Blairmore-Luscar-Fort St. John succession and Dunvegan 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 Blairmore Group in southwestern Alberta and southeastern British Columbia, as well as the presence of red shales, could have resulted from more arid 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 ramifications for coal development, has been postulated for the Upper Cretaceous and Paleocene deposits that overlie the Blairmore and Luscar groups, respectively (Jerzykiewicz and Sweet, 1988).

The Gates Formation comprises an 80 to about 300 m thick succession of non-marine to marginal marine sandstones, 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 (Kalkreuth and Leckie, 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 Blairmore groups in the area now occupied by the foothills, the Lower Cretaceous Mannville Group and correlative units (e.g., Fahler, Grand Rapids, McMurray and Swan River formations), were being deposited in the southern and central area of the Interior Plains. Coal occurs in varying amounts in each of these stratigraphic units. The Mannville Group is a mainly non-marine succession with a middle interval of marine shale and limestone, and glauconitic sandstone of the Ostracod Zone and Glauconitic Sandstone, respectively. Although only thin beds of coal originated in alluvial-plain and deltaic environments during deposition of the Lower Mannville, several thicker coal beds in the Upper Mannville originated during the withdrawal of the sea.

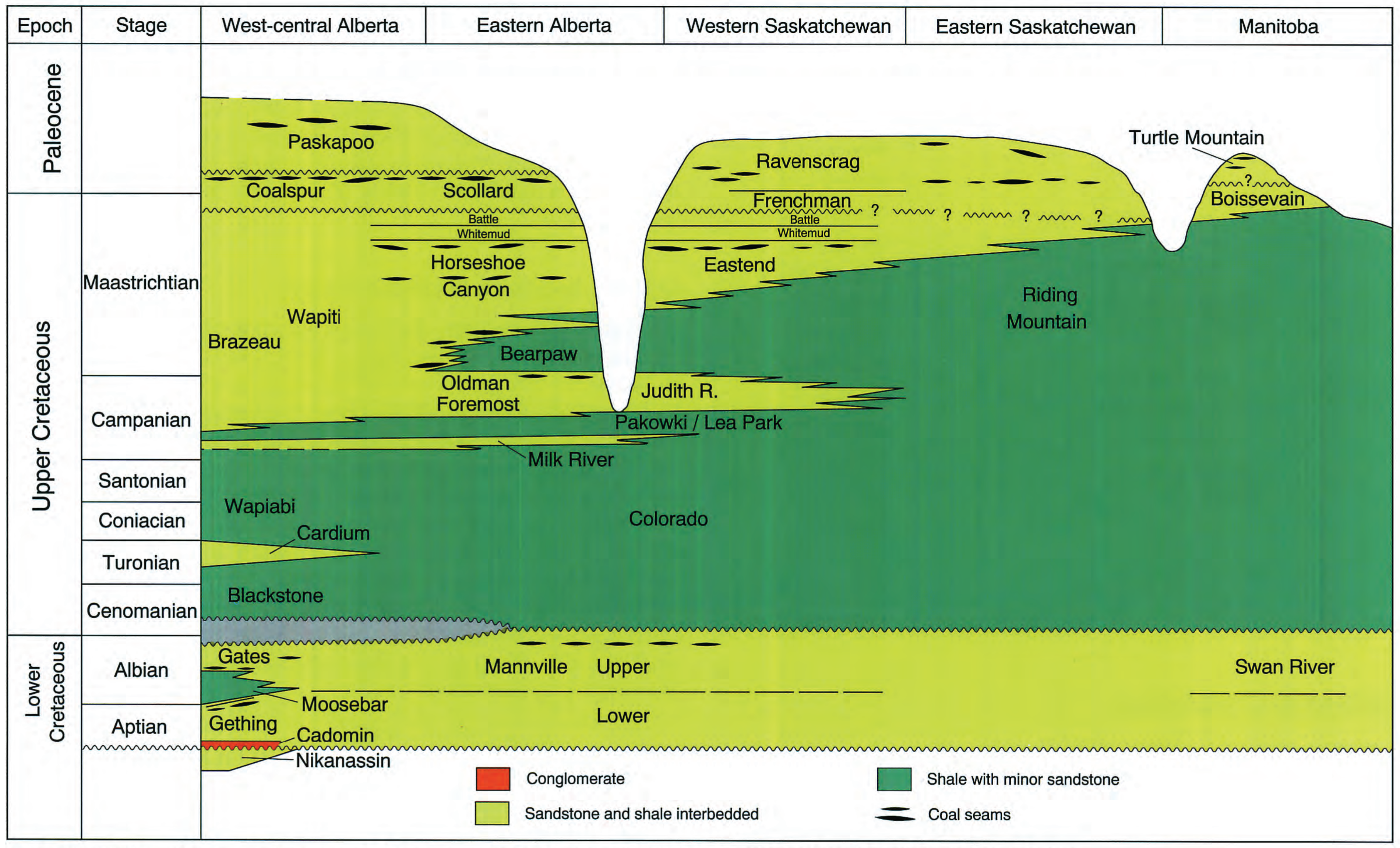

Figure 33.4 Schematic cross section illustrating the correlation and stratigraphic relations of major coal-bearing units in the Interior Plains.

Upper Cretaceous

The major coal-bearing units of the outer foothills occur within the non-marine Campanian, Maastrichtian and Paleocene strata that overlie the Upper Cretaceous nearshore strata and the marine Wapiabi Formation. Deposition of post-Wapiabi strata began during the Late Cretaceous early phase of the Laramide Orogeny (Stott, 1984). Of the five formations that constitute post-Wapiabi strata in the outer foothills of southern Alberta, including Belly River, Bearpaw, St. Mary River, Willow Creek and Porcupine Hills, only the Belly River Formation contains appreciable amounts of coal (Figs. 33.2a, 33.3; Jerzykiewicz, 1992). The non-marine post-Wapiabi succession in west-central Alberta is assigned to the Saunders Group, which includes the Brazeau, Coalspur and Paskapoo formations (Fig. 33.2c).

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 Saskatchewan, where correlative strata are assigned to the Judith River Formation. In the outer foothills, the Belly River Formation extends 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 syndepositional climatic conditions indicated by the presence of well-developed caliche deposits (Jerzykiewicz and Sweet, 1988). An unstable 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 easterly prograding coastal plain during withdrawal of the Pakowki Sea in Campanian time. In late Campanian time a major transgression occurred in southern Alberta leading to deposition of the marine Bearpaw Formation. The transgression did not extend into the central or northern foothills, where strata correlative to the Belly River and Bearpaw formations are assigned to the predominantly continental Saunders Group (Fig. 33.3).

Extensive Upper Cretaceous coal deposits in the Interior Plains originated mainly in deltaic environments, near the shores of the epicontinental Pakowki (Campanian) and Bearpaw (Maastrichtian) 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 Pakowki 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 repeated fining-upward cycles 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 southern 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 epicontinental Bearpaw Sea inundated the southern and central Interior Plains. Sedimentation during this last major Late Cretaceous marine transgressive-regressive cycle was characterized by a series of coarsening-upward cycles that have been interpreted as representing repeated delta construction cycles following transgressive pulses. A transition between the marine sediments of the Bearpaw Formation and continental sediments of the overlying Horseshoe Canyon Formation reflects the withdrawal of marine influence following the last major transgressive pulse (Shepheard and Hills, 1970). Major coal beds were deposited toward the top of the transitional sequence (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 coal-barren Whitemud and Battle formations. These latter formations contain high proportions of altered volcanic ash, including distinct white-weathering montmorillonite-rich sediments (Kneehills Tuff). 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 peat.

Wapiti Group

In the west-central Interior Plains, strata correlative with the Belly River-Bearpaw-Edmonton successions have been 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 excluded from the Wapiti Group (Fig. 33.2d; Dawson et al., *this volume*, Chapter 24). The Wapiti Group comprises interbedded sandstones, siltstones and mudstones, commonly cut by thick, coarse-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 about 1300 m above the base of the Wapiti Group (Dawson and Kalkreuth, op. cit.). These coal-bearing strata may be correlative with similar coal-bearing strata of the Brazeau Formation (Saunders Group) in west-central Alberta and to the Carbon-Thompson Coal Zone in the Horseshoe Canyon Formation (Edmonton Group) in the west-central Interior Plains.

Upper Cretaceous-Paleocene

Coalspur Formation (Saunders Group)

The Saunders Group is over 3600 m thick (Jerzykiewicz and McLean, 1980) and is divisible into the Brazeau, Coalspur and Paskapoo formations. Although all three units include carbonaceous partings and thin coal seams, major coal deposits are restricted to the Coalspur and Paskapoo formations.

Strata of the Saunders Group were deposited mainly within lacustrine and alluvial environments. The Brazeau and Coalspur formations were deposited as a series of five cyclothems, each consisting of a lower part that comprises mainly channel sandstones, and an upper part consisting mostly of mudstones with coaly shales and/or coal beds, and lacustrine rythmites (Jerzykiewicz and Sweet, 1988). The fifth cyclothem is the Coalspur Formation (Jerzykiewicz, 1985). The thickest coal beds are associated with alluvial deposits in the upper part. The Coalspur Formation is up to 250 m thick and includes seven major seams, which range to 22 m in thickness (Engler, 1983; Jerzykiewicz and McLean, 1980). This formation contains the vast majority of coal resources in the outer foothills.

Scollard Formation (Edmonton Group)

The Scollard Formation, which is correlative with the Coalspur 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 Paleocene age (Fig. 33.4). The Paskapoo Formation overlies the Coalspur Formation in the central and northern outer foothills and the Scollard Formation in the Interior Plains. Correlative strata of the Porcupine Hills Formation unconformably overlie the Willow Creek Formation in the southern outer foothills (Jerzykiewicz and Sweet, 1988). Both the Paskapoo and Porcupine Hills formations are continental alluvial-plain deposits and include thick successions of poorly indurated mudstones and sandstones. Economically important coals are restricted to the Paskapoo Formation north of Hinton, Alberta (Obed Mountain coalfield), where a coal-bearing interval about 140 m thick contains up to six seams of high volatile bituminous coal, with individual seams up to 5 m thick (Horachek, 1985).

The absence of coal deposits in the Porcupine Hills Formation is probably a result of more arid syndepositional climatic conditions than those that prevailed farther north. A south-north paleoclimatic variation has been recognized in the Willow Creek and Coalspur formations that underlie the Porcupine Hills and Paskapoo formations, respectively (Jerzykiewicz and Sweet, 1988).

Ravenscrag Formation

The southeastern Interior Plains, from about the Alberta-Saskatchewan border to southwestern Manitoba, are underlain by the coal-bearing Ravenscrag Formation and correlative Turtle Mountain Formation. The Ravenscrag Formation is an eastward-thickening wedge with relatively few coal beds in southwestern Saskatchewan. 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 and coalescing of coal beds that occur within relatively close stratigraphic proximity, were apparently controlled by the underlying deltaic deposits of the Frenchman Formation, as well as by depositional features formed 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-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,b; 1989).

Figure 33.5 Tectonically thickened coal, resulting from cataclastic flow from the limbs into the hinge area of a major structure, Front Ranges of southwest Alberta.

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 upright 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 slip 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).

Figure 33.6 Tectonically thickened coal,resulting from imbrication, outer foothills of west-central Alberta.

Figure 33.7 Flat-lying lowermost Edmonton Group, Interior Plains, central Alberta.

Figure 33.8 Near-surface strata deformed by overriding glacial movement, Interior Plains, south-central Alberta.

In some areas, such as Grassy Mountain in southwestern Alberta, and Coal Mountain in southeastern British Columbia, coal seams have been thickened by up to an order of magnitude in response to cataclastic flow of coal from limbs into the hinge areas of major structures (Fig. 33.5). In other areas, shearing of coals has: 1) resulted in increased ash yields; 2) locally promoted in situ oxidation; and 3) resulted in unpredictable roof conditions, making underground mining difficult.

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 southwesterly dipping thrust faults. The surface structural expression in the inner foothills tends to be fold dominated in the northwest (northeastern 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.

Figure 33.9 Fault in the Ravenscrag Formation caused by dissolution of underlying salt deposits, Interior Plains, southeastern Saskatchewan.

Outer Foothills

In the outer foothills, regional structures can be characterized as northwesterly-trending open folds and widely spaced southwest-dipping thrust faults. Locally, structures are commonly more complex and, as elsewhere in the Cordillera, they have both enhanced and complicated coal mining possibilities (Fig. 33.6).

Interior Plains

The Alberta Syncline, Sweetgrass and subsidiary arches, and Williston Basin are the major structural features of the southern Interior Plains (Herbaly, 1974). These features affected drainage and sedimentation patterns during Cretaceous and Tertiary time and controlled burial depth and subsequent maturation of preserved organic material. They have left a regional structural impression on the Cretaceous and Tertiary stratigraphic sequences. Generally, the coal measures have not been tectonically deformed except in a broad regional sense (Fig. 33.7). They have been deformed, however, by differential sediment compaction. Commonly, strata near the present bedrock surface have been variably faulted and folded by glacial movements (Fig. 33.8). Additionally, faulting of coal measures has been caused by collapse resulting from dissolution of underlying salt deposits (Fig. 33.9; Broughton, 1985). These latter types of deformation have affected both coal bed geometry and physical properties of the enveloping rocks, and tend to complicate mining operations.

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 these plant remains underwent eogenesis and catagenesis (peatification and coalification), they were continually altered, both physically and chemically.

The inorganic component of coal (mineral matter) originates mainly from the introduction of non-organic detritus into peat-forming swamps, 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 variable proportions 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, liptinite and part of the semifusinite constituents are considered reactive, whereas the remainder of the semifusinite and other inertinite macerals are considered inert.

The mean optical reflectance of vitrinite, measured in oil at a wavelength of 546μm, is commonly used to express the level of organic maturity or coal rank. Vitrinite reflectance values can be related directly to ASTM (1981) coal ranks (Fig. 33.1; Cameron, 1989). Coals of different rank have different properties and, therefore, can have different uses (Fig. 33.1).

For the most part, 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 Grieve, 1985). A notable exception to this pattern is in northeastern 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 initially increases to the west then decreases, reflecting the pre-tectonic depth of burial (Figs. 33.11 - 33.14; Karst 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 Crowsnest Pass area north to Canmore (Cascade Coal Basin), which has been interpreted as reflecting higher paleo-heatflow to the north (England and Bustin, 1986).

Coal rank distribution in the Interior Plains was controlled predominantly by maximum depth of burial, which increased in the western Interior Plains toward the axis of the Alberta Syncline. Isomaturity contours across the Interior Plains of Alberta approximately parallel the eastern margin of the deformed belt (Figs. 33.11 - 33.14; Nurkowski, 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 composed mainly of vitrinite, semifusinite and other inertinite. For the most part the coal rank is too high for recognition of liptinite 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, 1989; Bustin and Dunlop, 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 Dunlop and Bustin (1987) to reflect systematic variation in plant types with increasing arboraceous vegetation in younger sediments in response to varying depositional conditions.

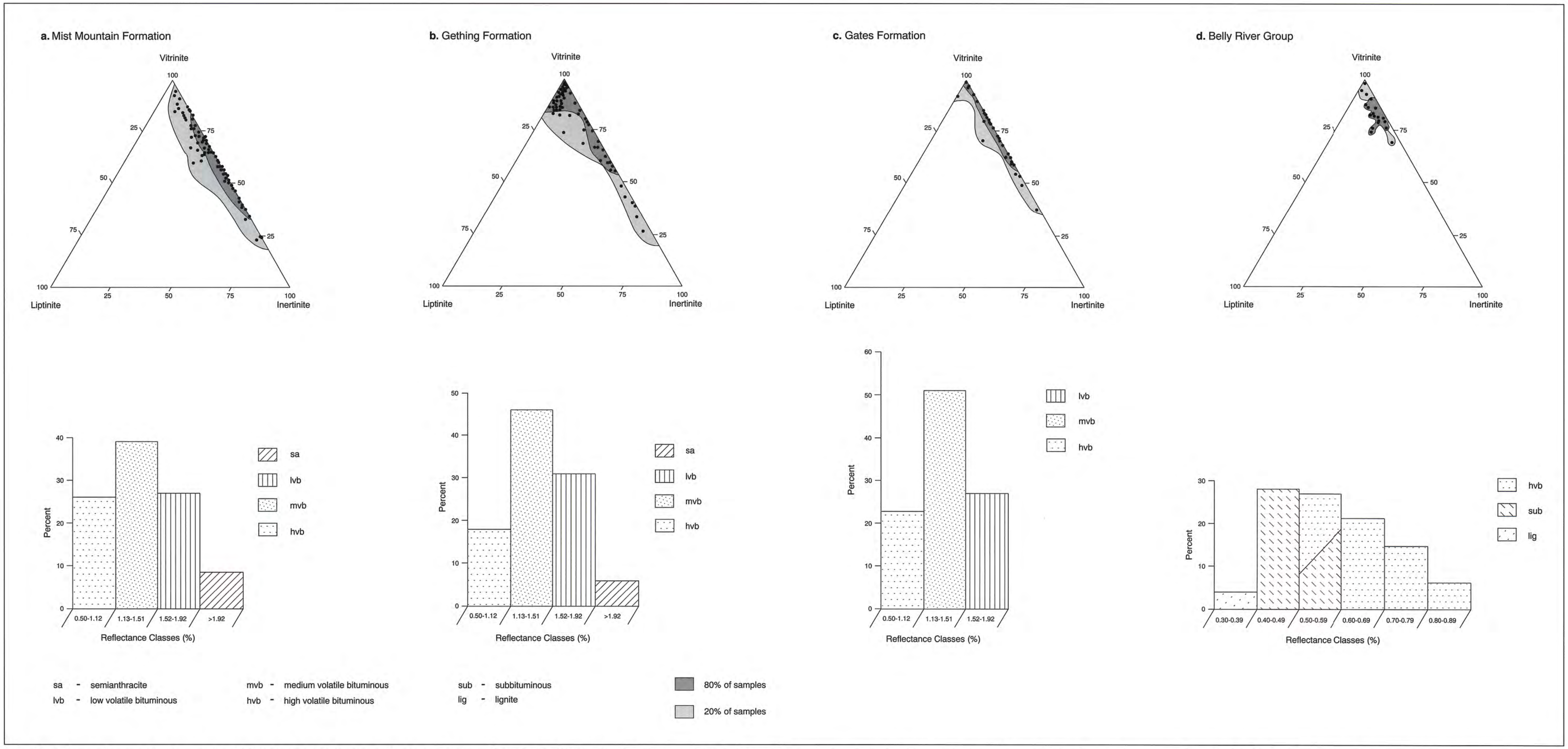

Figure 33.10 Ternary diagrams showing proportional distribution of vitrinite, inertinite and liptinite maceral groups in coals of the Western Canada Sedimentary Basin. Reflectance histograms show distribution of measured values of % mean vitrinite reflectance for corresponding coals. All reflectances are random, either measured directly or calculated from maximum reflectances according to the formula $Ro_{random} = Ro_{max}/1.066$. Rank/reflectance thresholds are according to Figure 33.1. For lower rank coals (e.g., Horseshoe Canyon) the data are plotted in smaller reflectance classes (0.10%Ro) than is the case for the higher rank coals (e.g., Mist Mountain). Although Figure 33.1 shows a tentative reflectance threshold between subbituminous and high volatile bituminous at 0.50%Ro, the boundary is most likely between 0.50 and 0.60%Ro. That is why in histograms such as the Belly River, containing the reflectance class 0.50 - 0.59%, the class has been arbitrarily halved, with one part coded subbituminous and the other high volatile bituminous. The minimum reflectance values are 0.75% Ro_{random} for the Mist Mountain Formation **(a),** 0.76% Ro_{random} for the Gething Formation **(b)**, and 1.00%Ro_{random} for the Gates Formation **(c)**. Note that the ternary diagram for the Ravenscrag Formation **(h)** shows huminite maceral group instead of vitrinite.

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 overriding 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).

Coals 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-coking (or weakly coking) high volatile bituminous and semianthracitic coals also occur in notable quantities in some areas. The local occurrence of relatively high ranks, such as in the vicinity of Canmore and Banff, might have resulted from anomalously high geothermal conditions caused by intrusive activity (Hacquebard 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.

Coals of the Gething Formation are commonly composed of 50 to 90% vitrinite with highly variable amounts of inertinite (up to 75%). In most cases semifusinite 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; Lamberson et al., 1989).

The commercially significant coals of the Gething and Gates formations range in rank between high and low volatile bituminous (Fig. 33.10b,c) 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.

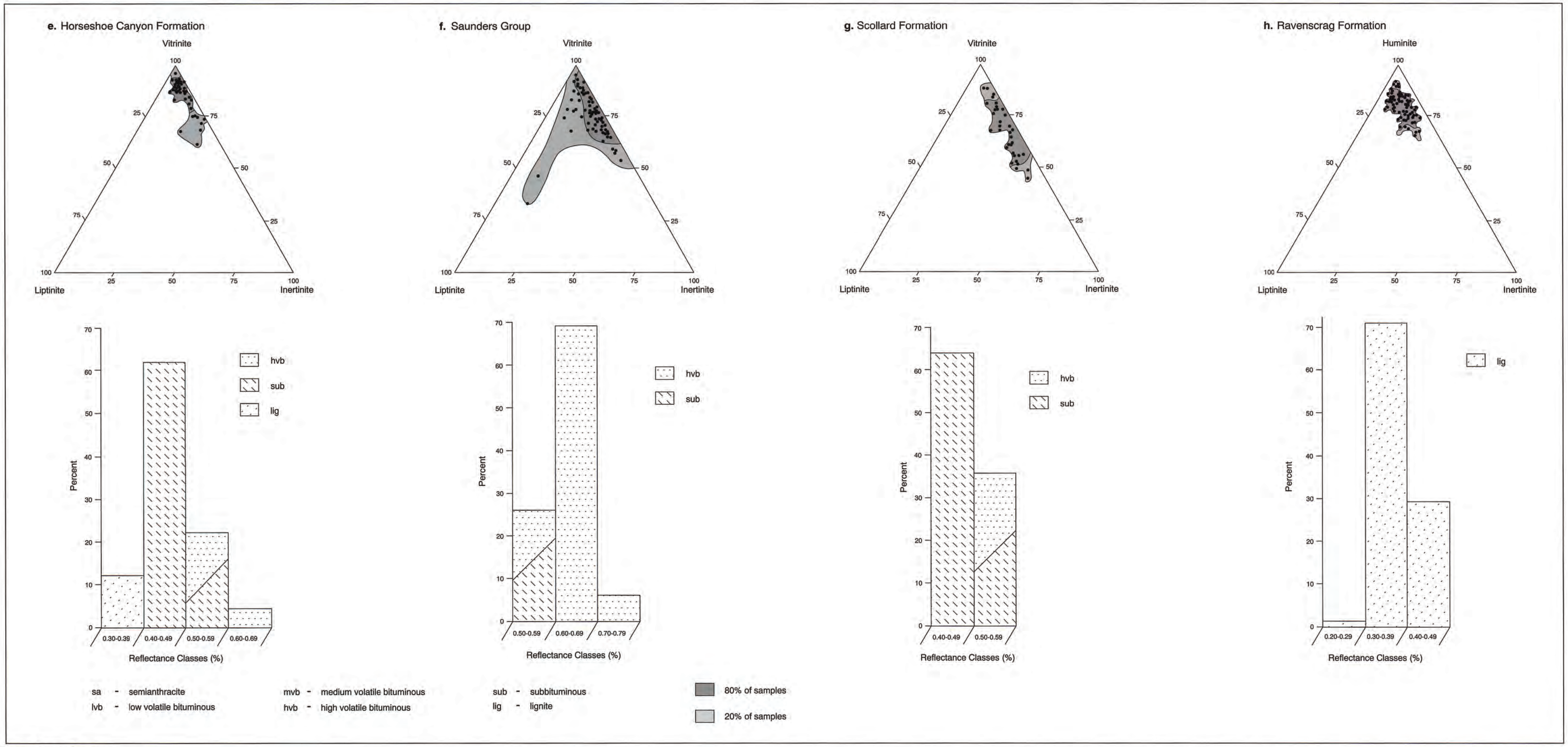

Figure 33.10 *Continued*

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 Firebag Coalfield. Coals with similar characteristics occur in the Swan River Formation, south of Lac La Ronge, in the Wapawekka Coalfield. Some coal resources of immediate interest occur in these coalfields (Fig. 33.18; 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 semifusinite) and liptinite (3-10%). These coals are generally high volatile bituminous in 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. 33.10d). Sulphur content is characteristically less than 0.5%.

Horseshoe Canyon Formation (Edmonton Group)

Coals in the Horseshoe Canyon Formation, like the Belly River coals, are also rich in reactives (Fig. 33.10e) 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. 33.10e). 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 (75-94%), moderate inertinite content (4-21%), 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 (0.1-0.8%).

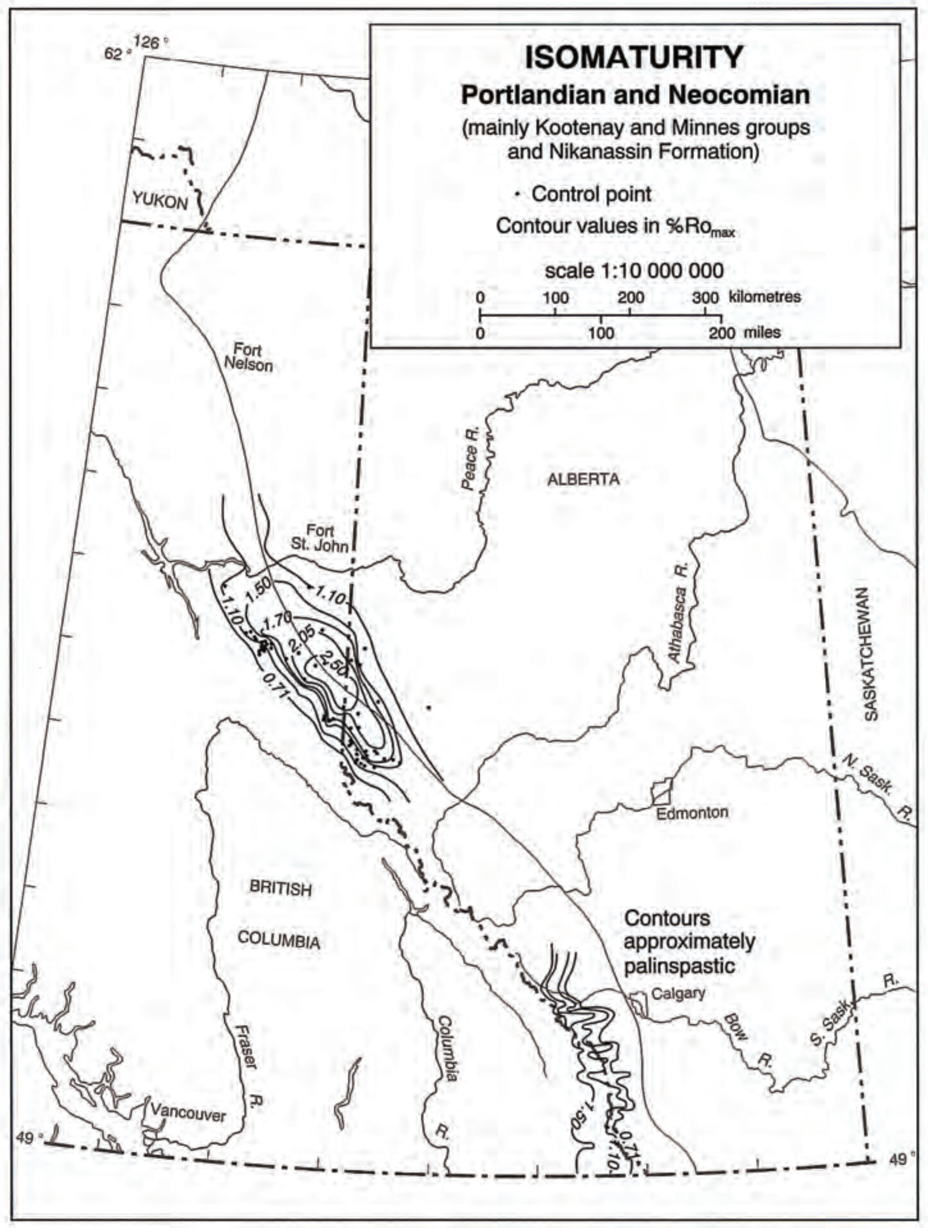

Figure 33.11 Isomaturity map of Portlandian and Neocomian strata. Data are mainly from the Kootenay and Minnes groups and the Nikanassin Formation. Contours are in %Ro$_{max}$. Points of control data are not shown where contours are shown approximately restored to pre-deformational position (Bustin, 1991).

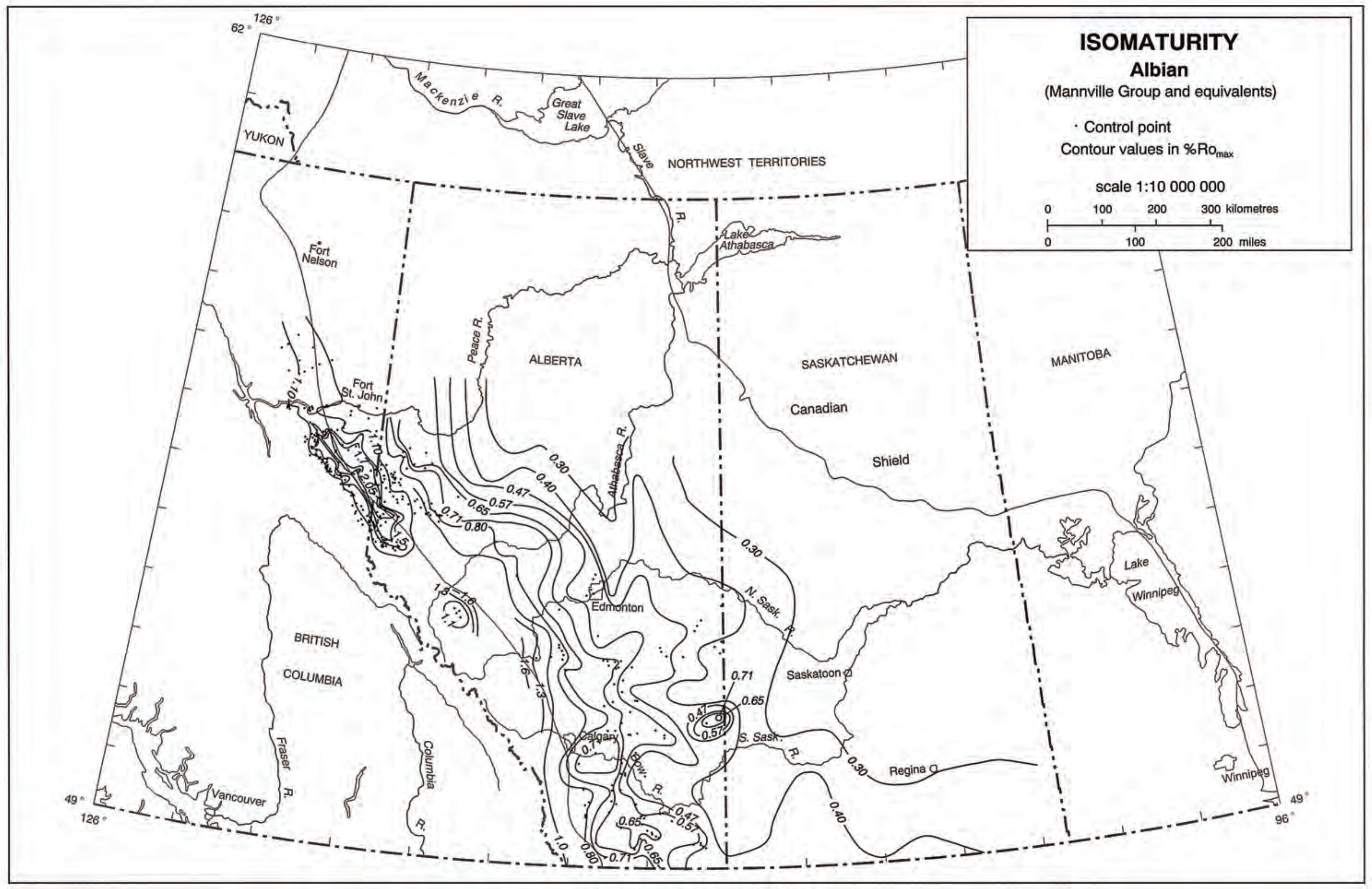

Figure 33.12 Isomaturity map of Albian strata. Data are from the Blairmore, Luscar and Mannville groups and the Gates and Spirit River formations (Bustin, 1991). Contours are in %Ro$_{max}$. The 0.30 and 0.40% contours are modified from Ozadetz et al. (1990).

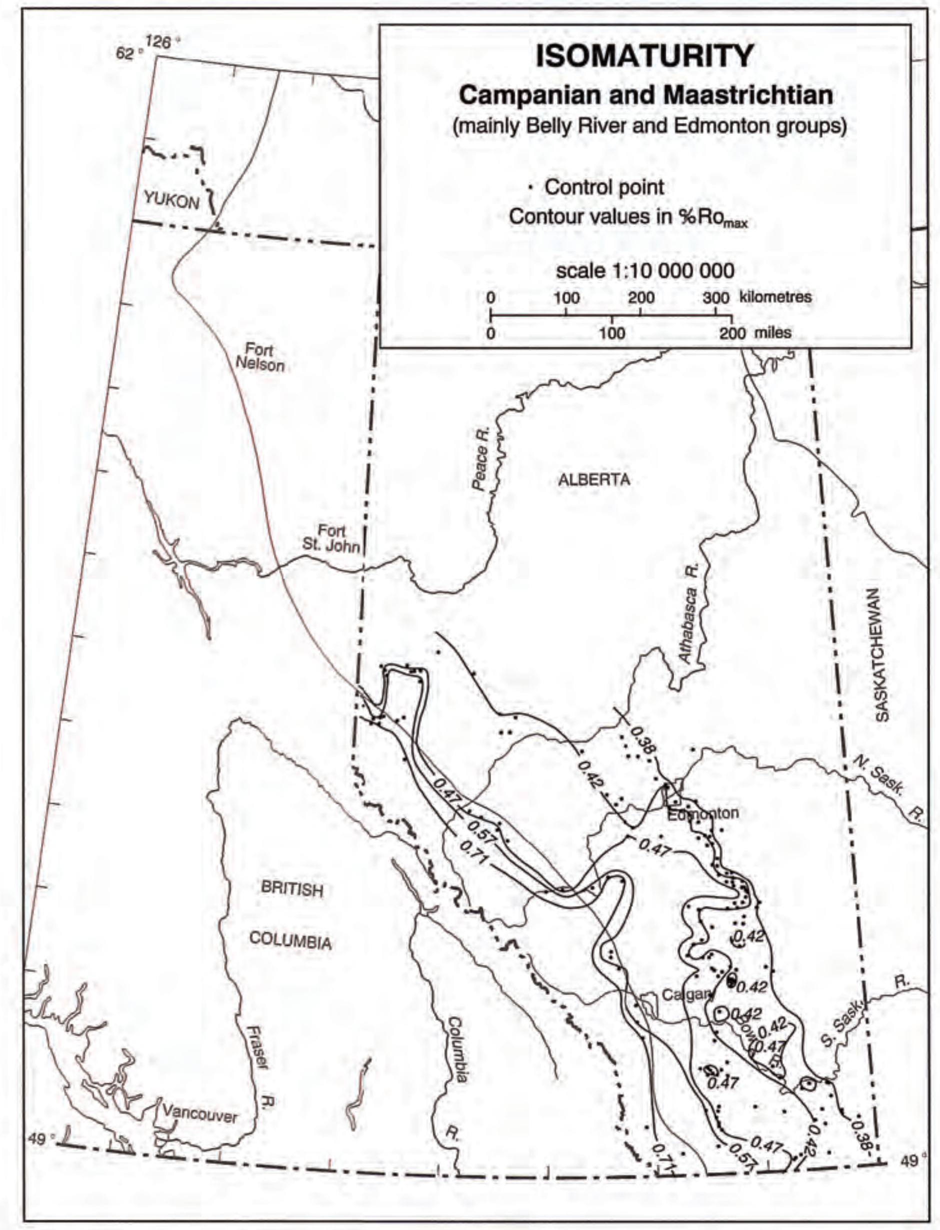

Figure 33.13 Isomaturity map of Campanian and Maastrichtian strata. Data are mainly from the Belly River and Edmonton groups. Contours are in %Ro$_{max}$ (Bustin, 1991).

Coalspur Formation (Saunders Group)

Coals of the Saunders Group in the outer foothills contain, on average, about 80% reactive and 20% inert components (Fig. 33.10f). The Upper Cretaceous-Paleocene Coalspur Formation includes the majority of coal resources in the outer foothills. The coals of the Coalspur Formation have low sulphur contents (%) and ash yields that average about 15% (Jerzykiewicz and McLean, 1980). The petrographic composition of the coals is known mainly for the Val d'Or and Mynheer seams from the Coalspur Coalfield. These thermal coals are generally high volatile C bituminous (Fig. 33.10f). 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 reactives than the Belly River and Horseshoe 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 west of Edmonton to fuel large-scale mine-mouth electric power generating stations. More deeply buried Scollard coals reach high volatile bituminous rank farther to the west.

Paskapoo Formation

Economically important coals in the Paleocene Paskapoo Formation are restricted to the Obed Mountain and Hannington coalfields 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 (Macdonald, 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 (Gentzis 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 extant patterns (Cameron, 1991). These coals characteristically include 75 to 80% huminite A, 10 to 15% inertinite, and 5 to 10% liptinite (Fig. 33.10h). Sulphur content averages about 0.5%. The Ravenscrag lignites are being mined at several locations 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 on three levels: basin wide (1st order), regional (2nd order), and local (3rd order) (Bustin, 1991) First-order variations are manifest 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 in maturity are 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. Figures 33.11 through 33.13 show patterns of maturity for various chronostratigraphic units (in some cases regionally restricted) in the Western Canada Sedimentary Basin. Figures 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 0.10 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 conductive heat transport in the deformed belt of the foothills and Front Ranges.

Maturation of Phanerozoic strata occurred mostly during deep burial by Upper Cretaceous and/or Paleogene sediments in foredeeps that developed in response to crustal loading during the easterly 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 Cordillera, significant maturation postdates structural deformation of the strata, whereas in northeastern British Columbia and adjacent parts of Alberta, maturation primarily predates structural deformation. Data from some deep boreholes and surface samples in the southern part of the Cordillera provide evidence for maturation postdating or accompanying emplacement of major overthrust sheets (tectonic 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.

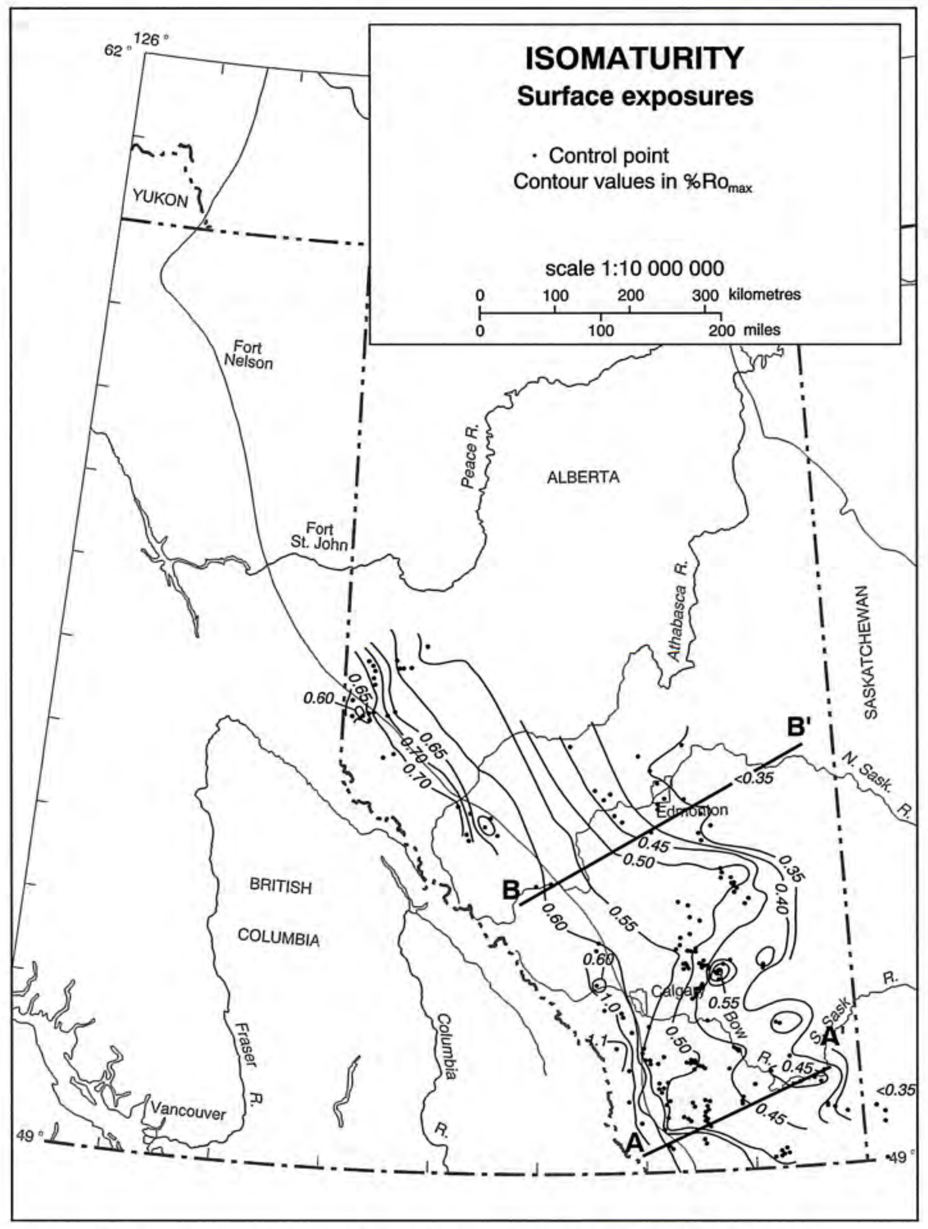

Figure 33.14 Isomaturity map of surface exposures in the Western Canada Sedimentary Basin. Contours are in %Ro$_{max}$. Lines of cross section are for Figures 33.16 and 33.17.

The maturation gradients and levels of maturity of surface and near-surface strata in the western Interior Plains and Rocky Mountain Foothills indicate that an extremely thick succession (several kilometres) of Paleogene strata was deposited in these regions (foredeep) and subsequently eroded in response to post-Laramide isostatic uplift (Fig. 33.15).

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 500 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 coalbed methane resources.

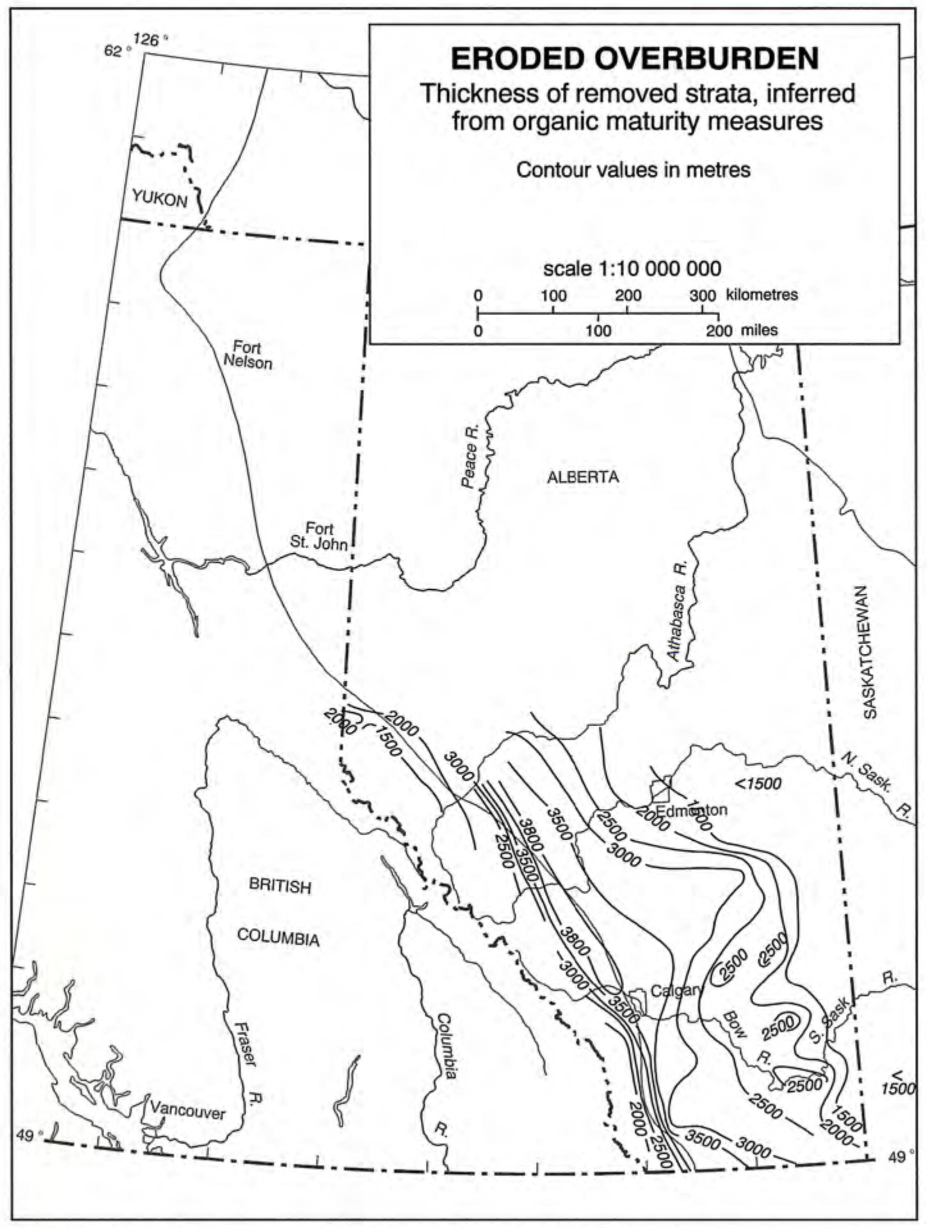

Figure 33.15 Inferred thickness of eroded overburden in the Western Canada Sedimentary Basin based on extrapolating measured maturation gradients to 0.25%Ro$_{max}$ and utilizing surface maturity values. The map is highly schematic and generalized, and no attempt has been made to honour local variations in maturation gradient (Bustin, 1991).

Coal resource quantities are estimated and categorized with respect to relative exploitation potential and assurance of existence (Smith, 1989a). Relative exploitation 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, quality and location. Coal deposits having less 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 megatonnes (i.e., million metric tonnes), 10 000 indicated megatonnes and 28 000 inferred megatonnes (Fig. 33.18). Coal resources of future interest in the basin comprise about 1000 measured megatonnes, 15 000 indicated megatonnes, 46 000 inferred megatonnes and 55 000 speculative megatonnes on a tonnes coal equivalent basis (Fig. 33.18). The following approximations illustrate the energy equivalence of one tonne of coal (tce basis) in terms of volume of crude petroleum and natural gas:

1 tce = 29 300 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.

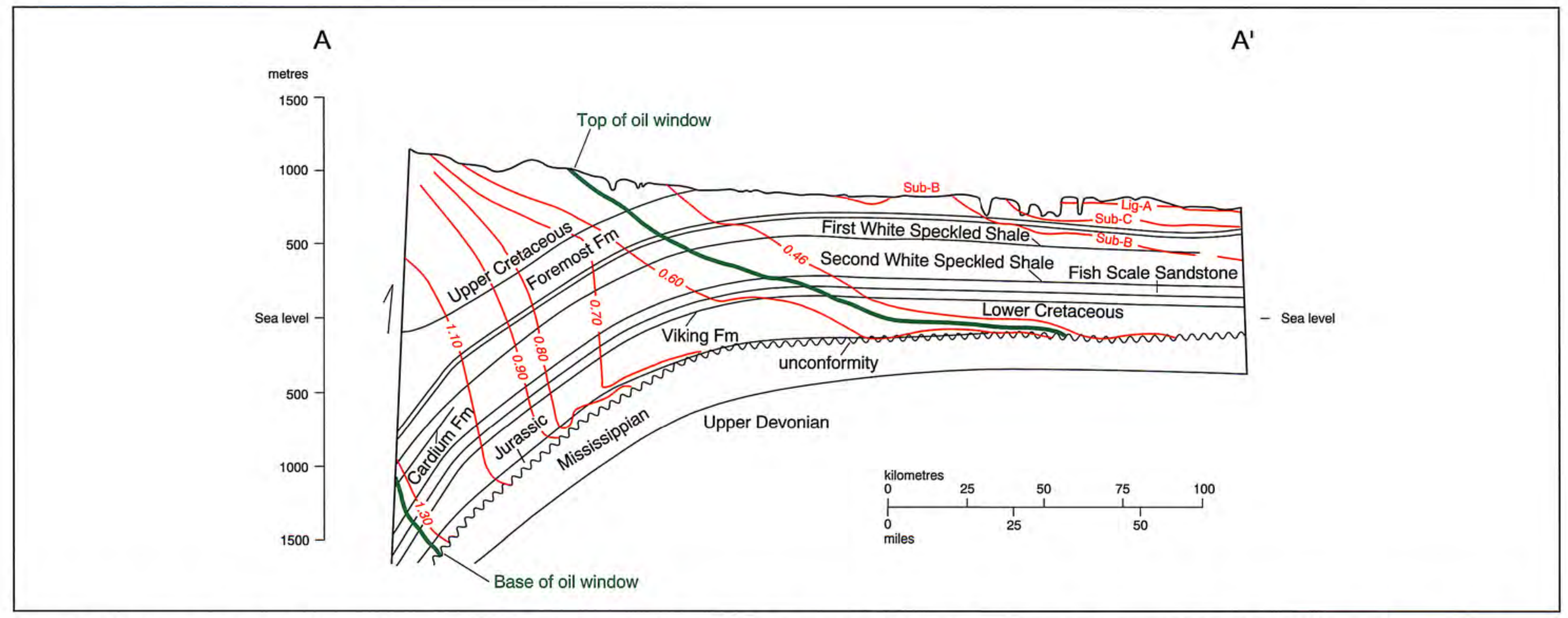

Figure 33.16 Cross section A-A' showing isomaturity lines and approximate position of oil window. Oil window is defined as between 0.55 and 1.35%Ro$_{max}$. Cross section location is shown on Figure 33.14 (Bustin, 1991).

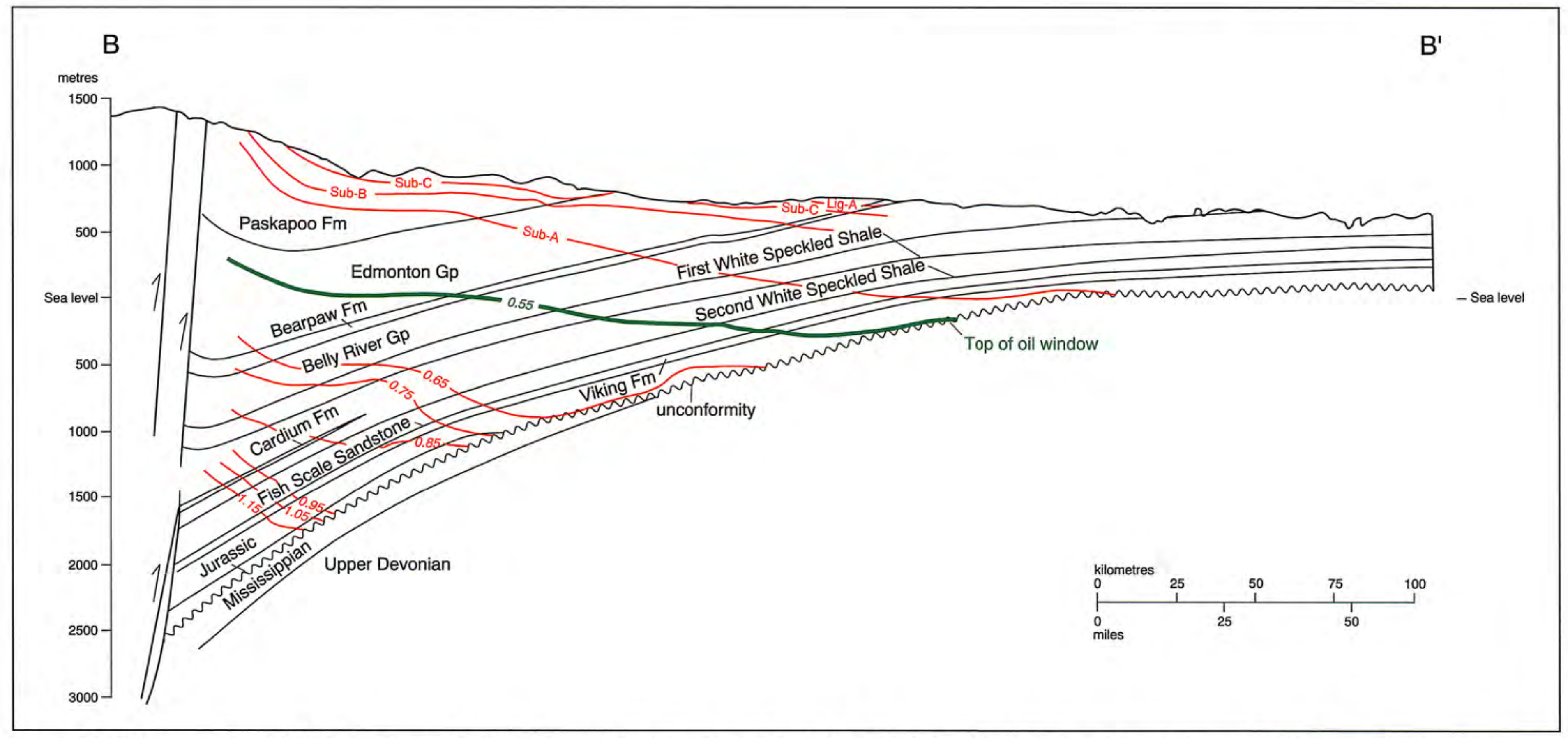

Figure 33.17 Cross section B-B' showing isomaturity line and approximate position of oil window. Oil window is defined as between 0.55 and 1.35%Ro$_{max}$. Cross section location is shown on Figure 33.14 (Bustin, 1991).

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 (Chakrabartty and du Plessis, 1985; Alberta Research Council, 1988; 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 (Wyman, 1984). Additionally, large volumes of coalbed 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.

Stratigraphic unit	Rank class	Immediate interest			Future interest			
		Measured	Indicated	Inferred	Measured	Indicated	Inferred	Speculative
JURASSIC-CRETACEOUS								
Kootenay Group – Mist Mountain Formation	lvb-an	240	120	455	15	225	700	–
	m-lvb	265	140	510	–	130	–	–
	h-mvb	1720	1490	4670	–	2770	–	–
	(tce)	(2110)	(1655)	(5330)	(15)	(2950)	(700)	–
LOWER CRETACEOUS								
Bullhead Group – Gething Formation	m-lvb	285	255	1735	–	100	–	–
	(tce)	(270)	(240)	(1650)	–	(95)	–	–
Fort St. John Group – Gates Formation	m-lvb	830	2130	4535	–	–	–	–
	(tce)	(790)	(2025)	(4310)	–	–	–	–
Luscar Group – Gates Formation	m-lvb	635	320	1145	–	245	–	–
	h-mvb	150	75	275	–	–	–	–
	(tce)	(745)	(375)	(1345)	–	(230)	–	–
Mannville Group	lig-sub	–	35	100	–	–	30	–
	(tce)	–	(20)	(60)	–	–	(15)	–
UPPER CRETACEOUS								
Belly River Group (Formation)	sub-hvb	290	135	415	–	735	–	–
	lig-sub	255	115	360	–	560	–	–
	(tce)	(385)	(175)	(545)	–	(915)	–	–
Edmonton Group – Horseshoe Canyon Formation	sub-hvb	1395	625	1945	–	2115	–	–
	lig-sub	3675	1460	4945	–	5935	–	–
	(tce)	(3250)	(1345)	(4425)	–	(5145)	–	–
Wapiti Group	sub-hvb	5	40	100	–	–	–	–
	lig-sub	50	25	60	–	130	–	–
	(tce)	(35)	(45)	(110)	–	(75)	–	–
UPPER CRETACEOUS – PALEOCENE								
Saunders Group – Coalspur Formation	sub-hvb	830	735	1955	–	200	–	–
	(tce)	(620)	(550)	(1465)	–	(150)	–	–
Edmonton Group – Scollard Formation	subbit.	7430	3125	10610	–	5365	–	–
	(tce)	(4600)	(1940)	(6580)	–	(3325)	–	–
PALEOCENE								
Paskapoo Formation	sub-hvb	120	60	175	–	25	–	–
	(tce)	(85)	(40)	(125)	–	(20)	–	–
Ravenscrag Formation	lignite	1445	2680	3440	165	3910	23510	–
	(tce)	(795)	(1475)	(1890)	(90)	(2150)	(12930)	–
Cretaceous-Paleocene: Deep Coal – Plains	sub-hvb	–	–	–	1200	4000	50000	85000
	(tce)	–	–	–	(780)	(260)	(32500)	(55250)
TOTALS (tonnes coal equivalent basis)	(tce)	(13685)	(9885)	(27835)	(885)	(15315)	(46145)	(55250)

General rank classes: lig-sub = lignitic and subbituminous B/C, sub-hvb = subbituminous A and high volatile B/C bituminous, h-mvb = high volatile A and medium volatile bituminous, m-lvb = medium and low volatile bituminous, lvb-an = low volatile bituminous and anthracitic.

Figure 33.18 Summary of estimated coal resource quantities in the Western Canada Sedimentary Basin. All figures are in million metric tonnes (megatonnes). Figures in brackets are estimates on a tonnes coal equivalent basis, which refers unit heat values of different coals to a standard 29.3 MJ/kg.

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Frontispiece 34.0 Industrial and metallic minerals. Earth works for avalanche diversion around the CPR main line and the Trans Canada Highway on the shoulder of Mount Stephen (right), Yoho National Park near Field, British Columbia. Mount Cathedral in the distance. The rip rap is made up of gangue material derived from (now abandoned) portals located in the cliffs above the scree line on Mount Stephen. The Monarch Mine is a MVT lead-zinc-silver orebody in the dolomites of the Middle Cambrian Cathedral Formation. Closed in 1952, it was one of several mines permited to operate in National Parks in the early years. Photograph by W.N. Hamilton.