Chapter 20 - Cretaceous Colorado/Alberta Group of the Western Canada Sedimentary Basin

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Introduction
The middle Cretaceous Colorado/Alberta Group consists predominantly of mudstone interspersed with relatively thin sandstone and conglomerate beds. Other minor lithotypes include shaly chalk, chalky limestone, bentonite, pelayocopied coquinas, horizons of fish debris, nodular phosphorite, and siderite, calcite and pyrite concretions. The Colorado Group is of significant economic importance in that it contains about 14 percent of the total Western Canada hydrocarbon reserves and about 80 percent of the reserves within the Middle Jurassic to Cretaceous foreland basin succession (Podruski et al., 1988; Porter, 1992). The largest and historically oldest gas pool in Canada occurs within the Medicine Hat Sandstone of the Colorado Group; this pool was discovered in 1890 during early exploration for coal resources.

This chapter presents an overview of the dominantly shaly Colorado and Alberta groups, hereinafter referred to as the Colorado Group. Other following chapters describe in detail the coarser clastic wedges represented by the Viking, Dunvegan and Cardium formations (Figures 2.21 and 23, respectively).

Previous Work
Earlier regional syntheses of the Colorado Group are in Caldwell (1986) and Williams and Burke (1964). Detailed lithostratigraphic and micropaleontological aspects of the Colorado Group in the Mainbeart Republic and adjacent subsurface were described in McNeil and Caldwell (1981) and McNeil (1984). In Saskatchewan, detailed lithostratigraphic descriptions were carried out by Simpson (1982). Scott (1965, 1967, 1965) meticulously mapped the foothills of Alberta and British Columbia, providing a comprehensive lithostratigraphy of the Upper Cretaceous strata. This lithostratigraphic framework has served as an excellent starting point for more detailed studies. The biostratigraphic zonation of Cretaceous strata in Western Canada was synthesized by Caldwell et al. (1975).

Summary lithological and stratigraphical descriptions of the units making up the Colorado Group across the basin are in Glass (1990). Highly generalized maps illustrating the extent of marine inundation were presented by Williams and Slech (1975). Detailed paleo-geographic maps illustrating the evolution of the Western Canada Sedimentary Basin are presented in Leckie and Smith (1992).

Geological Framework
The Alberta to Santonian Colorado Group was deposited within the Western Canada Foreland Basin during an approximately 25 to 30 million year period. Global sea level was high during this time, with specific sea-level maxima in the Late Albian, Early Torrington and Middle Santonian (Caldwell, 1982; Hurl et al., 1987). Deposition at this time was also coincident with a regional tectonic down-flooding of the North American craton (Lambert et al., 1987). The major marine inundations were separated by four major regressive pulses represented by the Peace River-Viking, Dunvegan, Cardium-Bed Heart and Milk River formations. During the highstands, warm Tethyan water from the Gulf of Mexico mixed with the cooler boreal water extending south from the Arctic to form a shallow epicontinental.

The Colorado Group contains several sandstone and conglomerate units, some of which are prolific hydrocarbon producers (Table 20.1). These include, in ascending order, the Bailey Colorado Sandstone, Spiney Hill Sandstone, Viking Formation, St. Walburg Sandstone, Barons Sandstone, Dunvegan Formation, sandstones of the lower Kaskapau Formation (Doe Creek Member), sandstones of the Second White Speckled Shale (the Phillips Sandstone), Cardium Formation, the Medicine Hat Sandstone and the Alderson Member of the Lea Park Formation (Fig. 21.1). Within the Colorado Group, the first and Second White Speckled Shales, the w-Zone, and shale of the Kaskapau Formation are more radioactive than overlying and underlying shales, have high total organic carbon contents, and have considerable hydrocarbon generating potential. An interval such as the Second White Speckled Shale is potentially both a source and a reservoir rock for hydrocarbons.

The Colorado Group thins eastward from about 700 m in southwestern Alberta to 200 m in the Manitoba Escarpment (Fig. 20.2). In northwestern Alberta, the Colorado Group exceeds 1500 m in thickness where it overlies the Peace River Arch, which was subsiding during much of the Cretaceous. Regional cross sections constructed across the basin show the eastward thinning of the Colorado Group away from the Cordillera, with maximum thickening occurring in the northwest. The distribution of the Harmo, Cadotte and Paddy members is restricted to the general vicinity of the Peace River Arch where the Joli Fou Formation is absent.

Major structural elements affecting Colorado Group deposition in the basin are represented in the structure maps constructed on the Base of Fish Scales Zone (Fig. 20.3) and the top of the Milk River Formation (Fig. 20.4). The major elements identified on Figure 20.3 are similar to those identified by Williams and Burk (1964).

Positive structural elements include the Bow Island Arch (also referred to as the Sweetgrass Arch) in southeastern Alberta, and the Bowtow Zone and Swayt Current Platform in southern Saskatchewan. The Bow Island Arch separates the Alberta Basin from the Williston Basin.

Table 20.1 Sandstone and conglomerate bodies within the Colorado Group

<table>
<thead>
<tr>
<th>Formation</th>
<th>Hydrocarbon Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk River Formation</td>
<td>immature, biogenic gas, no production natural gas</td>
</tr>
<tr>
<td>Chinook Formation</td>
<td>immature, biogenic gas</td>
</tr>
<tr>
<td>Medicine Hat Sandstone</td>
<td>light crude oil, natural gas</td>
</tr>
<tr>
<td>Cardium Formation</td>
<td>natural gas, light (7) crude oil</td>
</tr>
<tr>
<td>Second White Speckles/Phillips Sandstone</td>
<td>natural gas, light crude oil, natural gas</td>
</tr>
<tr>
<td>Doe Creek Member of Kaskapau Formation</td>
<td>light crude oil, natural gas</td>
</tr>
<tr>
<td>Dunvegan Formation</td>
<td>light crude oil, natural gas</td>
</tr>
<tr>
<td>Barons Sandstone</td>
<td>natural gas, light crude oil</td>
</tr>
<tr>
<td>St. Walburg Formation</td>
<td>natural gas</td>
</tr>
<tr>
<td>Viking Formation</td>
<td>light crude oil, natural gas</td>
</tr>
<tr>
<td>Bow Island Sandstone</td>
<td>heavy and light crude oil, natural gas</td>
</tr>
<tr>
<td>Paddy Member</td>
<td>natural gas</td>
</tr>
<tr>
<td>Newcastle Sandstone</td>
<td>natural gas, heavy crude oil, natural gas</td>
</tr>
<tr>
<td>Bash Sandstone</td>
<td>natural gas</td>
</tr>
<tr>
<td>Spiney Hill Sandstone</td>
<td>natural gas</td>
</tr>
</tbody>
</table>
Figure 20.2 Isopach map of the Colorado Group from the top of the Milk River Formation to the top of the Mannville Group. The bulk of the petroleum production from the Colorado Group is from the Viking, Dunvegan and Cordium formations, illustrated in chapters 21, 22 and 23 (this volume), but major gas fields in the Milk River, Medicine Hat and Second Ottawa Synclines are shown here. Note that the tabulation of gas production (Table 20.2a) includes data from fields in overlying Boley River Formation strata (see Fig. 24.16).
Figure 20.3 Structure map constructed on the base of Fish Scales Zone. Note that in Saskatchewan, the Base of Fish Scales is not commonly picked and contours in Saskatchewan reflect the (stratigraphically higher) Lower Colorado marker.
Figure 20.4 Structure map constructed on top of the Milk River Formation (Milk River shoulder).
Negative structural elements include the Williston Basin and its northern extension, the Moose Jaw Syncline in southern Saskatchewan and the Eastern Syncline in southwestern Saskatchewan. In southwestern Saskatchewan and southwestern Manitoba, the influence of the Williston Basin is evident in structural lows centred southeast of Regina. In northwestern Alberta and northeastern British Columbia, the Peace River Arch began to subside, with accompanying block faulting, during the Mississippian. It remained a topographic low during the Early Cretaceous and through to the Late Cretaceous (Cant, 1988). The Peace River Arch may have become a subtle high again by at least the latest Turonian-earliest Santonian. Isolated stratigraphic and structural anomalies are attributed to local block-faulting over the Peace River Arch during the deposition of the Colorado Group.

The influence of the dissolution of Devonian-aged salts has been described elsewhere in this atlas (Wright et al., this volume, Chapter 3). Salt solution during or prior to deposition of the Colorado Group sediments created local anomalous thickening. Salt solution subsequent to deposition of the Colorado Group has resulted in depressions on structural surfaces.

**Cross Sections and Maps**

Regional cross sections (Figs. 20.5 - 20.10), regional maps (Figs. 20.2, 20.17), structural maps (Figs. 20.3, 20.4) and reference logs (Fig. 20.18) make up much of the database for this chapter. Detailed sections and maps are provided for the Milk River-Church units and the Muskox, Marshybank and Bad Heart formations (Figs. 20.20 - 20.27).

Regional cross sections from the top of the Mannville Group to the top of the Milk River Formation are illustrated in Figures 20.7 to 20.10. The datum for all these sections is the Base of Fish Scales Zone, which occurs across most of the basin, although it is sometimes difficult to identify in parts of Saskatchewan. Some difficul-
The stratigraphic terminology of the Colorado Group includes several informal but generally accepted names such as the First and Second White Speckled Shales and the Fish Scales Zone. The terminology, summarized in Figure 20.1, varies from province to province and between regions in the provinces. Since the Colorado Group is a predominantly marine shale succession, it has been well constrained biostatigraphically using foraminifers (Caldwell et al., 1978; McNeil and Caldwell, 1981), ammonites (Jelkskly, 1971) and microfors (Singh, 1983).

Stratigraphic History

The base of the Colorado Group is represented by a basin-wide unconformity. The Colorado Group overlies the Blairmore Group in western Alberta, the Mannville Group in the subsurface of eastern Alberta and Saskatchewan, the Caddie Member of the Fort St. John Group in northeastern British Columbia and the Northwest Alberta, and the Swan River Formation in Manitoba (Figs. 20.1 and 20.20.10). The basal contact of the Colorado Group with the Mannville Formation is generally represented by a thin conglomerate layer containing chert or infratidalstromal shale clasts. In the Manitoba Escarpment, the unconformity likely occurs within the Swan River Formation. The upper part of the Swan River is marine (Pense equivalent) and the lower part is terrestrial (Cartmair equivalent).

The lowermost formal lithostratigraphic unit of the Colorado Group is represented by the Spinney Hill Sandstone in eastern and central Saskatchewan, the Basal Colorado Sandstone in southeastern Alberta and shale of the Joli Fou Formation in most other areas (Figs. 20.1 and 20.20.10).

The Basal Colorado Sandstone, in southeastern Alberta, southern Saskatchewan, northern Montana and North Dakota, is a thin (< 1 cm thick), sheet-like unit underlying the Joli Fou marine shales and overlying the non-marine Mannville Group (Raneeje, 1989). In the Crossfield area (Type 25-26R 10-16W4), the Basal Colorado Sandstone (also called Crosswell Sand) occurs as a northwesterly-trending sandstone body, 20 km wide, 6 to 8 m thick, and situated in a paleo-topographic low. In Saskatchewan, the approximate correlative Spinney Hill Formation is a grayish to yellowish green, very fine to coarse-grained sandstone with noncalcareous shale interbeds and glauconite. Other lithotypes include infratidalstromal conglomerates, clasts of nodular phosphorite, preleucyco cuquins and concretions of siderite and pyrite. The formation is up to 36.5 m thick and occurs as a sandstone body up to 60 km wide in central Saskatchewan (Simpson, 1982).
In northwest Alberta and northeast British Columbia, the basal contact of Colorado Group sediments is represented by a major erosion surface between the Paddy and Cadotte members of the Peace River Formation (Figs. 20.9, 20.10). This unconformity has bevelled the underlying Cadotte and Harmon members toward the east and south. Westward, in the Rocky Mountain Foothills of northeastern British Columbia, the unconformity approximately corresponds to the position of the lowermost pakoocids within the Boulder Creek Formation (Leckie et al., 1989).

**Joli Fou Formation**

The Upper Albian Joli Fou Formation (Figs. 20.1 and 20.5 - 20.10) is a dark gray, noncalcareous marine shale with a small proportion of interbedded fine- to medium-grained sandstone. Minor amounts of nodular phosphorite, bentonite, pectenoid ecoses and concretions of siderite, calcite and pyrite also occur. The Joli Fou Formation is extremely widespread, and is distributed throughout the subsurface, except in parts of northwestern Alberta and northeastern British Columbia (Figs. 20.9, 20.10) where it has been apparently truncated by an unconformity at the base of the Paddy Member. In the Manitoba Escarpment, the Joli Fou Formation is called the Skull Creek Member. In western and central regions, the Joli Fou Formation unconformably overlies the Mannville Group where the Basal Colorado/Spinney Hill are absent, and underlies the Viking Formation, conformably in places. In eastern Saskatchewan, the Joli Fou Formation is underlain by the Swan River Sandstone, and in parts of Manitoba, it locally overlies Jurassic-aged sediments. The Joli Fou passes laterally southwestward into the Bow Island Formation (Fig. 20.7) and is not known to occur in outcrop of the Rocky Mountain Foothills. It is exposed and has a type section along the Athabasca River (Wickersham, 1949). Fauna within the Joli Fou shale suggest that the marine sea way extended from central Alberta to the Gulf of Mexico.

**Viking Formation and Equivalent Units**

The Albian Viking Formation, which is found in central and southwestern Alberta and Saskatchewan, was first named by Sliper (1918) to describe a gas-bearing sandstone encased in shale in east-central Alberta. Correlative units (Fig. 20.3) include the Bow Island Formation in southwestern Alberta (Fig. 20.7), the Newcastle Sand in Manitoba (Fig. 20.8), the Pelican Formation in northeastern Alberta, the Paddy Member (Peace River Formation) in the northwestern Alberta and northeastern British Columbia subsurface (Fig. 20.9), part of the Walton Member of the Boulder Creek Formation in northeastern British Columbia, and the Flattened Lake Sandstone in Saskatchewan. The Bow Island Formation thins eastward and northward from the Rocky Mountain Foothills, where it crops out as the Mill Creek Formation.

The Viking Formation and equivalent units are an eastward flattening wedge of coarse clastic deposits, which extends from British Columbia to Saskatchewan. In central Alberta, the thickness of the Viking Formation is 15 to 30 m; southward, it thickens to more than 75 m, and eastward, it decreases until the unit pinches out in central and eastern Saskatchewan. The formation is described in detail by Reinson et al. (this volume, Chapter 21). It consists of interbedded fine- to coarse-grained marine sandstone and conglomerate but grades into non-marine sediments in southwestern Alberta. In much of southeastern Alberta and southwestern Saskatchewan, the Viking Formation consists of multiple, upward-coarsening cycles. Elsewhere, it is a single sandstone body only a few metres thick. Sandstone- and conglomerate-filled channels are present in several areas such as the Sundance, Edson and Crystal oil pools of west-central Alberta. Conglomerates occur as far east as the Dedigrand-Hoosier area in Saskatchewan.
Distribution of the Upper Albian Paddy Member is restricted to that area defined by the Peace River Arch in northeastern British Columbia and southwestern Alberta. The Paddy Member is a heterolithic sandstone, siltstone and shale that thins eastward from 90 m near the Rocky Mountain Foothills to less than 5 m in the Interior Plains (Tip 70, R 27 W 5). The Paddy Member was deposited under brackish-water conditions in the inner to outer reaches of a large estuarine system (Lecie and Singh, 1991). Westward, sediment becomes increasingly fluvial in nature. Much of the Paddy Member in northwestern Alberta was deposited within a broad, shallow valley, a few hundred kilometres long and several tens of kilometres wide, which was cut into previously deposited sediments of the Cadotte Member (Lecie et al. 1990). A thick sequence of paleo-proximal and correlative Boulder Creek Formation from the Rocky Mountain Foothills (Lecie et al., 1989) is related to the valley incision and subsequent sea level rise.

The Flotten Lake Sand in central Saskatchewan and eastern-central Alberta north of Township 50 is an interval of sandstone and shale approximately equivalent to the Viking Formation (Simpson, 1982). Up to 21.3 m thick, it is a fine- to medium-grained sandstone with minor shale interbeds. The Flotten Lake Sandstone thins and decreases in grain size toward the southeast.

In Manitoba, the Newcomb Member consists of bioturbated, interbedded fine-grained sandstones and shales up to 12 m thick (McNeil and Caldwell, 1981). In southeastern Saskatchewan and southern Manitoba, the unit forms lobate sand bodies 12 to 23 m thick. Sandstones in the upper portion of the Newcomb Sandstone are more sheet-like.

In northeastern Alberta and southwestern Saskatchewan, the St. Walburg Sand consists of interbedded sandstone, siltstone and shale occurring below the Fish Scales Zone. The sandstone is fine-grained and highly quartzose, glauconitic and kaolinitic. It is present only north of Township 46 and thickens northwest to a maximum of 32.9 m (Simpson, 1982).

Westgate Member

The Upper Albian Westgate Member (McNeil and Caldwell, 1981) comprises shale above the Newcomb and below the Belle Fourche members. The sand is about 20 m thick and consists of dark mudstone with minor amounts of bioturbated silty shale and bentonite. The top of the unit is drawn at the Base of Fish Scales Zone of the Belle Fourche Member.

Fish Scales Zone

The Fish Scales Zone (Figs. 20.1 and 20.5 - 20.10) is a basin-wide marker that demarcates the Albian/Cenomanian boundary (Lower/Upper Cretaceous). It contains abundant fish remains (scales and skeletal material) within finely laminated, generally nonbioturbated sandstone and siltstone. Pebbles and nodular phosphorites occur locally. The Fish Scales Composite is zoneable, and there may be at least three such beds across the basin.

The Fish Scales Zone is characterized by high organic carbon contents and a low concentration of benthic foraminifera, and is interpreted as representing deposition under poorly oxygenated bottom conditions. In Saskatchewan and Manitoba, the Base of Fish Scales Zone may represent a major hiatus with substrates missing below and above it (Caldwell et al., 1979; Bhattacharya and Ponomer, this volume, Chapter 25), whereas in western Alberta, strata above and below the marker unit appear to be more conformable (Stelck and Armstrong, 1981).

Barons Sandstone

In southwestern Alberta, the Cenomanian Barons Sandstone overlies the bioturbated, radiolarian cherts of the Fish Scales Zone (Fig. 20.1). The Barons Sandstone includes a series of isolated pods of sandstone and conglomerate up to 7 m thick, 3 to 5 km wide and 5 to 15 km long. The sandstones thicken westward and become more continuous toward the Rocky Mountain Foothills.

Big River Formation

In Saskatchewan, the term Big River Formation was assigned by Simpson (1982) to the interval between the top of the Viking Formation or Fotten Lake Sand and the base of the Second White Speckled Shale. The formation varies from 42.7 to 150 m in thickness. It is predominantly shale, with minor amounts of fine- to medium-grained sandstone, pelycypod and fish debris, thin chert, pebbles, bentonite and phosphatic sandstone. The Fish Scales Zone and the St. Walburg Sandstone occur within the Big River Formation.

Upper Albian Outcrop

In the Rocky Mountain Foothills of southern Alberta, deposits equivalent to the subsurface Joli Fou, Viking and lowermost Cretaceous shales up to the Fish Scales Marker Bed are not recognized. The lowest sediments of the Blackstone Formation appear to have been deposited diachronously. In southwestern Alberta, the lowermost Blackstone Formation falls within the late Cenomanian Duneganwasee Zone (Stott, 1963) whereas northward, it lies within the Late Albian Negapatomi Zone. The Crownest Formation in southwestern Alberta is considered a stratigraphic unit within the Blairmore Group. However, the formation may be, in part, correlative with the Joli Fou and Viking formations of the Colorado Group (Fig. 20.13). The age of volcanic agglomerates making up the Crownest Formation is poorly constrained but is generally considered to be Late Albian. Source rocks or pipes for the volcanic detritus are thought to be in the Ma Butte and Colman areas, where maximum sediment thicknesses of up to 484 m also occur.

Duvernag Formation

The middle/upper Cenomanian Duvernag Formation represents a southeastward thinning and fining, fluvial-lacustrine wedge deposited above the Shaffesbury Formation (Fig. 20.6; Stott, 1982). The formation is recognized in southwestern Alberta, northeastern British Columbia and southeastern Yukon Territory and reaches up to 380 m in thickness, thinning eastward and southward. Outcrops in northeastern British Columbia and southern Yukon Territory are of conglomerates and coarse-grained sandstones deposited in a braided-river and alluvial-planar setting. In northwestern Alberta, at least ten sand-rich, progradational cycles separated by regional transgressive surfaces represent the south-easterly advance of the Duvernag Formation (Bhattacharya, 1988; Bhattacharya and Walker, 1991). The progradation, though attributed to global lowering of sea level at 94 Ma (Bhattacharya, 1988), also coincides with a major uplift in the Omineca and Interior mountain belts (Stott, 1982). The Duvernag has been recognized as far south as the Athabasca River (Stott, 1963). Further south, the Duvernag Formation is replaced by marine siltstone and shale of the Saddleback Member of the Blackstone Formation, where sedimentation was dominated largely by pelagic deposition. The Duvernag Formation is described in considerable detail by Bhattacharya (1988; volume, Chapter 22).

Figure 20.10 Regional cross section J - J'. Logs are gamma ray and SP.
Figure 20.11 Isopach map of the interval from the base of the Fish Scales Zone to the Viking-Row Island; Lower Colorado to Viking in Saskatchewan.
Kaskapau Formation

The Kaskapau Formation in northwestern Alberta is a predominately shale succession 250 to 860 m thick lying between the Dunvegan and Cardium formations (Figs. 20.1, 20.9). Directly above the Dunvegan Formation, the Cenomanian to Turonian Kaskapau Formation contains a series of northeast-trending, shingled and backstepping, shallow-marine sandstone bodies encased in marine shale (Wallace-Dudley and Leckie, 1993, in press). These are, in ascending order, the Doe Creek, Fosse-Coupe and Howard Creek members, which were deposited in a generally retrogradational pattern, following the regional transgression of the Dunvegan Formation (Fig. 20.19). The Doe Creek Member consists of several discrete, 0.5 to 7 m thick, sandstone bodies which are 2.1 to 27 km long and 5 to 7 km wide. The Howard Creek Member underlies the organic-rich, radiocative shales of the Second White Speckled Shale, which likely was the source for hydrocarbons in the Doe Creek Member. The Tuskaola and Wardenbe sandstones are poorly understood units within the Kaskapau Formation, occurring above the Vinny Member in outcrop in northeastern British Columbia (Sutt, 1967). In southwestern Saskatchewan and southeastern Alberta, the thin, shallow-marine Phillips Sandstone/Second White Speckled Sandstone may be correlated with the sandstones of the lower Kaskapau Formation. The Phillips Sandstone occurs about 6 m below the top of the Second White Speckled Shale and can be up to 38 m thick. Geographically, the sandstone coincides with the location of the Sweetgrass Arch (Fig. 20.3).

Second White Speckled Shale/Favel Formation

The Second White Speckled Shale is a basin-wide marker named from early drillers' reports of abundant white specks in the shale, now known to be sand-sized fecal pellets comprising coccoliths and coccospheres, concentrated by currents. The shale is characterized by a high total organic carbon content, high hydrogen indices and high radioactivity on well logs. Other elements include rare, thin, coarse- to very coarse-grained sandstone beds, ammonites, polycysta (Inoceramus), benthonites, pyrite, calcite crystals and fish debris. On gamma-ray logs the Second White Speckled Shale interval is typically radioactive as a result of elevated uranium contents associated with abundant kerogen in the shale. Discrete radioactive spikes also occur as a result of benthonites deposited in the shales.

Kaskapau Shale is the northern correlate of part of the Greenhorn Formation in the United States and appears to correspond to a global anoxic event and maximum sea-level rise that occurred near the end of the Cenomanian (Kaufman, 1977). In the western region of the basin, adjacent to the Rocky Mountain Foothills where the source rock is mature, considerable volumes of liquid hydrocarbons have been generated. In eastern Alberta, Saskatchewan and Manitoba, sandy units in the Second White Speckled Shale form an important reservoir for sweet, dry, biogenic methane.

The calcareous, non-concretionary shale making up the Vinny Member of the Blackstone and the middle Kaskapau formations in northern Alberta and British Columbia is, in part, correlative with the widespread Second White Speckled Shale. In Manitoba, the equivalent Favel Formation consists of highly fossiliferous, chalk-speckled shale, anglicaceous limestone, calcrete and benthoniite beds, ranging from 11 to 46 m thick. The Kofeld Member of the Favel Formation is of latest Cenomanian and Turonian age (McNeil and Caldwell, 1981) and is correlative with the Second White Speckled Shale and with the Greenhorn Limestone in Colorado, Kansas, Wyoming and South Dakota. The overlying Assiniboine Member is predominantly black, calcareous, chalk-speckled shale with thin bentonite and calcareous interbeds.
Figure 20.16 Isopach map of the interval from the base of the Fish Scales Zone to the top of the Mannville Group; Lower Colorado to Mannville in Saskatchewan.
The Cardium Formation may have been erosionally truncated in parts of eastern Saskatchewan and western Manitoba (McNeill and Caldwell, 1981).

In the west, the upper Turonian is marked by a regressive event capped by an erosional unconformity which can be traced across the basin. In Alberta, this unconformity is marked by the conglomerate-veneered E5 surface of the Cardium Formation, whereas in Manitoba, it lies between the Morden and Niobrara formations (McNeill and Caldwell, 1981). The unconformity approximately coincides with the 90 Ma eustatic lowstand of Haq et al. (1987).

Plint and Walker (1987) attributed Cardium shoreline progradation and the development of unconformities within the formation as having a tectonic component at the western margin of the basin as well.

Cardium Formation

The Turonian/Coniacian Cardium Formation of the Smoky Group in northwestern Alberta, Rocky Mountain foothills and interior Plains is from 15 to 125 m thick and consists of marine silstone, sandstone and conglomerate, locally overlain by non-marine sediments. The Cardium progradational wedge is restricted to northwestern and west-central Alberta and northeastern British Columbia (Figs. 20.6, 20.10). The formation generally thins eastward and southward, grading into shales of the Colorado Group. The depositional history of the Cardium Formation is complex, with six upward-coarsening cycles capped by erosional surfaces (Plint et al., 1998). The Cardium shoreline trended northwest-southeast and migrated eastward in northeastern Alberta. The formation is described in considerable detail by Krause et al. (this volume, Chapter 23).

SECOND SPECKS TO BASE OF FISH SCALES ISOPACH
Generalized thickness contours - Second White Speckled Shale to Base of Fish Scales
Contour Interval = 20 metres

Figure 20.16 I isopach map of the interval from the Second White Speckled Shale to the base of the Fish Scales Zone.

The Cardium Formation and its correlative units are disconformably overlain by the Coniacian to early Campanian marine shales and sandstone of the upper Colorado Group (Wapiti and Niobrara formations).

Morden Formation

In Manitoba and eastern Saskatchewan, the Morden Formation, which is partly correlative with the Cardium and upper Blackstone formations (Fig. 20.11) is a mobile-bearing, dark grey to black, nonglauconitic shale with rare, thin bentonites. Thicknesses vary from 3.5 to 35 m and the unit thins northwestward from the Morden Escarpment. The formation is absent in central Saskatchewan (North and Caldwell, 1975).

Muskoki, Marshybank and Bad Heart Formations

The Muskoki (Figs. 20.18a, 20.21) overlies the Cardium Formation, and consists of mottled, weathering shales, conformably overlain by silstone and sandstone of the Marshybank Formation. A regional unconformity marks the top of the Marshybank Formation and separates this from the younger Bad Heart Formation of the plains (Plint, 1990; Plint et al., 1990). The Marshybank and Bad Heart formations are overlain by the Wapiti and Paskwaskau formations, respectively, a predominately shale succession with minor amounts of sandstone, which ranges in thickness from 114 to 506 m. Members of the Paskwaskau Formation include the Dowling, Thistle, Hansen, Chungo and Nomad members.

The type locality of the Bad Heart Formation was defined by McLean (1919) at the junction of the Smoky and Bad Heart rivers (in the northern plains of Alberta). McLean (1919) described the Bad Heart sandstone as "10-25 feet of coarse sandstone, weathering reddish brown". Plint and Walker (1987) documented a regional unconformity at the top of the Marshybank (then termed the 'Bad Heart') which extended several hundreds of kilometres into the basin, and marked a period of erosion in response to relative sea level fall. This unconformity also marked the base of the Bad Heart Formation in the Alberta Plains (Plint et al., 1990).

The Bad Heart Formation has been redefined (Plint et al., 1990) as a unit comprising fine-grained, silty sandstones containing abundant ooliths and areally restricted to the Alberta Plains. The older portion has been reassigned to the Marshybank Formation, which comprises non-siliceous, marine shelf and coastal plain sandstones and silts in the foothills and adjacent subsurface. It includes rocks formerly included in the Bad Heart Formation.

Figure 20.17 I isopach map of the interval from the First White Speckled Shale to the Second White Speckled Shale.

First White Speckled Shale/Niobrara Formation

The First White Speckled Shale is the informal name for a calcareous mudstone with subordinate amounts of bentonite, fish remains, nodular phosphate, and concretions of siderite and calcite. It is the upper of two white-speckled units that occur across the whole basin (Figs. 20.1 and 20.5-20.10). The thickness of the First White Speckled Shale is highly variable, ranging from 6 to 157 m. In Saskatchewan, the First White Speckled Shale lies directly and unconformably on the Second White Speckled Shale. The First White Speckled Shale is represented in part by the Thistle Member of the Wapiti Formation in the Rocky Mountain foothills and by the Niobrara Formation in the Morden Escarpment and southeast Saskatchewan. The First White Speckled Shale occurs within the Lacbiche Formation in northeastern Alberta, in the Paskwaskau Formation in northwestern Alberta and in southern Alberta, within the Colorado Group.

On gamma-ray logs, the First White Speckled Shale interval is typically radiometric as a result of high uranium content associated with abundant kerogen. Discrete, radiometric spikes also occur as a result of bentonites deposited in the shales.
Figure 33.18 Reference well logs through the Cretaceous-Alberta Group (continued overleaf). Note that all logs are standard 1:5000 vertical scale, except a. Peck Valhalla (1:4000), which is condensed to fit the page.
Cretaceous Colorado/Alberta Group

The Niobrara Formation (latest Turonian to earliest Campanian in age) in Manitoba is up to 73 m thick and consists of a lower carbonaceous shale overlain by cherty siltstone. A local to regional unconformity exists between the Niobrara and the overlying Pierre Formation; the break is less pronounced to the west (North and Caldwell, 1975; McNeil and Caldwell, 1981; McNeil, 1984). The three lowest members (Gammon Ferruginous Member, Pembina and Milkwood members) of the Pierre Formation are correlative with the uppermost Alberta Group to the west. The Gammon Ferruginous Shale is a bentonitic shale ranging from 5 to 50 m in thickness. The Pembina Member consists of 3 to 15 m of carbonaceous shale containing abundant bentonite beds overlain by a non-carbonaceous succession. The late Campanian Milkwood Member consists of 30 to 130 m of shale containing abundant fossiliferous and nonfossiliferous calcareous concretions.

The Santonian Medicine Hat Formation (Warren, 1985), which occurs in southeastern Alberta and southwestern Saskatchewan below the first White Speckled Shale, consists of at least three upward-coarsening, very fine-grained sandstone and siltstone successions, 3 to 11 m thick, deposited in a shallow-marine shelf setting (Gilboy, 1987; Hankel et al., 1989). The formation is up to 60 m thick. The Medicine Hat Formation (Fig. 20.1d) forms a shallow-gas reservoir, the largest and oldest gas field in Canada, containing locally derived biogenic gas.

**Milk River/Chungo**

The early Campanian Milk River Formation (Fig. 20.1.1) is a sandy clastic wedge confined to the plains of southern Alberta and Saskatchewan (Fig. 20.25) and the southern and central Rocky Mountain Foothills. The Milk River Formation occurs, in part, within the Alberta Group and within the Montana Group, but is not considered part of the Colorado Group. Sediments of the Milk River Formation are exposed in southern Alberta along the Milk River, as a result of uplift on the Sweetgrass Arch, but dip into the subsurface farther north where the formation passes into shales, siltstones, and sandstones of the Alderson Member of the Lea Park Formation (Fig. 20.26). The Alderson Member contains nearly 150 billion m³ of recoverable gas reserves in the "Milk River" gas pool (Meijer Drees and Myhr, 1981). It is dated at late Santonian to early Campanian in age (Sweet and Brahman, 1990). In the foothills, the equivalent rocks are named the Chungo Member of the Wapiti Formation. The older term Clarksand sandstone has been used in the central foothills (Gledhill, 1949). In the southwest corner of Alberta the Nomad cannot be recognized and the Chungo has been included within the overlying Bely River Group (Bott, 1963; Dawson et al., this volume, Chapter 24).

The Milk River Formation is thought to be disconformably overlain by marine shales of the Falakwi Formation (Brauman and Hills, 1990), the contact marked by a layer of chert pebbles. The disconformity can also be recognized in the foothills, where age-equivalent Nomad Member shales of the Wapiti Formation overlie the Chungo Member (Sweet and Brahman, 1990).

At Writing-On-Stone Provincial Park (Fig. 20.25), the Milk River Formation is about 100 m thick (Fig. 20.26) and has been subdivided into three members (Meijer Drees and Myhr, 1981). The lowermost Telegraph Creek Member comprises interbedded shales and sandstones that overlie the first White Speckled Shale. The Telegraph Creek grades up into the massive clastic sandstone of the Virgile Member. The Virgile includes a lower unit interpreted as a storm-dominated shoreline sandstone (McCrory and Walker, 1986) and an upper unit, which has been interpreted as a tidal inlet complex (Cheek and Leckie, 1990). Paleocurrent data and general mapping indicates that paleoshorelines were oriented approximately east-west (Fig. 20.25). The overlying Deadhorse Coulee Member is a heterolithic coal-bearing unit (Fig. 20.25) interpreted as being of non-marine origin. The Milk River Formation passes basinward into bioturbated sandy mudstones of the subsurface Alderson Member, which is equivalent to the Hanson Member in outcrop. The Hanson Member outcrops have been described by Rosenthal et al. (1984) and Rosemary and Walker (1987). A modified correlation of these outcrops is shown in Figure 20.27. The Chungo is interpreted as comprising a set of offsetting, stacked, coarsening-upward units (i.e., parasequences) capped by a widespread erosion surface marked by chert pebbles. In southwestern Alberta, the Chungo sequence deposits interfinger southwestward with Chungo non-marine sediments and pass northward into the mudstones of the Hanson and Thistle members. Rosenthal et al. (1984) showed a similar relation with Chungo-equivalent Hanson Member mudstones farther north.

Figure 20.18 Continued from previous page.
CRETACEOUS COLORADO/ALBERTA GROUP

Major Drees and Myhr (1981) demonstrated that, in the subsurface (Fig. 20.26), parasequences in the equivalent Milk River Formation similarly dip to the northeast onto a widespread, radioactive log marker coinciding with the top of the First White Speckled Shale, which probably represents a condensed section. Re-evaluation of the age of the Chungo Member and its lithostratigraphic equivalents shows that it becomes younger to the northeast (Wall and Gerrandmaun, 1963; Sweet and Bratman, 1989). The unconformity between the Milk River/Chungo and the overlying marine shales of the Nemad/Pakokwik, documented by Sweet and Bratman (1990), suggests a different relation at the upper boundary than that indicated by Rosenthal and Walker (1987). The contact between Chungo and Nemad is sharp and unconformable as suggested by Rosenthal et al. (1984), rather than interfingering. In the subsurface, this unconformity is shown as a prominent "shoulder" on sonic and resistivity well logs and has been used as a major stratigraphic datum for mapping purposes (Figs. 20.15, 20.16. and 20.18).

The duration and significance of the basal Pakokwik unconformity apparently decreases northeastward, with sandy mudstones of the Alderson Member in Saskatchewan being late early to late Cam- panian in age (i.e., Pakokwik equivalent, Bratman, pers. comm.)—rather than early Campanian. This is also supported by the offlap- ping geometries depicted in Figures 20.26 and 20.27.

Isopach Maps

Isopach maps (Figs. 20.11 - 20.17) were constructed over stratigraphic intervals that were well constrained by consistent markers (maps of the Viking, Dunvegan and Cardium formations are shown in Chapters 21, 22 and 23, respectively). The maps show that over relatively short intervals of time, zones of maximum sediment accumulation shifted across the basin.

Maximum sediment thickness from the Base of Fish Scales to the top of the Viking Formation (Fig. 20.11) is found in northeastern British Columbia, thinning regularly from 400 to 60 m into north- western Alberta. Throughout most of Alberta, the interval is 20 to 60 m thick. The region of thickest sediment approximately coincides with the position of Peace River Arch. The thinnest sediments occur adjacent to the Rocky Mountain Foothills in southwest Alberta where the Fish Scales Zone laps onto sediments of the Blairmore Group or was not deposited. The interval from the top of the Dunvegan Formation to the Base of Fish Scales (Fig. 22.3, this volume) is thickest (>400 m) in northeastern British Columbia over the Peace River Arch and thins southeastern to 80 m in north- western Alberta.

The isopach of Cardium to Second White Speckled Shale marker (Fig. 20.12) shows maximum thicknesses northwest of the Peace River Arch. A general westward thickening trend is marred by a few, isolated sections locally thicker. The interval from the First White Speckled Shale marker to the top of the Peace River Arch (Fig. 20.13) shows a general thickening to the southwest from 140 to 240 m. The uppermost isopach interval, from the top of the Milk River Formation to the First White Speckled Shale marker (Fig. 20.14) shows two depressions: in the southwest, isopach values increase to a maximum of 150 m, whereas in the northwest, thick- nesses of 110 m are attained.

Lithology of the Colorado Group Shales

The Lower Colorado Group shales, exclusive of the Joli Fou, form a wedge of marine sediments comprising dominantly mudstone and claystone (Fig. 20.28) with subordinate amounts of siltstone and fine-grained sandstone. Bentonites are common and increase in abundance from west to east. Sand and silt contents increase westnorthward, reflecting the influence of more proximal prodelta and shelf environments. The shale is generally composed, in order of decreasing abundance, of mixed-layer illite/smectite, quartz, kaolinite, potassium feldspar, siderite and pyrite with minor micas, chlorite and biotite. The illite content of the mixed-layer clay increases to the west with increasing burial depth and diagenesis. The basal beds of the Fish Scales Zone are similar in composition to the adjacent shales but contain coarser clastic detritus. Locally, total organic carbon (TOC) and Hydrogen Index (HI) values may vary from 0 to 10 wt percent and 100 to 1000 mg HC/g of OC, respectively.

The Second White Speckled Shale contains abundant marine (Type II) organic matter and is mineralogically distinct from the underlying Colorado Group shales. The Second White Speckled Shale is a calcareous mudstone to claystone consisting up to approximately 38 wt percent calcite and/or dolomite with abundant pyrite (3 to 6 percent) and organic matter (6 to 11 wt percent). The calcite is largely bioclastic in origin, comprising hemisphaeric, planktonic foraminiferal and nannofossil remains. The "white specks" are fossil pellets composed of nannofossil fragments. The illicite mineralogy is similar to that of adjacent Colorado Group shales.

Geological History

The Colorado Group represents sedimentation within the Western Canada Foreland Basin during a period when global sea level was generally high and rising, but intertemporal major higher fre- quency sea-level falls. Sedimentation took place within an active foreland basin, adjacent to a tectonically active hinterland. The erosional and depositional events preserved within the Colorado Group reflect this intermix of tectonic and eustatic controls. The lowermost deposits of the Colorado Group are the Spiny Hill and Dassi Colandro sandstones. These are related to the initial marine transgression of the Colorado Group over the Mannville Group. The overlying Joli Fou Formation contains marine faunal evidence of the first connection between the Gulf of Mexico and the colder waters of the Boreal seas from the Arctic. As such, the Joli Fou Formation represents the first Cretaceous seaway to extend the entire length of the Western Interior. The seaway may have been subsequently closed for part of Lower Colorado deposition and possibly even landlocked when the connections to the Gulf of Mexico and Boreal seas were closed (Williams and Stotz, 1979). The coarse clastics of the Viking Formation are generally consid- ered to be of shallow-marine origin and, in places, tidally influ- enced. Several sea-level lowstands may be represented in the Viking Formation, the major one dated at about 97 Ma. During these sea-level lowstands, incised valleys were cut and sub- sequently infilled with estuarine sediments during sea-level rise. One of the valleys now contains thick conglomerates called the Crystal Oil Field (Reinson et al., 1988). Southwest winds dispersed volca- nic ash (bentonite) within the Joli Fou and Viking formations across southern Alberta (Amagie, 1985). In northern Alberta, a sea-level lowstand resulted in an incised valley system several hundred kilometers long cut into the Middle Albion Calotte Member, from the Rocky Mountain Foothills to the Interior Plateaus. This incised valley system is coeval with multiple paleosols in the Boulder Creek Formation in northern British Columbia (Leslie et al., 1987) and in the Mill Creek/Rose Island formations in southern Alberta. These paleosols formed when sedimentation rates on the floodplains decreased in the more westerly portions of the basin during lowstands. The subsequent sea-level rise deposited the estuarine, shallow-bay and shoreline deposits of the Paddy Member.

The volcanics that produced the Upper Albion(?) Crosscut Formation in southwestern Alberta were surrounded by an inland flood plain and were probably of high relief. The magama chamber may have been a hydrous alkaline trachyte (Pearce, 1970) that resulted from crustal melting at about 25 to 35 km depth. Regional subsur- face correlations show that the overlying Fish Scales Zone pinches out westward toward the Crowsnest Pass area (Fig. 20.7).

The shales of the uppermost Albion Shale Formation in northern Albert and British Columbia represent sea-level rise and a major basinward transgression above the Viking Formation and equivalent units. During this time, the Boreal sea connected for a second time with the northward-advancing seas from the Gulf of Mexico. The organic-rich Fish Scales Zone represents the join- ing of the two seas. The Fish Scales Zone is generally considered to contain a condensed section deposited during a peak trans- gression of the Cretaceous Interior Seaway. It also marks the Albion/Coniacian boundary. In southern Alberta, the oldest record of the transgression is the Coniacian Blackstone Formation where it overlies the Blaemere Group.

Figure 20.19 Cross section illustrating the retrogradational, backstepping pattern of linear sandstone bodies within the lower Kaskapau formation (modified from Wallace-Dudley and Leckie, 1969).

Figure 20.20 Map showing the location of the Marmarthian reference section on the Milkston Creek, and the type section of the Bad Heart exposed on the west bank of the Smoky River. The locations of wells used in Figure 20.21 are also shown.
Figure 20.22 Measured section of the Muskil and Marshybank formations on Mistassini Creek, British Columbia, and correlation with the gamma-ray log from well a-25-A, 94-1-16 which lies 10 km to the north-northeast. Note the marked negative i.e., condential deflection of the gamma-ray log that corresponds to the base of the Marshybank Formation (after Pint et al., 1980).

Figure 20.23 Summary stratigraphic terms of the Muskil and Marshybank formations. In sequence stratigraphic terms, the Muskil plus Marshybank unit A make up a transgressive systems tract, Marshybank units B through L make up a broadly progradational highstand systems tract that overlaps onto the top surface of unit A. Major relative sea-level fall following deposition of the Marshybank resulted in deep regional erosion that truncated the Marshybank and Muskil toward the northwest. The Bad Heart Formation was deposited above this erosion surface and probably constitutes a lowstand systems tract.

Figure 20.24 Map showing progradational limits for shoreline sandstones in Marshybank units F, J, and L (see Fig. 20.23), based on data in Pint and Norris (1991).

Figure 20.25 Location maps. a. Generalized paleogeography of prograding shorelines of the Chauge, Milk River, and Chinook. Shale sandstones of the Alderson Member are probably younger than the Milk River shoreline sandstones farther south (Brensen, pers. comm.). b. Northern limit of Milk River/Chinook shoreline sands and locations of detailed cross sections (modified after Rosenthal and Walker, 1987, and Meijer Drees and Myhr, 1981).

Figure 20.26 Cross section through Milk River based on well logs (after Meijer Drees and Myhr, 1981). The cross section emphasizes the overlapping nature of the Milk River onto the First White Speckled Shale and shows the interfingering nature of the Milk River with the Alderson Member. The Vergigoe sandstone is diachronous, with indication of at least two offlapping shorelines. Cross section located on Figure 20.25b.
The Durvengan Formation represents a major progradational event and a transgression in the Yakuton Territory and northern British Columbia. The Durvengan Formation consists of numerous stacked deposition cycles that prograded as wave, current, and mixed-influence deltas (Bhattacharya and Walker, 1991). The progradation, though attributed to global lowering of sea level at 94 Ma, coincided with a major uplift in the Omineca and Intermontane belts.

The sea-level rise that began in the Late Albian and reached its peak during the early Turonian is inferred to be eustatic (Hajati et al., 1997; Caldwell, 1984). It resulted in basin-wide deposition of the eustatic Second White Speckled Slate (Wimpy Member) within which the Cenomanian-Turonian boundary occurs (Stelck and Wall, 1956). The Second White Speckled Slate is represented by the argillaceous, highly calcareous Fivel Formation in Manitoba (McNeil and Caldwell, 1981). The calcite carbonate content of this interval generally increases seaward away from the Cordillera.

During the Turonian, a major regression, in large part related to eustatic fall, resulted in a basin-wide disconformity and deposition of the non-marine to shelf sediments of the Cardium Formation. High-frequency fluctuations in sea level resulted in the complex depositional patterns now preserved.

The peak of the marine transgression following Cenomanian sedimentation is represented by the First White Speckled Slate. Planktonic faunas in this unit indicate a warm-temperature climate in at least the eastern part of the basin during the latest Cenomanian, Turonian, and early Santonian to earliest Campanian (McNeil, 1984). During maximum marine transgressions, warm waters from the Gulf of Mexico possibly extended as far north as 54°N latitude, increasing water temperatures by up to 5°C to a temperature near 20°C (McNeil and Caldwell, 1981). In the First and Second White Specks and perhaps the Fish Scales Zone, the presence of bioclastic chalk and planktonic foraminifera indicate open-marine conditions within the seaway during the peaks of the marine transgressions.

The final regressive event of the Colorado Group began during early Campanian time, and was culminated by extensive fine- to medium-grained shoreline sandstones of the overlying Virgile Member (Milk River Formation) and the Chango Member (Wapiti Formation) which extend from southwestern Alberta and northern Montana to the central Alberta Foothills. The shoreline prograded as a sheet of wave-dominated sandstone up to 9 m thick; it extended along strike for at least 350 km. The Virgile and Chango members are exposed in outcrop grade laterally northward into interbedded sandstone, siltstone and shale of the Alderson Member (of the Lea Park Formation) in the subsurface (Meyer Dues and Myhe, 1981; Rosenthal and Walker, 1987). In west-central Alberta, the shoreline sandstone of the Chango Member is slightly younger than the Chango Member, although Stott (1987) included the Chango within the Chango Member. The influence of tides in the foreland basin at this time is recorded in a tidal-inlet sequence preserved in outcrop at Writing-On-Stone Park in southern Alberta (Cheek and Leckie, 1990). During early to late Campanian time, sea level rose again and the marine shales of the Pakowki Member/Nomad Member were deposited.

References


