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, pelecypod 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 (Chapters 21, 22 and 23, respectively).

Previous Work

Earlier regional syntheses of the Colorado Group are in Caldwell (1984) and Williams and Burke (1964). Detailed lithostratigraphic and micropaleontological aspects of the Colorado Group in the Manitoba Escarpment and adjacent subsurface were described in McNeil and Caldwell (1981) and McNeil (1984). In Saskatchewan, detailed lithological descriptions were carried out by Simpson (1982). Stott (1963, 1967, 1982) 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. (1978).

Summary lithological and stratigraphic 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 Stelck (1975). Detailed paleogeographic maps illustrating the evolution of the Western Canada Sedimentary Basin are presented in Leckie and Smith (1992).

Geological Framework

The Albian 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 Turonian and Middle Santonian (Caldwell, 1984; Haq et al., 1987). Deposition at this time was also coincident with a regional tectonic downflexing of the North American craton (Lambeck et al., 1987). The major marine inundations were separated by four major regressive pulses represented by the Peace River-Viking, Dunvegan, Cardium-Bad 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 epeiric seaway.

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 Basal Colorado Sandstone, Spinney 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. 20.1). Within the Colorado Group, the First and Second White Speckled Shales, the Fish Scales Zone, and shale at the base of the Shaftesbury 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 northwest 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 Harmon, 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 Bowdoin Dome and Swift Current Platform in southern Saskatchewan. The Bow Island Arch separates the Alberta Basin from the Williston Basin.

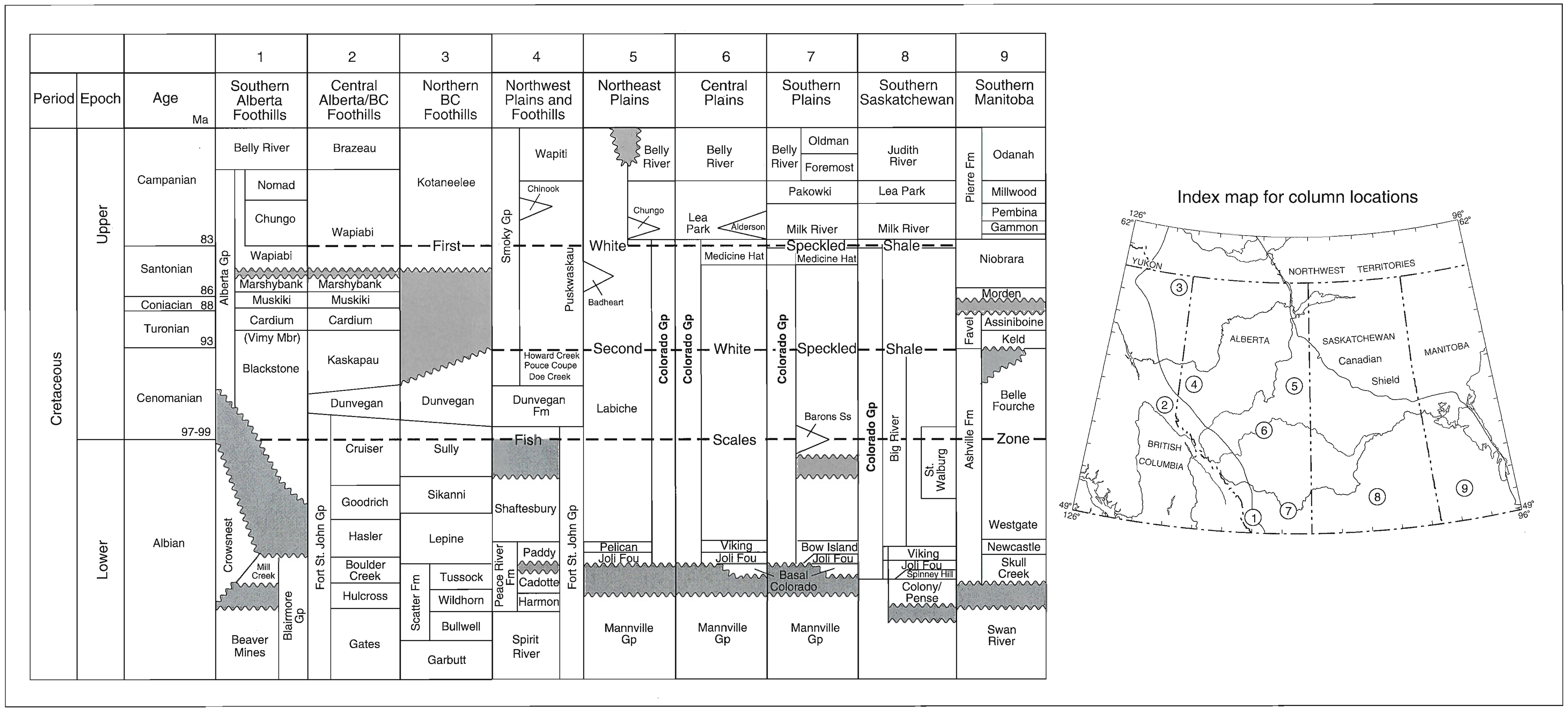

Figure 20.1 Stratigraphic terminology of the Colorado/Alberta Group.

Table 20.1 Sandstone and conglomerate bodies within the Colorado Group

Formation	Hydrocarbon Type
Milk River Formation	immature, biogenic gas, no production
Chinook Formation	natural gas
Medicine Hat Sandstone	immature, biogenic gas
Cardium Formation	light crude oil, natural gas
Second White Specks/ Phillips Sandstone	natural gas, light (?) crude oil
Doe Creek Member of Kaskapau Formation	light crude oil, natural gas
Dunvegan Formation	light crude oil, natural gas
Barons Sandstone	natural gas, light crude oil
St. Walburg Formation	natural gas
Viking Formation	light crude oil, natural gas
Bow Island Sandstone	heavy and light crude oil, natural gas
Paddy Member	natural gas
Newcastle Sandstone	shows only
Basal Colorado Sandstone	natural gas, heavy crude oil
Spinney Hill	natural gas

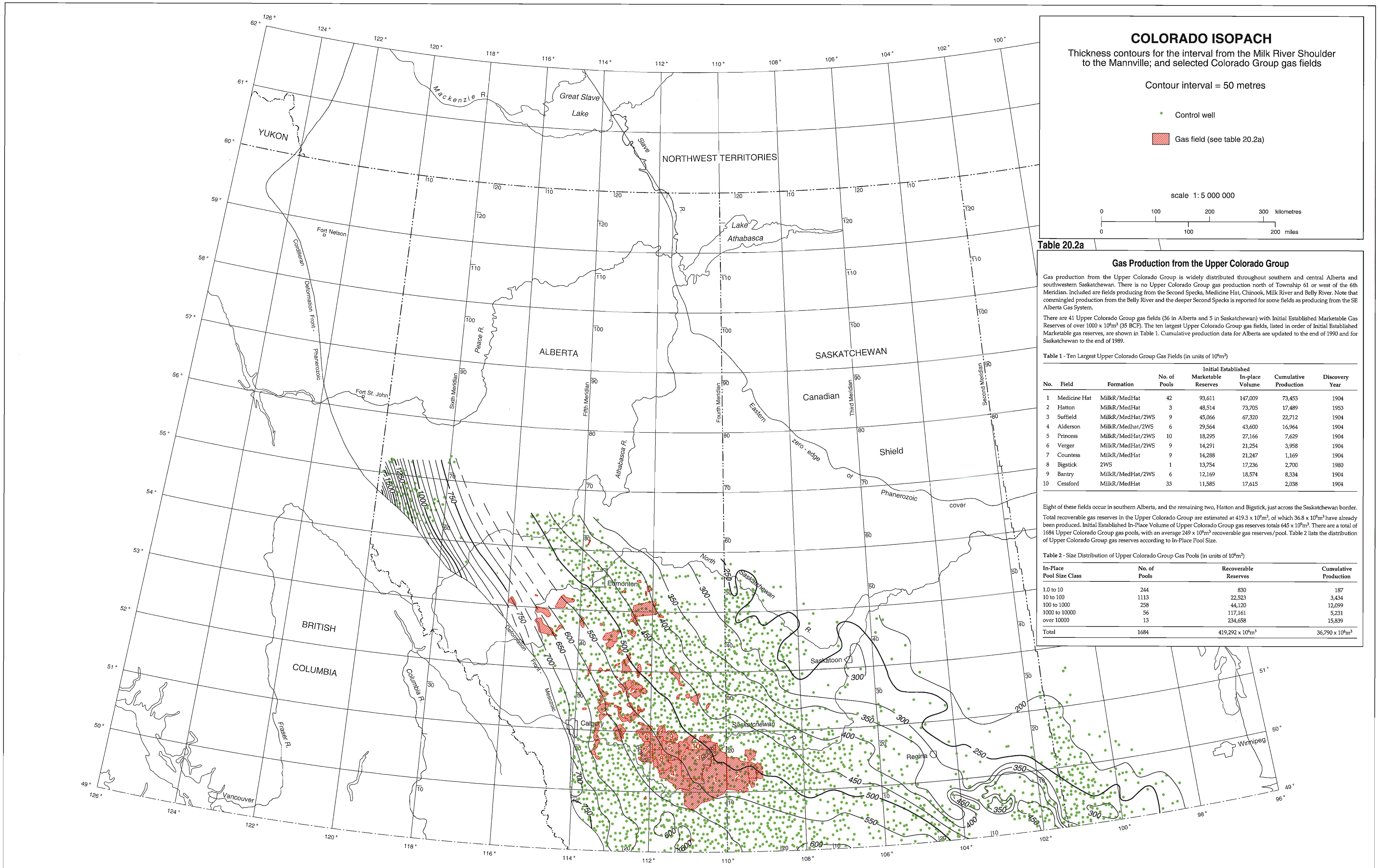

Table 20.2a

Gas Production from the Upper Colorado Group

Gas production from the Upper Colorado Group is widely distributed throughout southern and central Alberta and southwestern Saskatchewan. There is no Upper Colorado Group gas production north of Township 61 or west of the 6th Meridian. Included are fields producing from the Second Specks, Medicine Hat, Chinook, Milk River and Belly River. Note that commingled production from the Belly River and the deeper Second Specks is reported for some fields as producing from the SE Alberta Gas System.

There are 41 Upper Colorado Group gas fields (36 in Alberta and 5 in Saskatchewan) with Initial Established Marketable Gas Reserves of over 1000 x $10^6 m^3$ (35 BCF). The ten largest Upper Colorado Group gas fields, listed in order of Initial Established Marketable gas reserves, are shown in Table 1. Cumulative production data for Alberta are updated to the end of 1990 and for Saskatchewan to the end of 1989.

Table 1 - Ten Largest Upper Colorado Group Gas Fields (in units of $10^6 m^3$)

No.	Field	Formation	No. of Pools	Initial Established Marketable Reserves	Initial Established In-place Volume	Cumulative Production	Discovery Year
1	Medicine Hat	MilkR/MedHat	42	93,611	147,009	73,453	1904
2	Hatton	MilkR/MedHat	3	48,514	73,705	17,489	1953
3	Suffield	MilkR/MedHat/2WS	9	45,066	67,320	22,712	1904
4	Alderson	MilkR/Medhat/2WS	6	29,564	43,600	16,964	1904
5	Princess	MilkR/MedHat/2WS	10	18,295	27,166	7,629	1904
6	Verger	MilkR/MedHat/2WS	9	14,291	21,254	3,958	1904
7	Countess	MilkR/MedHat	9	14,288	21,247	1,169	1904
8	Bigstick	2WS	1	13,754	17,236	2,700	1980
9	Bantry	MilkR/MedHat/2WS	6	12,169	18,574	8,334	1904
10	Cessford	MilkR/MedHat	33	11,585	17,615	2,038	1904

Eight of these fields occur in southern Alberta, and the remaining two, Hatton and Bigstick, just across the Saskatchewan border.

Total recoverable gas reserves in the Upper Colorado Group are estimated at 419.3 x $10^9 m^3$, of which 36.8 x $10^9 m^3$ have already been produced. Initial Established In-Place Volume of Upper Colorado Group gas reserves totals 645 x $10^9 m^3$. There are a total of 1684 Upper Colorado Group gas pools, with an average 249 x $10^6 m^3$ recoverable gas reserves/pool. Table 2 lists the distribution of Upper Colorado Group gas reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Upper Colorado Group Gas Pools (in units of $10^6 m^3$)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	244	830	187
10 to 100	1113	22,523	3,434
100 to 1000	258	44,120	12,099
1000 to 10000	56	117,161	5,231
over 10000	13	234,658	15,839
Total	1684	419,292 x $10^6 m^3$	36,790 x $10^6 m^3$

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 Cardium formations, illustrated in chapters 21, 22 and 23 (*this volume*), but major gas fields in the Milk River, Medicine Hat and Second White Specks are shown here. Note that the tabulation of gas production (Table 20.2a) includes data from fields in overlying Belly River Formation strata (see Fig. 24.16).

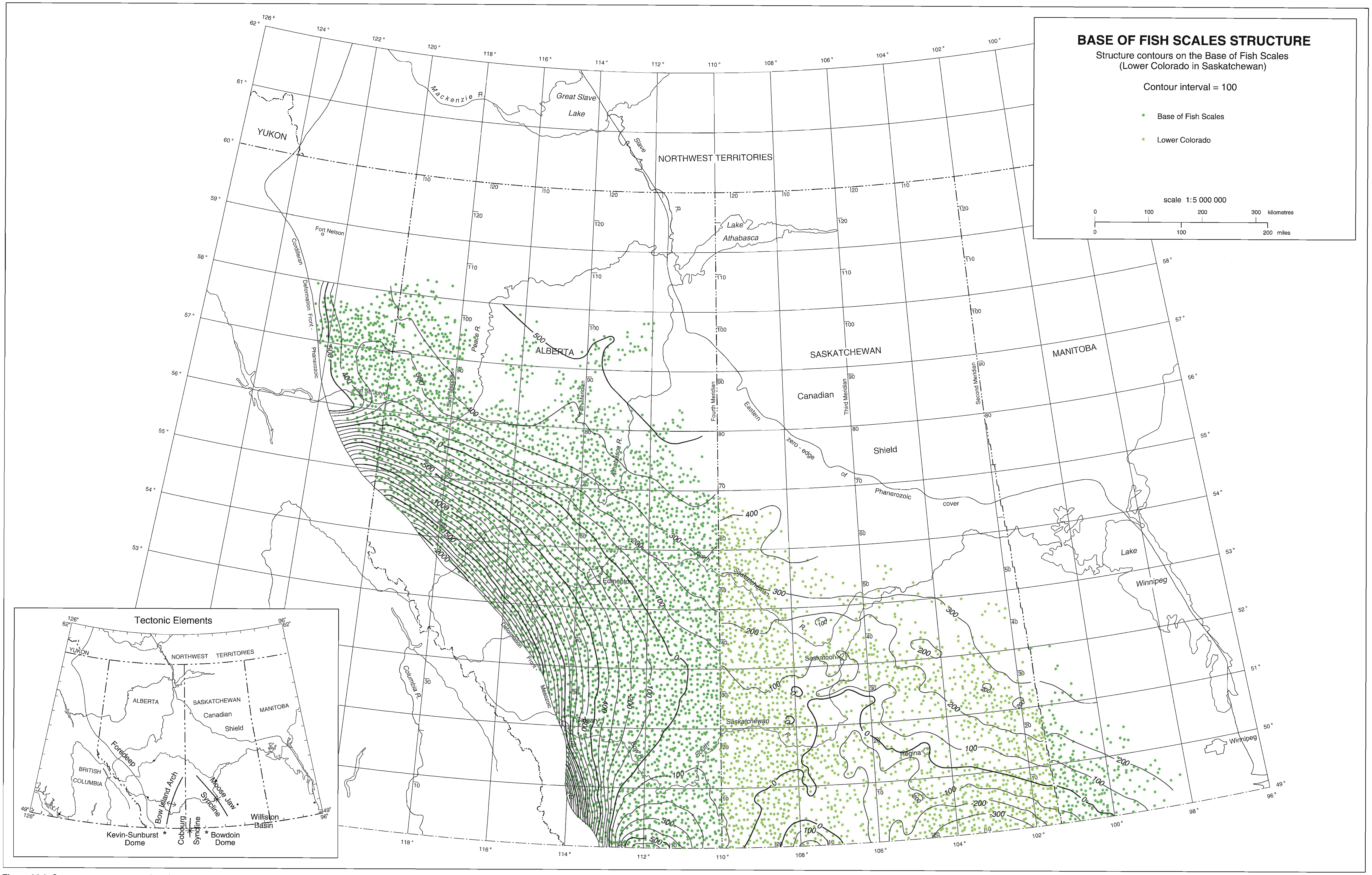

Figure 20.3 Structure map constructed on the base of Fish Scales Zone. Note that in Saskatchewan, the Base of Fish Scales is not commonly picked and contours in Saskatchewan reflect the (stratigraphically higher) Lower Colorado marker.

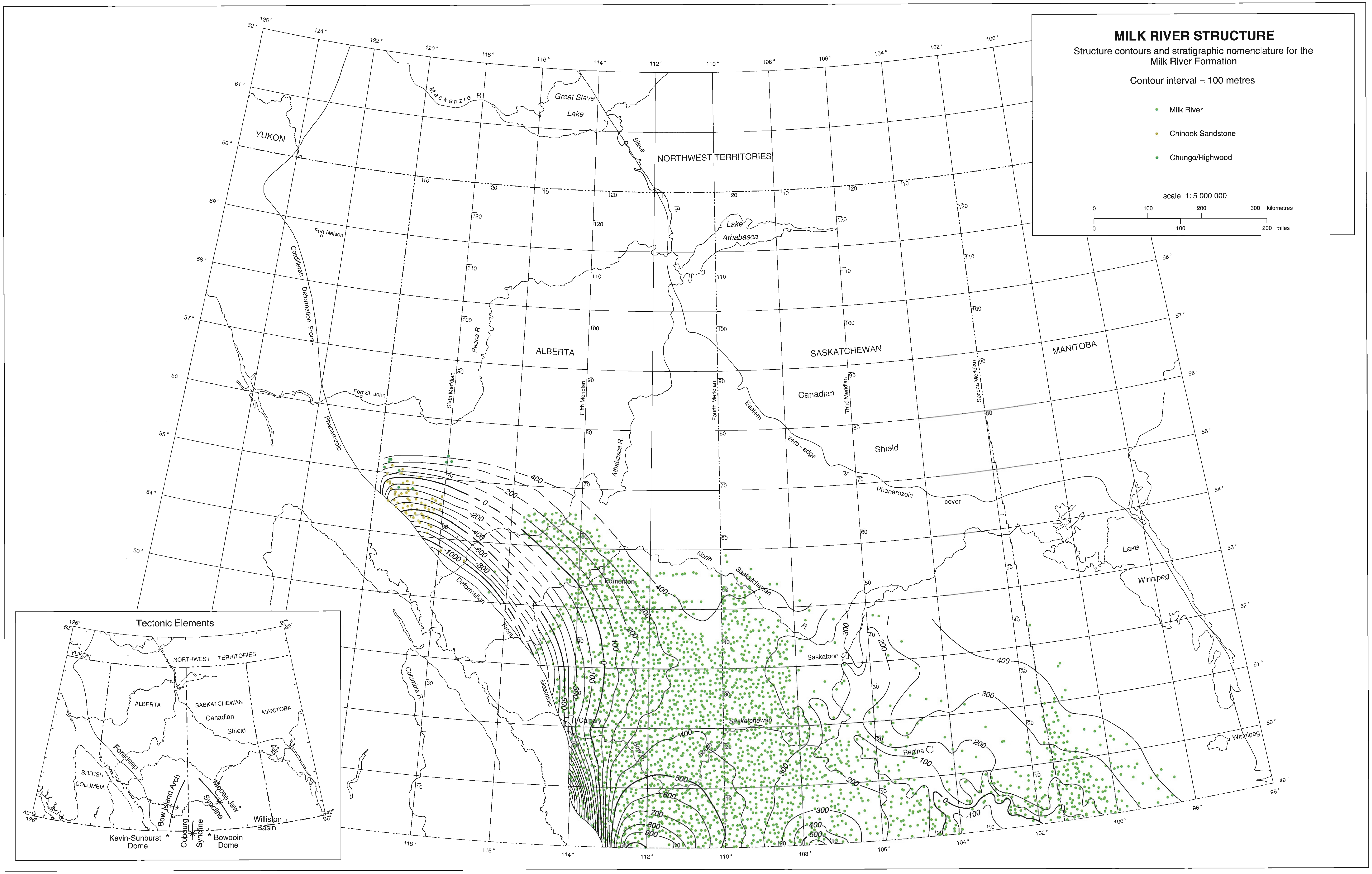

Figure 20.4 Structure map constructed on top of the Milk River Formation (Milk River shoulder).

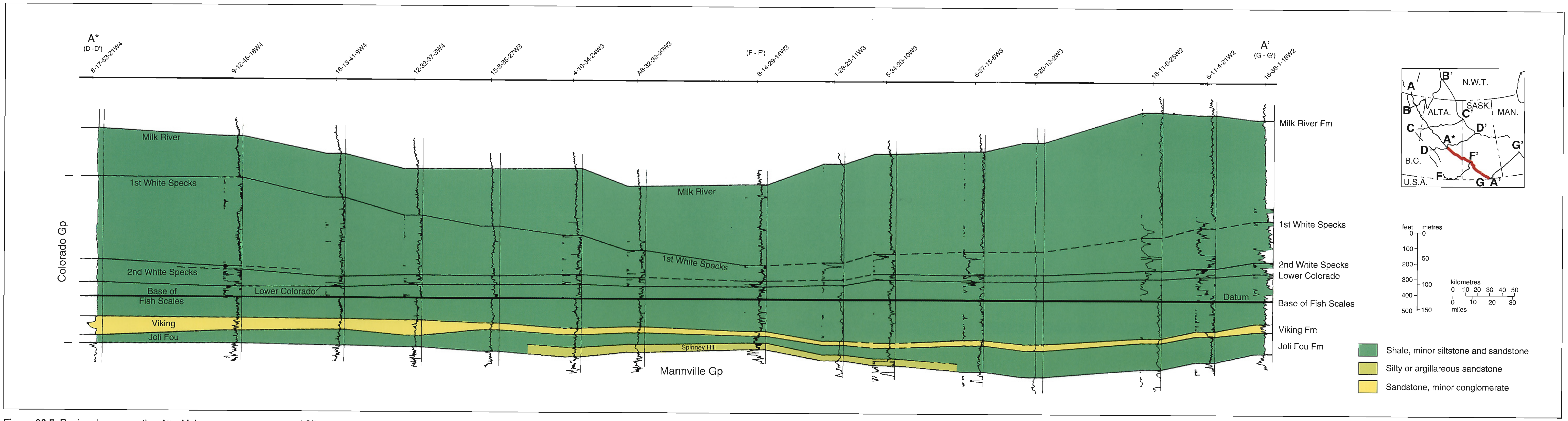

Figure 20.5 Regional cross section A* - A'. Logs are gamma ray and SP.

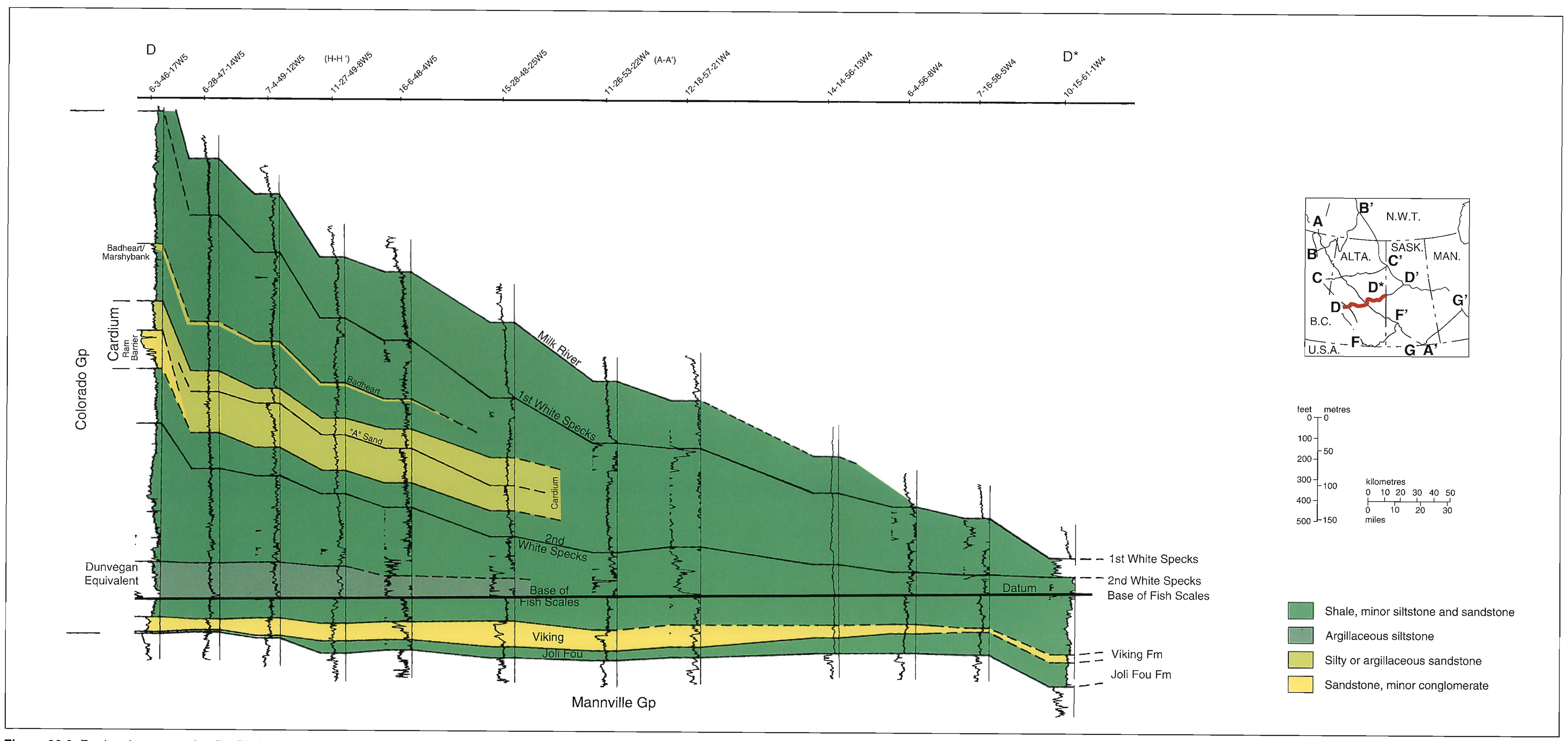

Figure 20.6 Regional cross section D - D*. Logs are gamma ray and SP.

Negative structural elements include the Williston Basin and its northern extension, the Moose Jaw Syncline in southern Saskatchewan and the Eastend Syncline in southwestern Saskatchewan. In southeastern 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 late Turonian-early 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), structure 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/Chungo units and the Muskiki, 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 20.5 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-

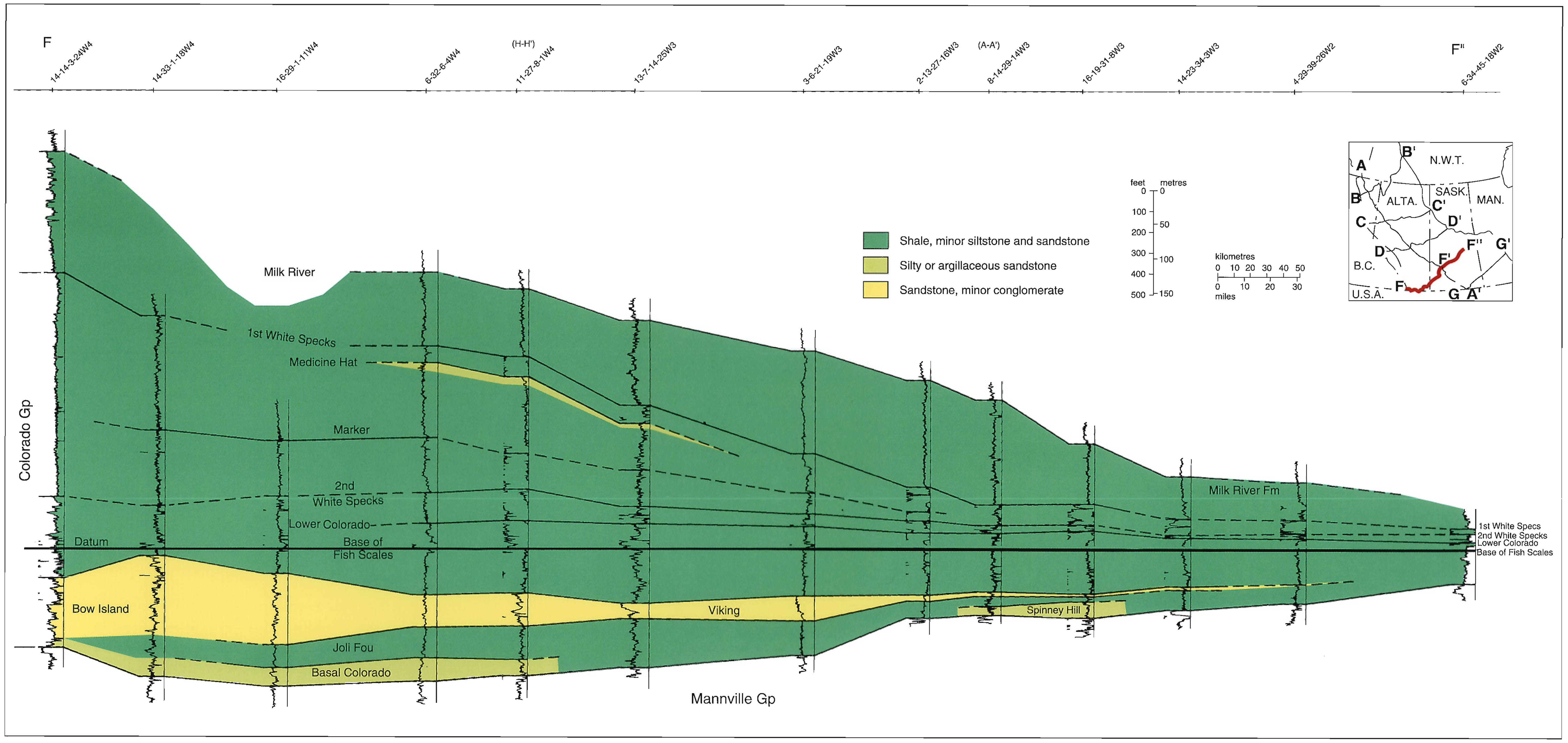

Figure 20.7 Regional cross section F - F". Logs are gamma ray and SP.

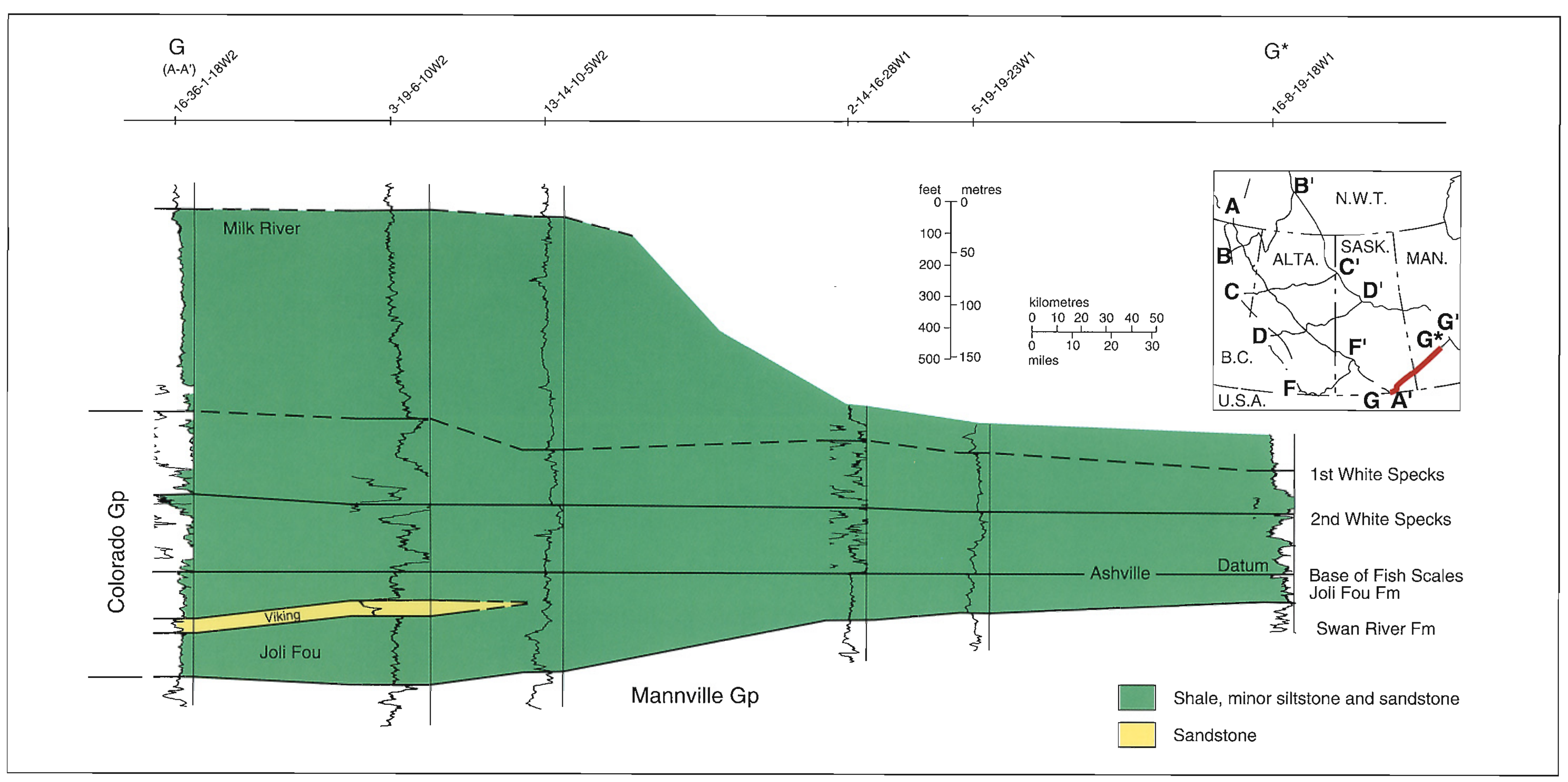

Figure 20.8 Regional cross section G - G*. Logs are gamma ray and SP.

ties with identification and correlation of the Second White Speckled Shale are evident in Figures 20.5, 20.9 and 20.10 because of changes in log character across the basin. Cross section H-H' (Fig. 20.9) is oriented along the axis of the western Alberta foreland basin and highlights the geometry of the Dunvegan clastic wedge. The northwestern end of the cross section stops where the units come to the surface in the Peace River valley.

The suite of reference logs (Fig. 20.18) illustrates the variability of the different components of the Colorado Group across the basin as well as the markers used for correlation.

Stratigraphy

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 biostratigraphically using foraminifera (Caldwell et al., 1978; McNeil and Caldwell, 1981), ammonites (Jeletzky, 1971) and microflora (Singh, 1983).

The Colorado Group was informally subdivided by Rudkin (1964) into upper and lower subgroups separated by the Base of Fish Scales Zone. In Saskatchewan, where the Fish Scales Zone is not always evident, Simpson (1982) subdivided the Colorado Group at the lower of two calcareous speckled shales (the Second White Speckled Shale). Neither subdivision is used herein.

The term Alberta Group is restricted to those strata south of the Smoky River in the southern Alberta Foothills and includes the Blackstone, Cardium and Wapiabi formations (Fig. 20.1). In northwestern Alberta and northeastern British Columbia, correlative strata include the Shaftesbury and Dunvegan formations and that part of the Smoky Group comprising the Kaskapau, Cardium, Muskiki, Marshybank, Badheart and lowermost Puskwaskau formations. In the subsurface of Alberta and Saskatchewan, the Colorado Group is used. In Manitoba, strata equivalent to the Alberta and Colorado groups are called the Ashville, Favel, Morden and Niobrara formations (McNeil and Caldwell, 1981). Within the Ashville Formation, only the Newcastle Member consists predominantly of sandstone. In northernmost British Columbia, correlative strata are the upper Lepine, Sikanni, Sully, Dunvegan and lower Kotaneelee formations.

Stratigraphic History

Basal Contact and Units

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 southern Alberta and Saskatchewan, the Cadotte Member of the Fort St. John Group in northeastern British Columbia and northwestern Alberta, and the Swan River Formation in Manitoba (Figs. 20.1 and 20.5 -20.10). The basal contact of the Colorado Group with the Mannville Formation is generally represented by a thin conglomerate layer containing chert or intraformational 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 (Cantuar 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 20.5 -20.10).

The Basal Colorado Sandstone, in southeastern Alberta, southern Saskatchewan, northern Montana and North Dakota, is a thin (< m thick), sheet-like unit underlying the Joli Fou marine shales and overlying the non-marine Mannville Group (Banerjee, 1989). In the Cessford area (Tp 22-26 R 10-16W4), the Basal Colorado Sandstone (also called Cessford Sand) occurs as a northwest-trending sandstone body, 20 km wide, 6 to 8 m thick, and situated in a paleotopographic low. In Saskatchewan, the approximately 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 intraformational conglomerates, clasts of nodular phosphorite, pelecypod coquinas and concretions of siderite and pyrite. The formation is up to 36.6 m thick and occurs as a sandstone body up to 60 km wide in central Saskatchewan (Simpson, 1982).

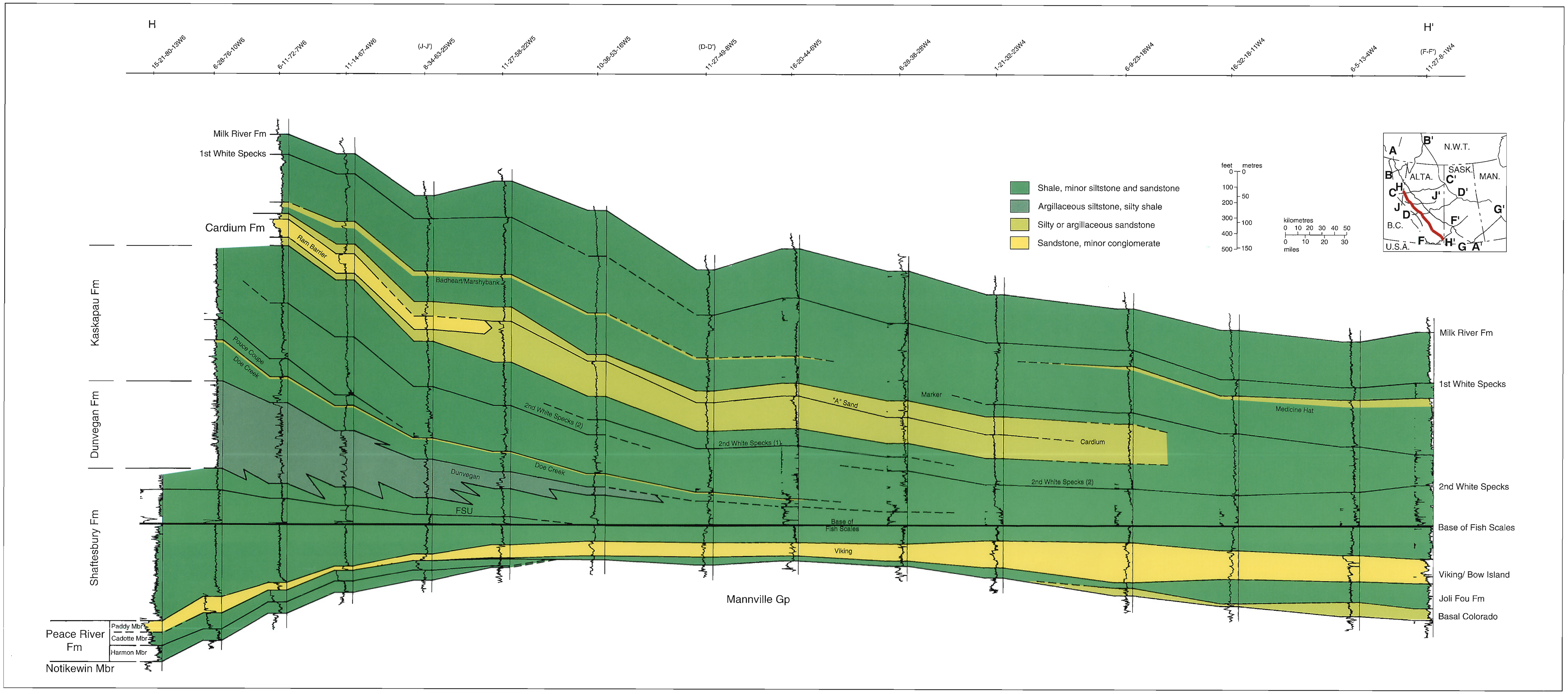

Figure 20.9 Regional cross section H - H'. Logs are gamma ray and SP.

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 paleosols 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, pelecypod coquinas 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 disconformably overlies the Mannville Group where the Basal Colorado/Spinney Hill are absent, and underlies the Viking Formation, disconformably in places. In eastern Saskatchewan, the Joli Fou Formation is underlain by the Swan River Sandstones, 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 (Wickenden, 1949). Fauna within the Joli Fou shale suggest that the marine seaway extended from central Alberta to the Gulf of Mexico.

Viking Formation and Equivalent Units

The Albian Viking Formation, which is found in central and southern Alberta and Saskatchewan, was first named by Slipper (1918) to describe a gas-bearing sandstone encased in shale in east-central Alberta. Correlative units (Fig. 20.1) 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 Flotten 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-thinning wedge of coarse clastic detritus, 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 Dodsland-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 northwestern 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 (Tp 70, R 27W5). The Paddy Member was deposited under brackish-water conditions in the inner to outer reaches of a large estuarine system (Leckie 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 (Leckie et al. 1990). A thick sequence of paleosols in the correlative Boulder Creek Formation from the Rocky Mountain Foothills (Leckie et al., 1989) is related to the valley incision and subsequent sea level rise.

The Flotten Lake Sand in west-central Saskatchewan and east-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 Newcastle 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 Newcastle Sandstone are more sheet-like.

In northeastern Alberta and northwestern 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 northward to a maximum of 32.9 m (Simpson, 1982).

Westgate Member

The Upper Albian Westgate Member (McNeil and Caldwell, 1981) comprises shale above the Newcastle and below the Belle Fourche members. The shale 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 Zone is composite, 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 substages missing below and above it (Caldwell et al., 1978; Bhattacharya and Posamentier, *this volume,* Chapter 25), whereas in western Alberta, strata above and below the marker unit appear to be more conformable (Stelck and Armstrong, 1981).

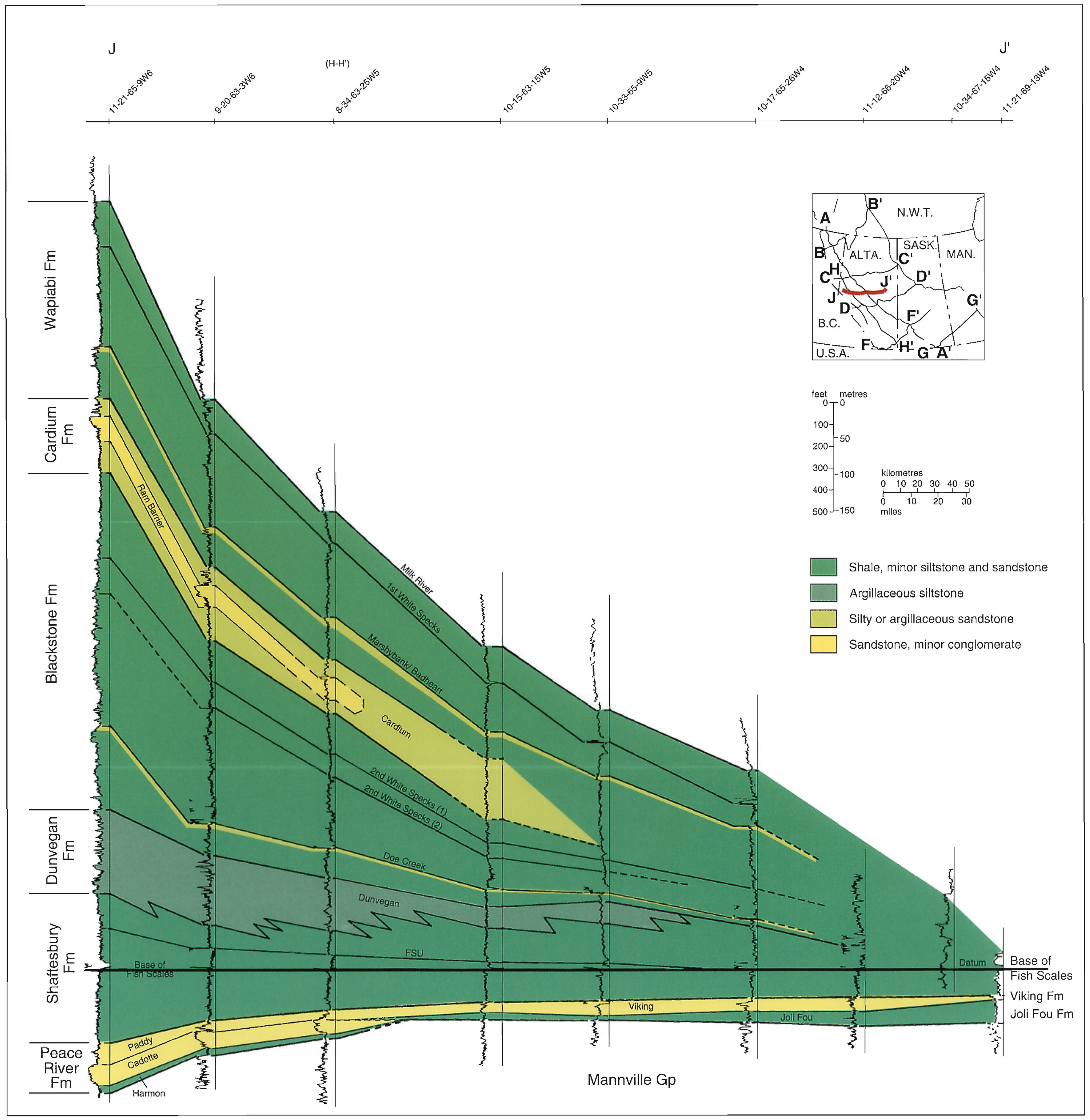

Figure 20.10 Regional cross section J - J'. Logs are gamma ray and SP.

The Fish Scales Zone ranges in thickness from less than 1.5 to 21 m and consists of very fine- to fine-grained sandstone, siltstone and shale with abundant fish scales and skeletal material. Chert granules and pebbles as well as nodular phosphorite occur locally. North and Caldwell (1975) noted that the *Textularia alcesensis* and most of the *Verneuilinoides perplexus* and *Flabellammina gleddiei* zones associated with the Fish Scales Zone were missing and presumed eroded in central Saskatchewan. The Fish Scales Zone is poorly defined in central Saskatchewan and is commonly difficult to recognize on wireline logs. In Manitoba, the Fish Scales Zone occurs within the lowermost 6 to 10 m of the Belle Fourche Member (Late Albian to Middle Cenomanian). Farther west, and in the northern United States, the Fish Scale Marker Bed occurs near the top of the Mowry Shale. Also within the Belle Fourche Member (Fig. 20.1) and above the Fish Scales Zone, the *Ostrea beloiti* limestone beds represent a distinctive marker consisting of inoceramid or ostreid fragments (McNeil and Caldwell, 1981) which, with an associated bentonite, can be traced as far south as Oklahoma and westward into Montana. McNeil and Caldwell (1981) considered this bentonite to correspond to the "X" bentonite in the United States. A disconformity separates the Belle Fourche Member from the overlying Keld Member of the Favel Formation (McNeil and Caldwell, 1981).

Barons Sandstone

In southwestern Alberta, the Cenomanian Barons Sandstone overlies the organic-rich, radioactive shales 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 Flotten 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, pelecypod and fish debris, thin chert-pebble layers, 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 Colorado 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 *Dunveganoceras* Zone (Stott, 1963) whereas northward, it lies within the Late Albian *Neogastroplites* Zone.

The Crowsnest 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. 20.1). The age of volcanic agglomerates making up the Crowsnest Formation is poorly constrained but is generally considered to be Late Albian. Source areas or pipes for the volcanic detritus are thought to be in the Ma Butte and Coleman areas, where maximum sediment thicknesses of up to 484 m also occur.

Dunvegan Formation

The middle/upper Cenomanian Dunvegan Formation represents a southeastward thinning and fining, fluviodeltaic wedge deposited above the Shaftesbury Formation (Fig. 20.6; Stott, 1982). The formation is recognized in northwestern 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-plain setting. In northwestern Alberta, at least ten sand-rich, progradational cycles separated by regional transgressive surfaces represent the southeastward advance of the Dunvegan 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 Intermontane belts (Stott, 1982). The Dunvegan has been recognized as far south as the Athabasca River (Stott, 1963). Farther south, the Dunvegan Formation is replaced by marine siltstone and shale beds of the Sunkay Member of the Blackstone Formation, where sedimentation was dominated largely by pelagic deposition. The Dunvegan Formation is described in considerable detail by Bhattacharya (*this volume,* Chapter 22).

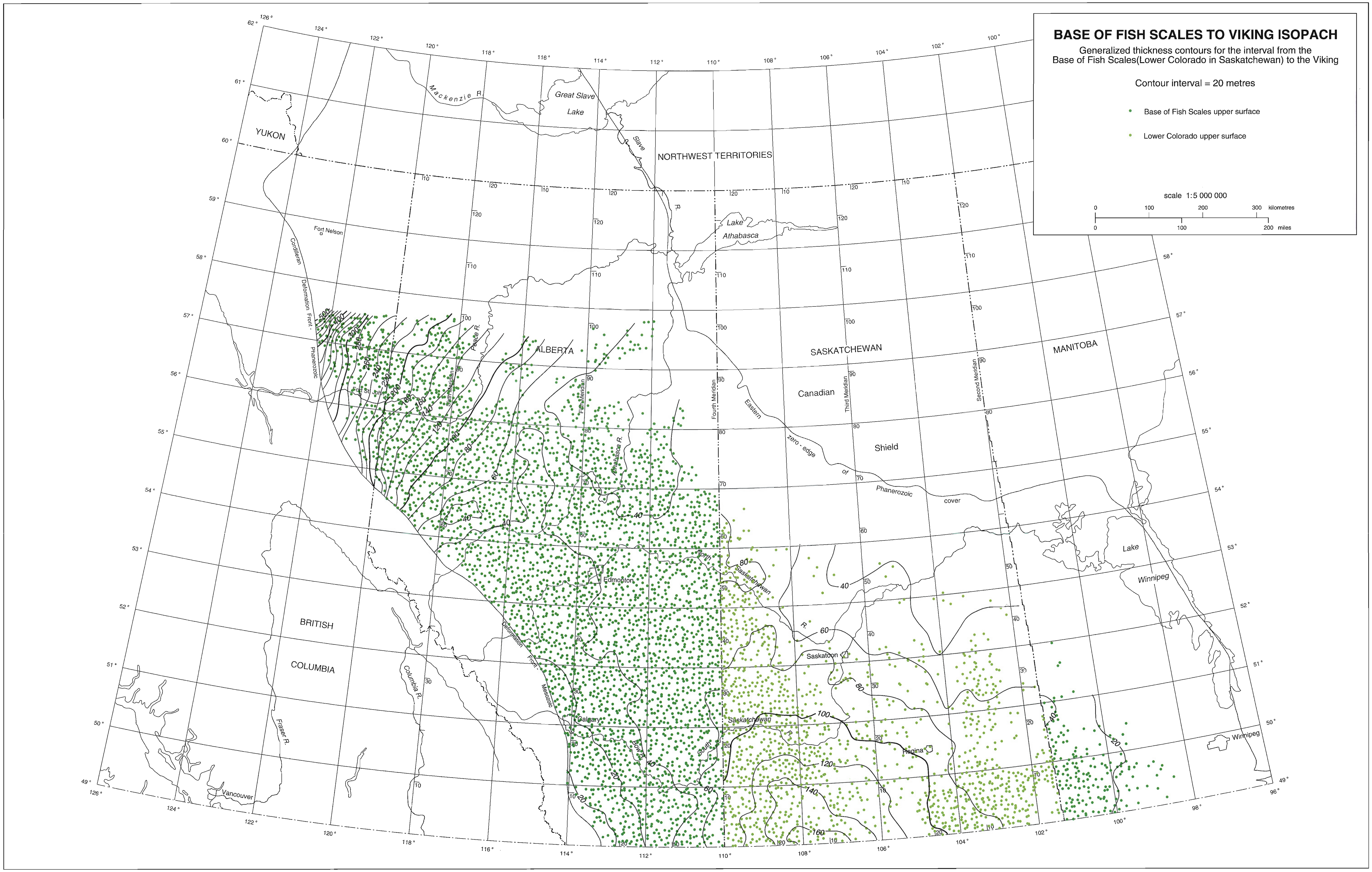

Figure 20.11 Isopach map of the interval from the base of the Fish Scales Zone to the Viking-Bow Island; Lower Colorado to Viking in Saskatchewan.

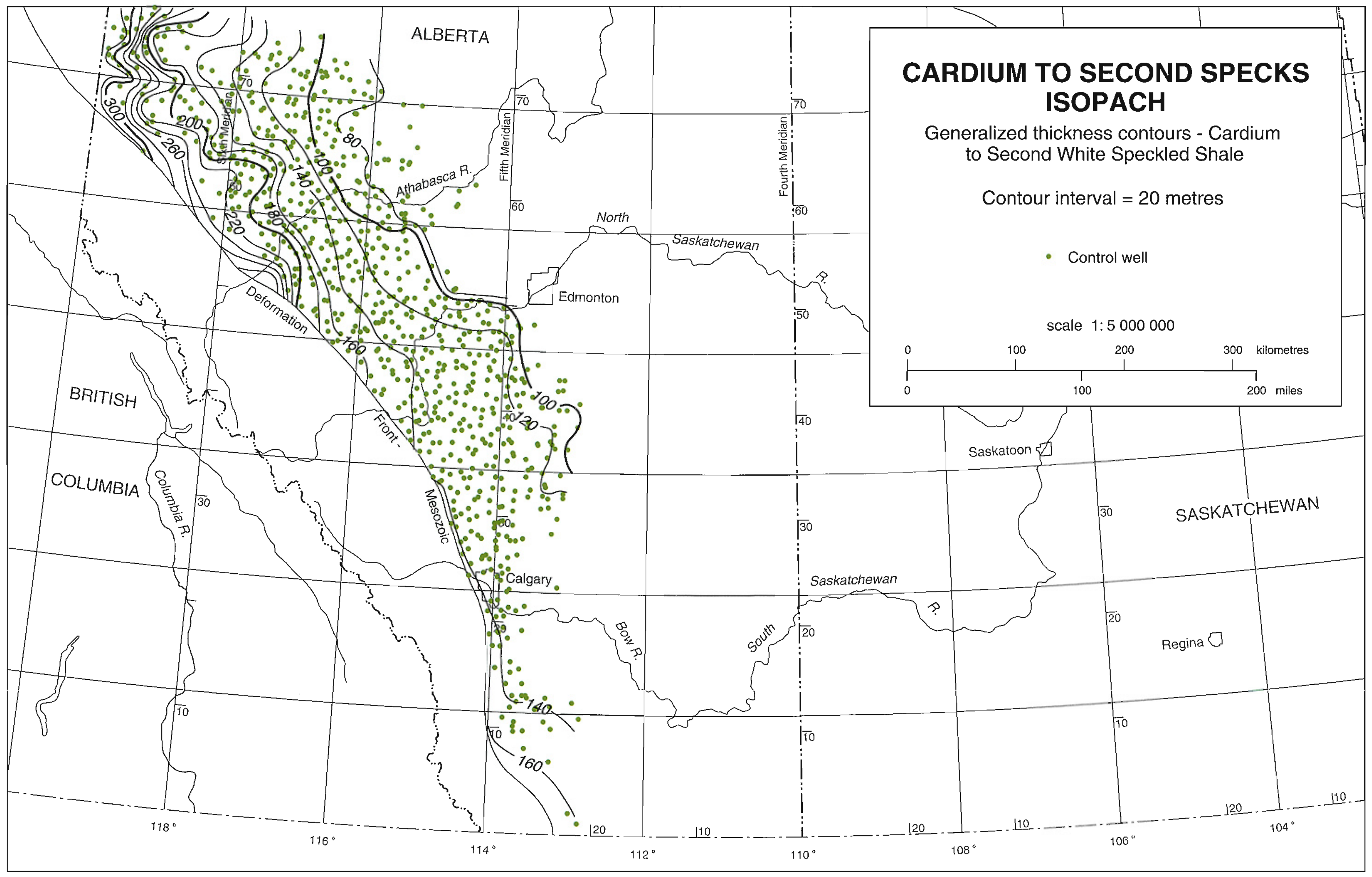

Figure 20.12 Isopach map of the interval from the top of the Cardium Formation to the Second White Speckled Shale.

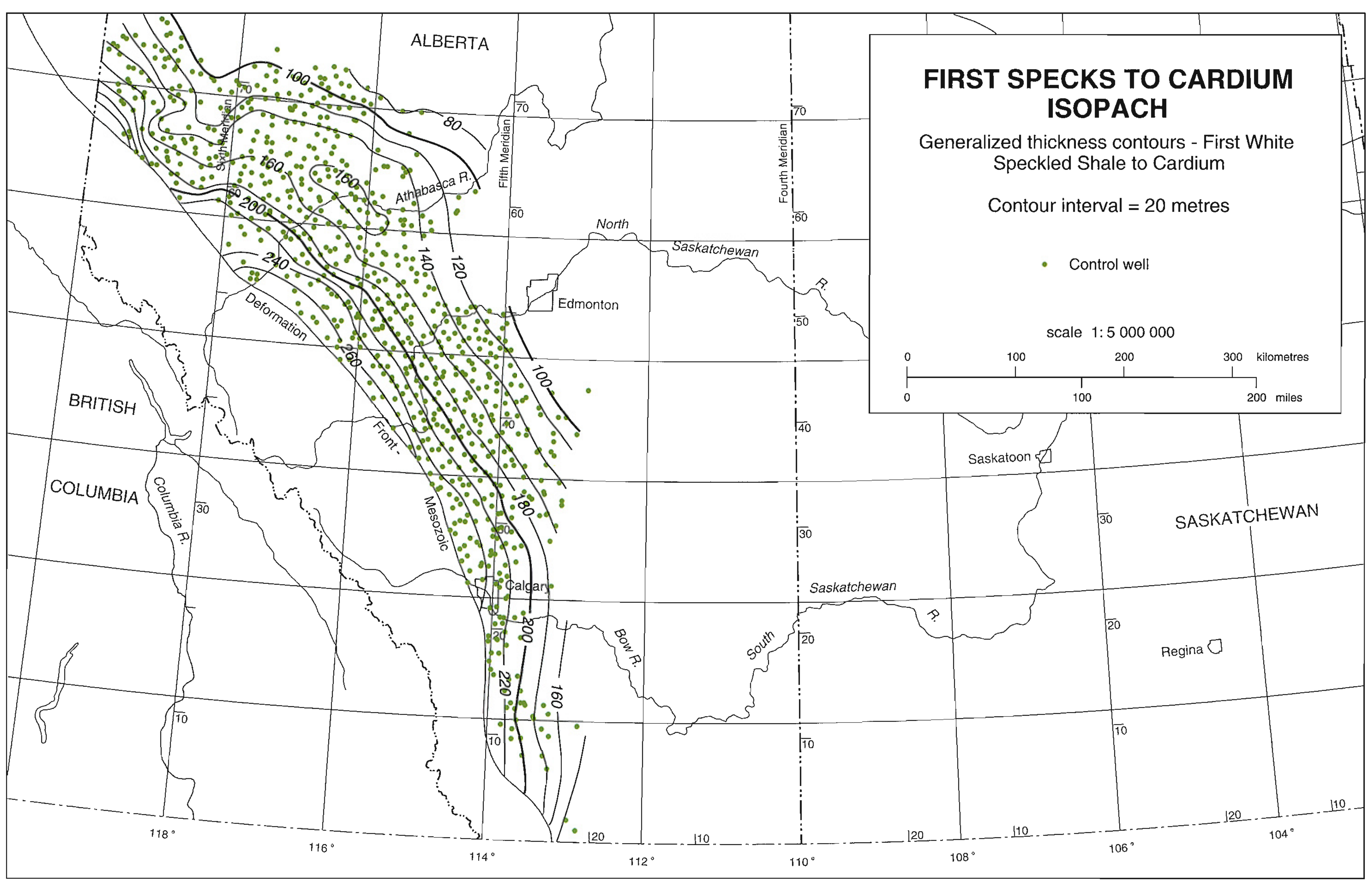

Figure 20.13 Isopach map of the interval from the First White Speckled Shale to the top of the Cardium Formation.

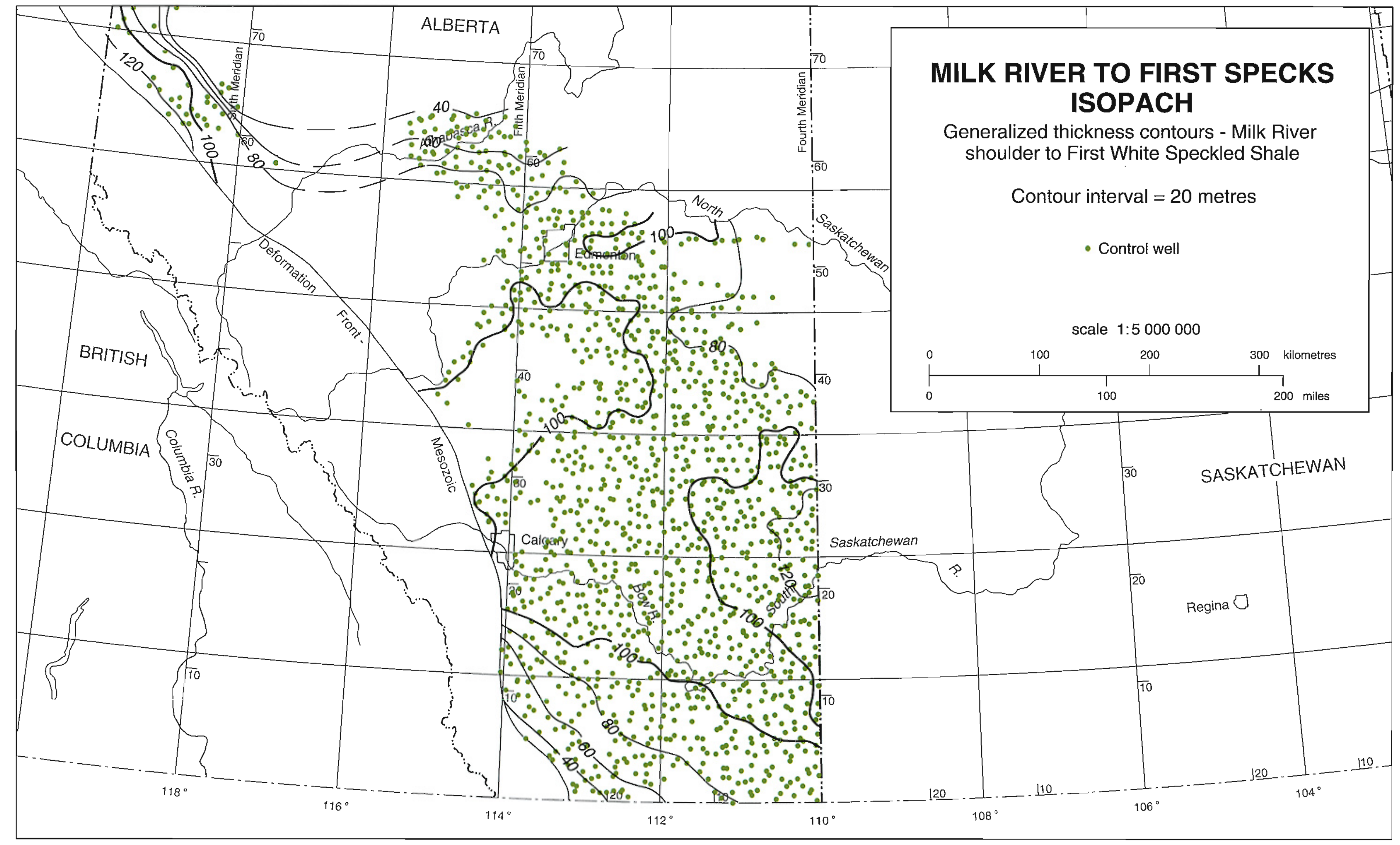

Figure 20.14 Isopach map of the interval from the Milk River shoulder to the First White Speckled Shale.

Kaskapau Formation

The Kaskapau Formation in northwestern Alberta is a predominantly 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, Pouce 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 21 to 37 km long and 5 to 7 km wide. The Howard Creek Member underlies the organic-rich, radioactive shales of the Second White Speckled Shale, which likely was the source for hydrocarbons in the Doe Creek Member. The Tuskoola and Wartenbe sandstones are poorly understood units within the Kaskapau Formation, occurring above the Vimy Member in outcrop in northeastern British Columbia (Stott, 1967). In southwestern Saskatchewan and southeastern Alberta, the thin, shallow-marine Phillips Sandstone/Second White Speckled Sandstone may be correlative 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, peleypcods (*Inoceramus*), bentonites, pyrite, calcite concretions 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 bentonites deposited in the shales.

The Second White Speckled Shale is the northern correlative 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 (Kauffman, 1977). In the western regions 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 Vimy 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, argillaceous limestone, calcarenite and bentonite beds, ranging from 11 to 46 m thick. The Keld 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 calcarenite interbeds.

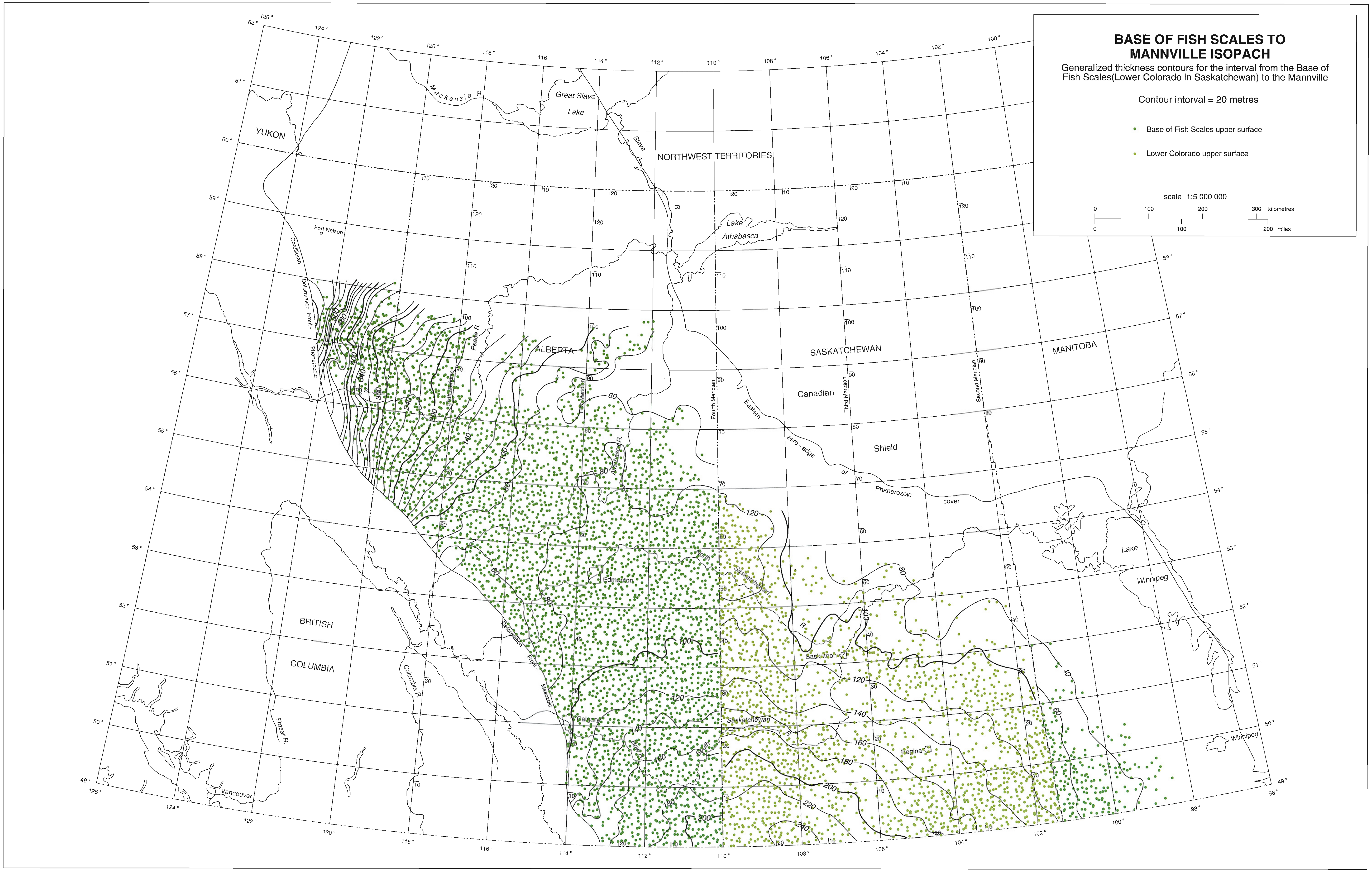

Figure 20.15 Isopach map of the interval from the base of the Fish Scales Zone to the top of the Mannville Group; Lower Colorado to Mannville in Saskatchewan.

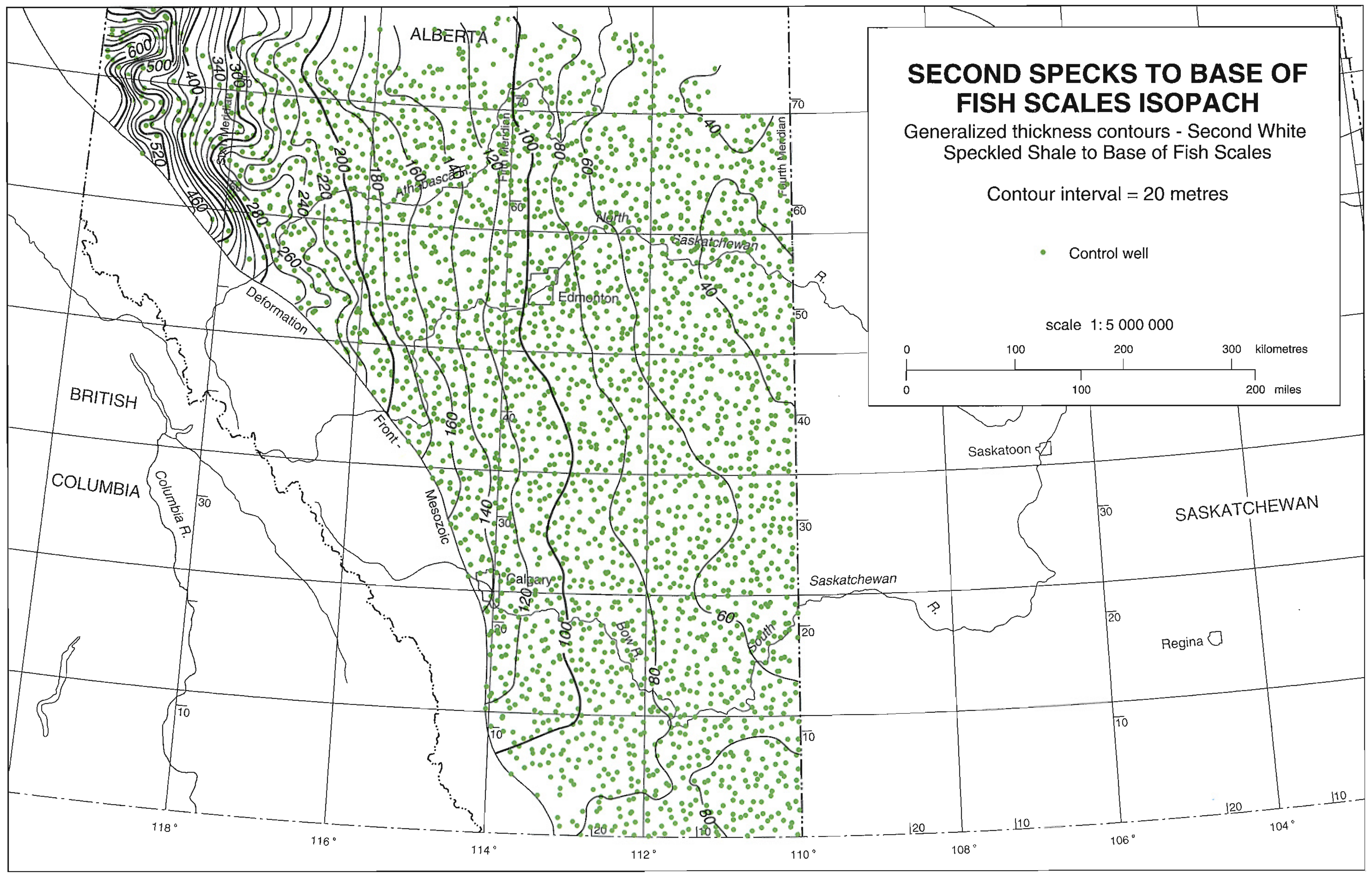

Figure 20.16 Isopach map of the interval from the Second White Speckled Shale to the base of the Fish Scales Zone.

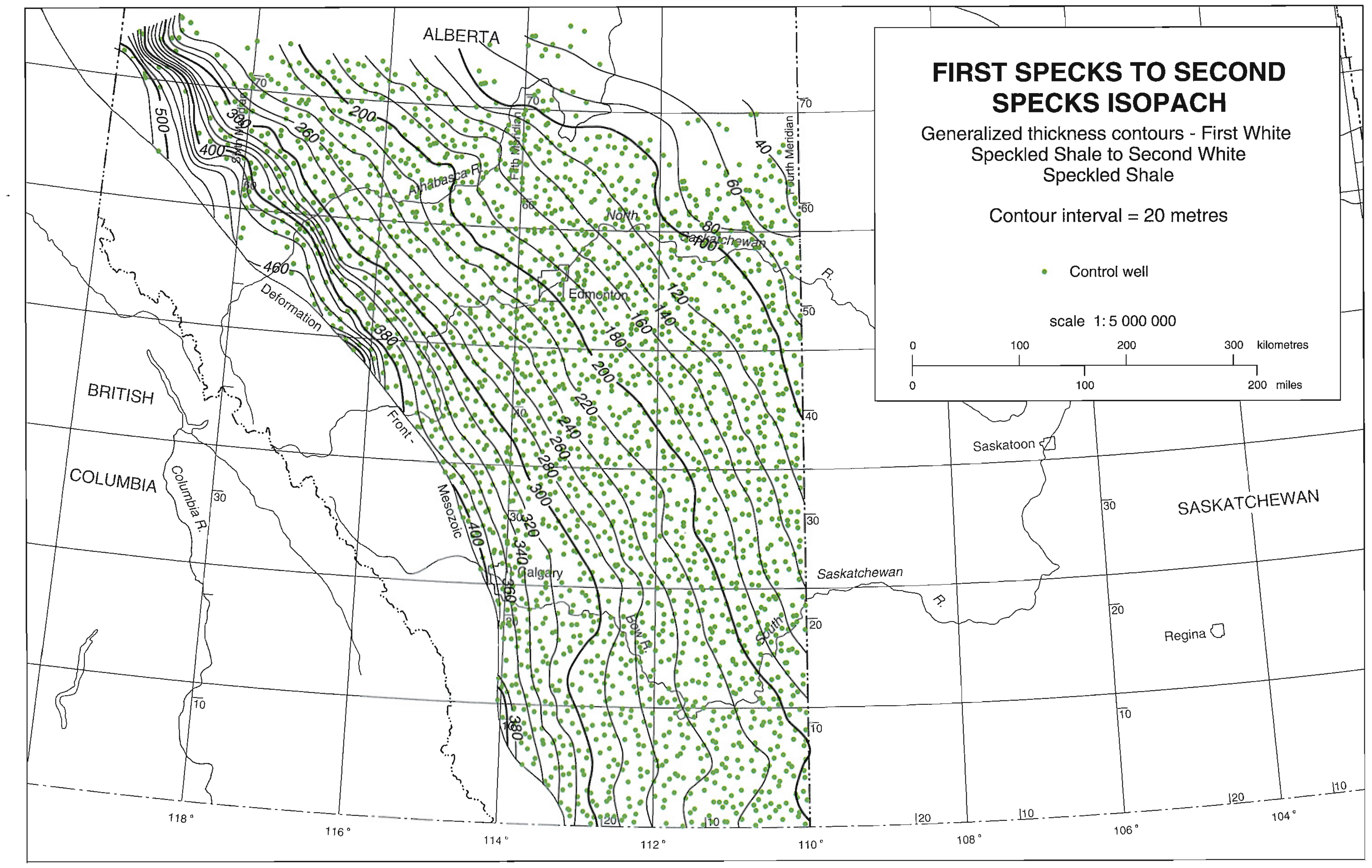

Figure 20.17 Isopach map of the interval from the First White Speckled Shale to the Second White Speckled Shale.

The Favel Formation may have been erosionally truncated in parts of eastern Saskatchewan and western Manitoba (McNeil and Caldwell, 1981).

In the west, the upper Turonian is marked by a regressive event capped by an erosional disconformity 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 (McNeil 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 siltstone, 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., 1988). 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).

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 (Wapiabi 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. 20.1) is a zeolite-bearing, dark gray to black, noncalcareous shale with rare, thin bentonites. Thicknesses vary from 3.5 to 55 m and the unit thins northwestward from the Manitoba Escarpment. The formation is absent in central Saskatchewan (North and Caldwell, 1975).

Muskiki, Marshybank and Bad Heart Formations

The Muskiki Formation (Figs. 20.18a, 20.21) overlies the Cardium Formation, and comprises rusty-weathering shales, conformably overlain by siltstone 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 Wapiabi and Puskwaskau formations, respectively, a predominantly shale succession with minor amounts of sandstone, which ranges in thickness from 114 to 360 m. Members of the Puskwaskau Formation include the Dowling, Thistle, Hanson, Chungo and Nomad members.

The type locality of the Bad Heart Formation was defined by McLearn (1919) at the junction of the Smoky and Bad Heart rivers (in the northern plains of Alberta; Fig. 20.20). McLearn (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-oolitic, marine shelf and coastal plain sandstones and siltstones in the foothills and adjacent subsurface. It includes rocks formerly included in the Bad Heart Formation.

Figure 20.21 shows a detailed cross section extending from the foothills of British Columbia eastward into the plains of Alberta, which illustrates the unconformity. The cross section shows the dramatic thinning of the Marshybank Formation in a basinward direction, as a result of erosional truncation, and the eventual disappearance of sandstone (e.g., in 3-30-67-26W5). The Mistanusk Creek outcrop (Fig. 20.20) is the principal reference section for the Marshybank Formation and can be tied to the subsurface using a nearby well (Fig. 20.22). The Marshybank comprises upward-coarsening marine sequences that grade into a series of fine-grained, hummocky and swaley crossbedded and parallel-bedded shoreline sandstones, commonly overlain by coastal plain coals and fluvial units. The Marshybank paleogeography is characterized by northeast- to southwest-trending shorelines (Fig. 20.24).

Farther basinward, sandstones of the Bad Heart Formation abruptly appear east of a northwest-trending line. The top of the Marshybank Formation is marked by a thin veneer of chert pebbles; this surface can be traced through the subsurface to the base of the Bad Heart Formation (Fig. 20.21). Detailed allostratigraphic outcrop and subsurface correlation of the Muskiki and Marshybank formations are summarized in Figure 20.23. Plint and Norris (1991) presented a detailed facies and paleogeographic analysis of the Muskiki and Marshybank formations. The Marshybank is made up of a series of upward-coarsening, dominantly mudstone and siltstone parasequences, many of which are capped by a pebble bed or an erosive-based shoreface sandbody. Integration of outcrop paleocurrent data with log-determined facies distributions allows former shoreline trends to be determined (Fig. 20.24).

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 Wapiabi Formation in the Rocky Mountain Foothills and by the Niobrara Formation in the Manitoba Escarpment and southeastern Saskatchewan. The First White Speckled Shale occurs within the Labiche Formation in northeastern Alberta, in the Puskwaskau Formation in northwestern Alberta and in southern Alberta, within the Colorado Group.

On gamma-ray logs, the First White Speckled Shale interval is typically radioactive as a result of high uranium content associated with abundant kerogen. Discrete, radioactive spikes also occur as a result of bentonites deposited in the shales.

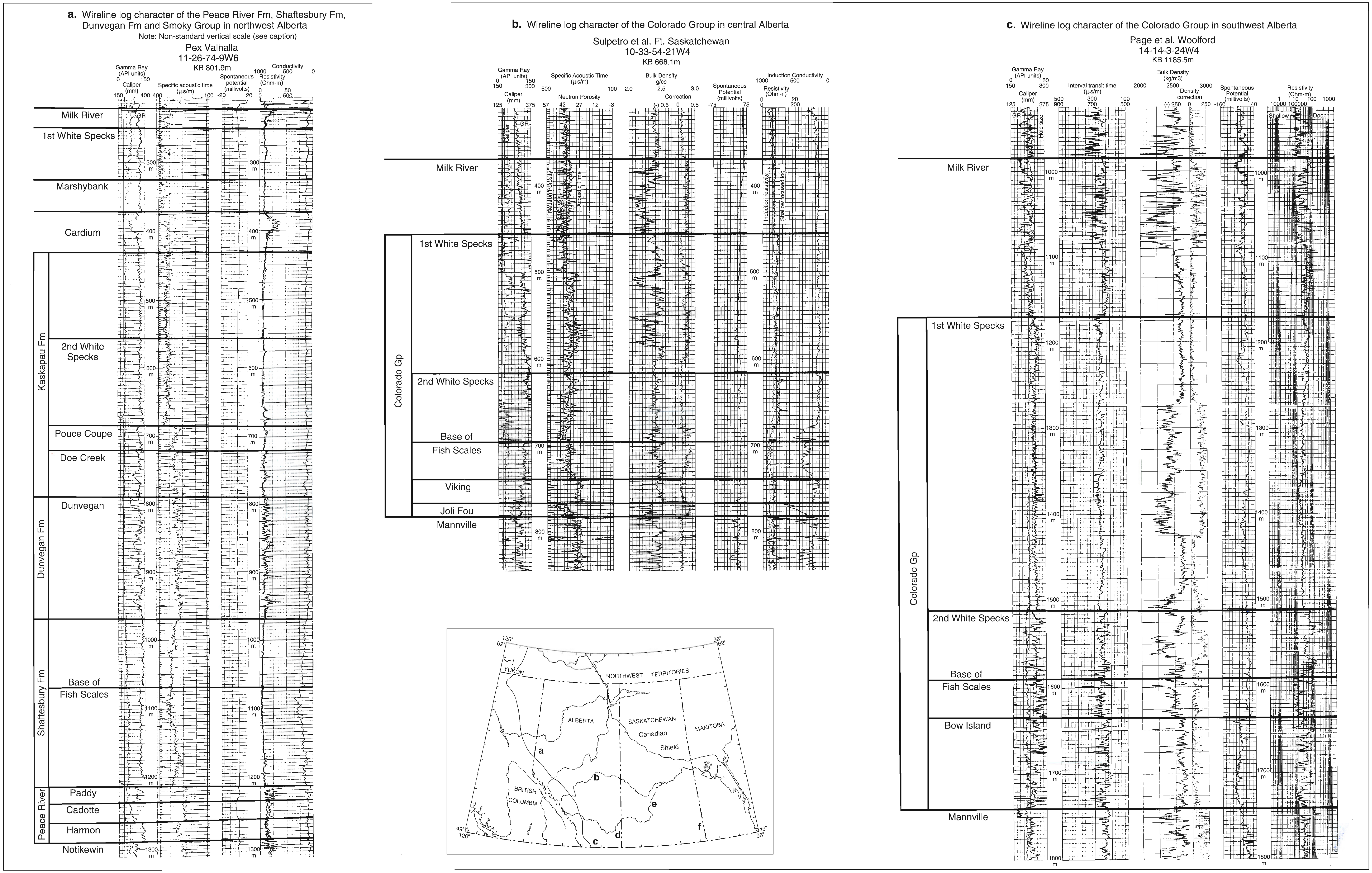

Figure 20.18 Reference well logs through the Colorado/Alberta Group (continued overleaf). Note that all logs are standard 1:3000 vertical scale, except **a.** Pex Valhalla (1:4000), which is condensed to fit the page.

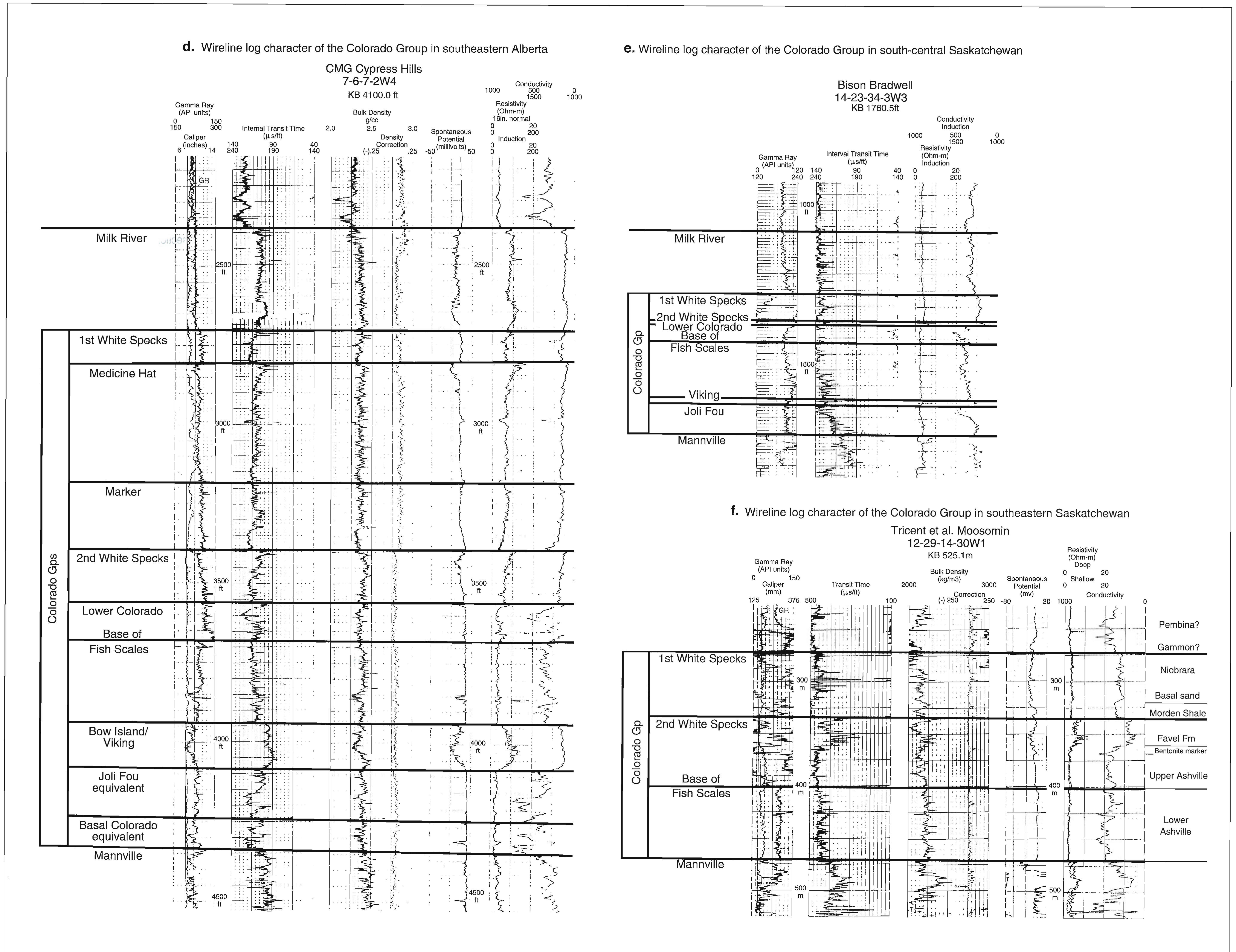

Figure 20.18 *Continued from previous page.*

The Niobrara Formation (latest Turonian to earliest Campanian in age) in Manitoba is up to 73 m thick and consists of a lower calcareous shale succession overlain by chalky shale. 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 Millwood 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 Millwood Member consists of 30 to 150 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. 20.18d) 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) 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 m^3 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 Braman, 1990). In the foothills, the equivalent rocks are named the Chungo Member of the Wapiabi Formation. The older term Chinook sandstone has been used in the central foothills (Gleddie, 1949). In the southwest corner of Alberta the Nomad cannot be recognized and the Chungo has been included within the overlying Belly River Group (Stott, 1963; Dawson et al., *this volume*,Chapter 24).

The Milk River Formation is thought to be disconformably overlain by marine shales of the Pakowki Formation (Braman 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 Wapiabi Formation overlie the Chungo Member (Sweet and Braman, 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 cliff-forming sandstone of the Virgelle Member. The Virgelle includes a lower unit interpreted as a storm-dominated shoreface sandstone (McCrory and Walker, 1986) and an upper unit, which has been interpreted as a tidal inlet complex (Cheel 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. 20.26) 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.

Chungo Member outcrops have been described by Rosenthal et al. (1984) and Rosenthal and Walker (1987). A modified correlation of these outcrops is shown in Figure 20.27. The Chungo is interpreted as comprising a set of offlapping, shingled, coarsening-upward units (i.e., parasequences) capped by a widespread erosion surface marked by chert pebbles. In southwestern Alberta, the Chungo shoreface deposits interfinger southwestward with Chungo nonmarine 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.

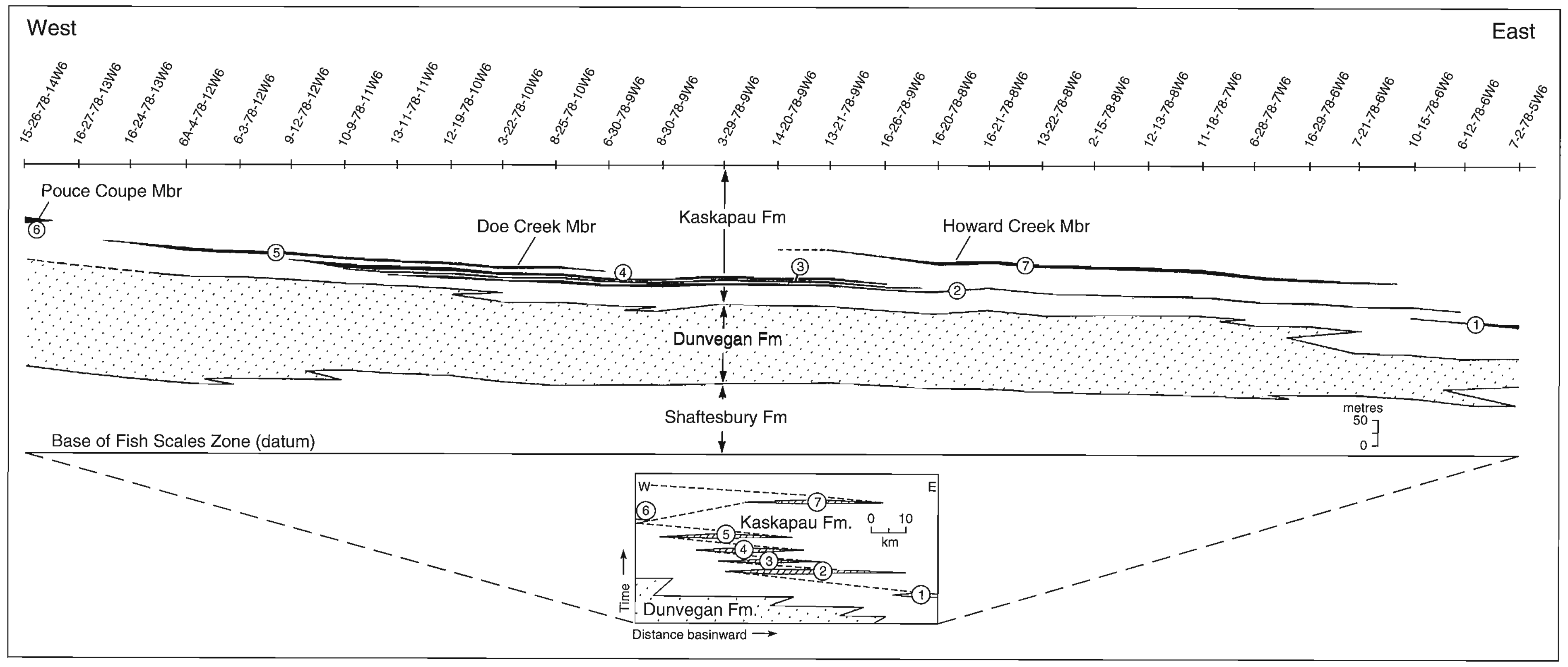

Figure 20.19 Cross section illustrating the retrogradational, backstepping pattern of linear sandstone bodies within the lower Kaskapau formation (modified from Wallace-Dudley and Leckie, 1993).

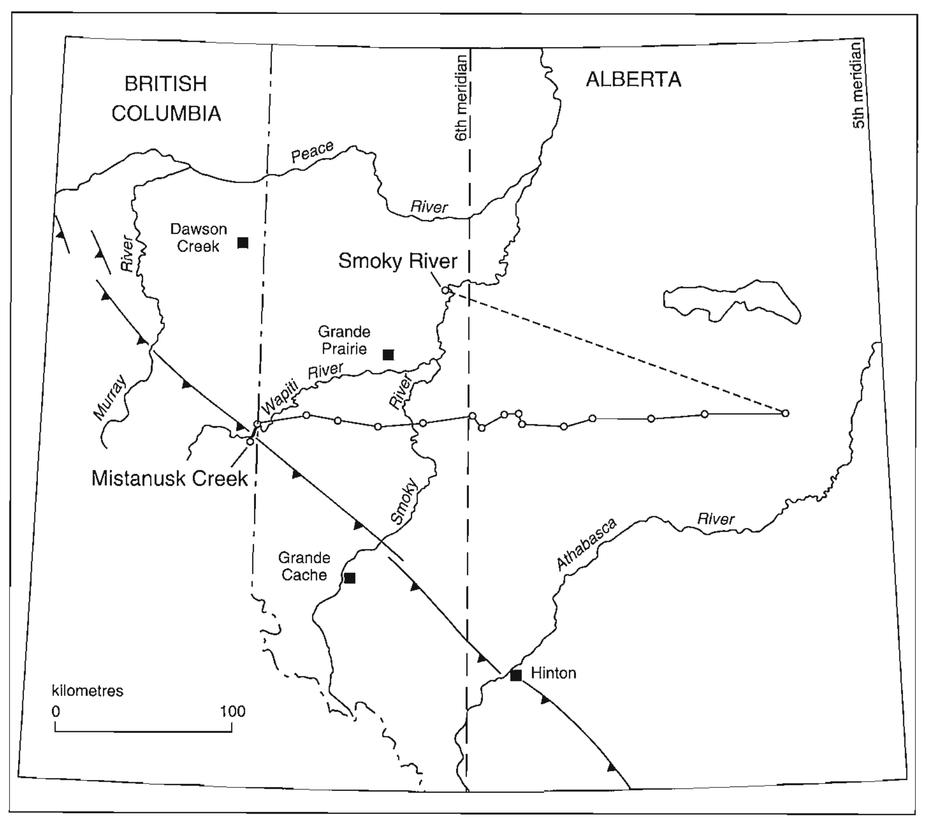

Figure 20.20 Map showing the location of the Marshybank reference section on Mistanusk Creek, and the type section of the Bad Heart exposed on the west bank of the Smoky River. The locations of wells used in Figure 20.21 are also shown.

Meijer Drees and Myhr (1981) demonstrated that, in the subsurface (Fig. 20.26), parasequences in the equivalent Milk River Formation similarly downlap 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 Germundsun, 1963; Sweet and Braman, 1989, 1990). The unconformity between the Milk River/Chungo and the overlying marine shales of the Nomad/Pakowki, documented by Sweet and Braman (1990), suggests a different relation at the upper boundary than that indicated by Rosenthal and Walker (1987). The contact between Chungo and Nomad 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. 20.5 - 20.10, and 20.18).

The duration and significance of the basal Pakowki unconformity apparently decreases northeastward, with sandy mudstones of the Alderson Member in Saskatchewan being late early to late Campanian in age (i.e., Pakowki equivalent, Braman, pers. comm.), rather than early Campanian. This is also supported by the offlapping 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 northwestern 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 southeastward to 80 m in northwestern 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 Cardium Formation (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 depocentres: in the southwest, isopach values increase to a maximum of 150 m, whereas in the northwest, thicknesses of 110 m are attained.

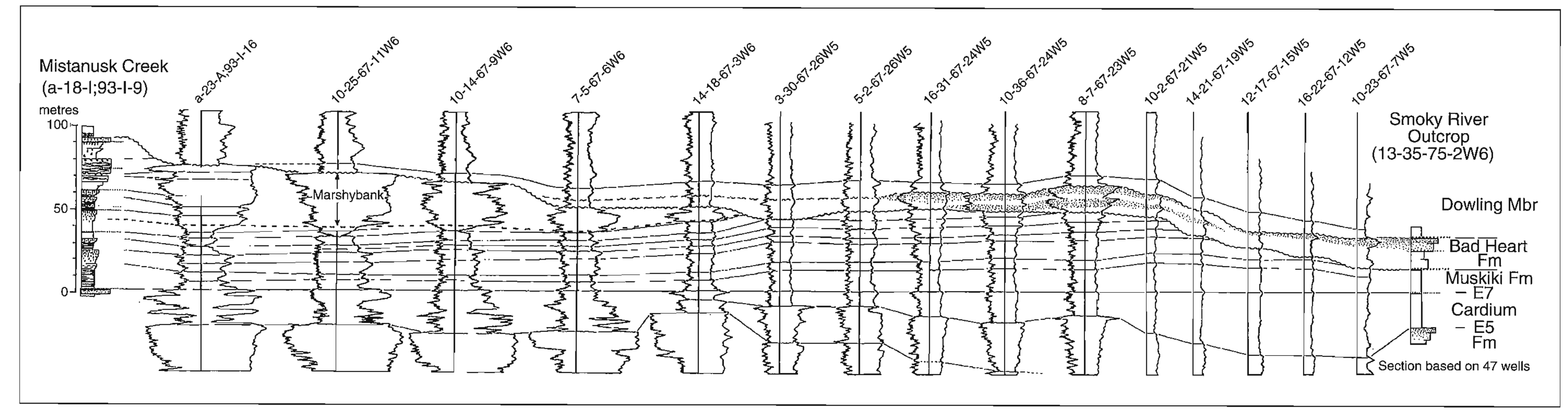

Figure 20.21 Cross section (located in Fig. 20.20) tracing the Marshybank and Muskiki formations eastward from Mistanusk Creek into the plains. Note the continuity and parallelism of markers in the Muskiki, and the abrupt resistivity log deflection that marks the base of the Marshybank Formation. The type section of the Bad Heart can be closely correlated with the most easterly well (after Plint et al., 1990).

Alternative isopach intervals, that include the entire Colorado Group of Alberta (Figs. 20.15, 20.16, 20.17), show regionally significant changes in sediment accumulation patterns for the period from the Albian to the Santonian, characterized by a shift in depositional strike from northeast-southwest to northwest-southeast.

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 toward the southwest. Sand and silt contents increase west-northwestward, 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 muscovite, 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 be up to 6 wt percent and 400 mgHC/gOC, 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 containing up to approximately 38 wt percent calcite and/or dolomite with abundant pyrite (3 to 6 percent) and organic matter (4 to 11 wt percent). The calcite is largely bioclastic in origin, comprising *Inoceramus*, planktonic foraminiferal and nannofossil remains. The "white specks" are fecal pellets composed of nannofossil fragments. The silicate 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 interspersed with major higher frequency 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 Spinney Hill and Basal Colorado 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 Stelck, 1975).

The coarser clastics of the Viking Formation are generally considered to be of shallow-marine origin and, in places, tidally influenced. 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 subsequently infilled with estuarine sediments during sea-level rise. One of the valleys now contains thick conglomerates of the Crystal Oil Field (Reinson et al., 1988). Southwest winds dispersed volcanic ash (bentonites) within the Joli Fou and Viking formations across southern Alberta (Amajor, 1985). In northern Alberta, a sea-level lowstand resulted in an incised valley system several hundred kilometres long, cut into the Middle Albian Cadotte Member, from the Rocky Mountain Foothills to the Interior Plains. This incised valley system is coeval with multiple paleosols in the Boulder Creek Formation in northern British Columbia (Leckie et al., 1989) and in the Mill Creek/Bow 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 volcanoes that produced the Upper Albian(?) Crowsnest Formation in southwest Alberta were surrounded by an inland flood plain and were probably of high relief. The magma chamber may have been a hydrous alkaline trachyte (Pearce, 1970) that resulted from crustal melting at about 25 to 35 km depth. Regional subsurface correlations show that the overlying Fish Scales Zone pinches out westward toward the Crowsnest Pass area (Fig. 20.7).

The shales of the uppermost Albian Shaftesbury Formation in northern Alberta and British Columbia represent sea-level rise and a major basinwide 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 may represent the joining of the two seas. The Fish Scales Zone is generally considered to contain a condensed section deposited during a peak transgression of the Cretaceous Interior Seaway. It also marks the Albian/Cenomanian boundary. In southern Alberta, the oldest record of the transgression is the Cenomanian Blackstone Formation where it onlaps the Blairmore Group.

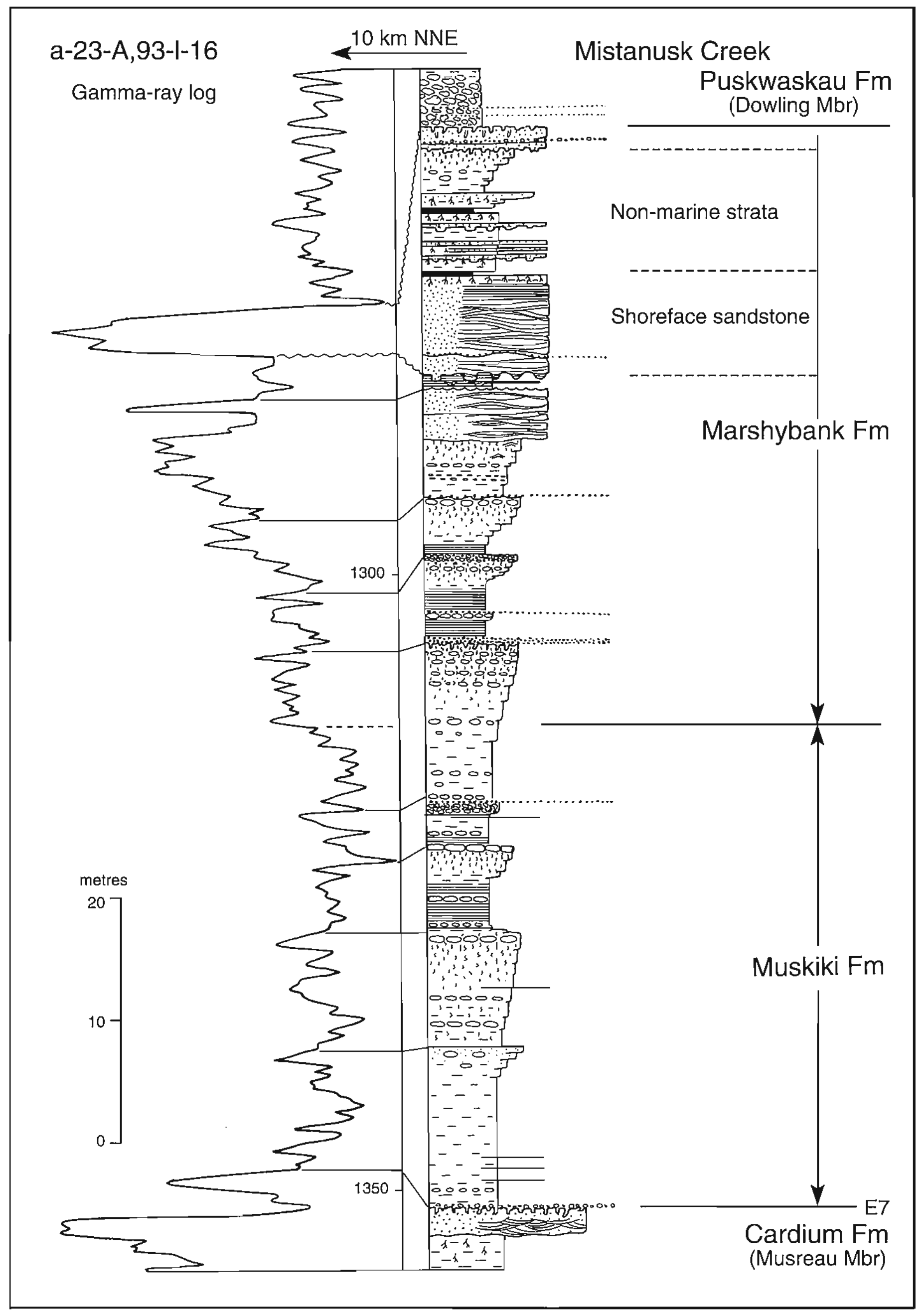

Figure 20.22 Measured section of the Muskiki and Marshybank formations on Mistanusk Creek, British Columbia, and correlation with the gamma-ray log from well a-23-A, 93-I-16 which lies 10 km to the north-northeast. Note the marked negative (i.e., sandier) deflection of the gamma-ray log that corresponds to the base of the Marshybank Formation (after Plint et al., 1990).

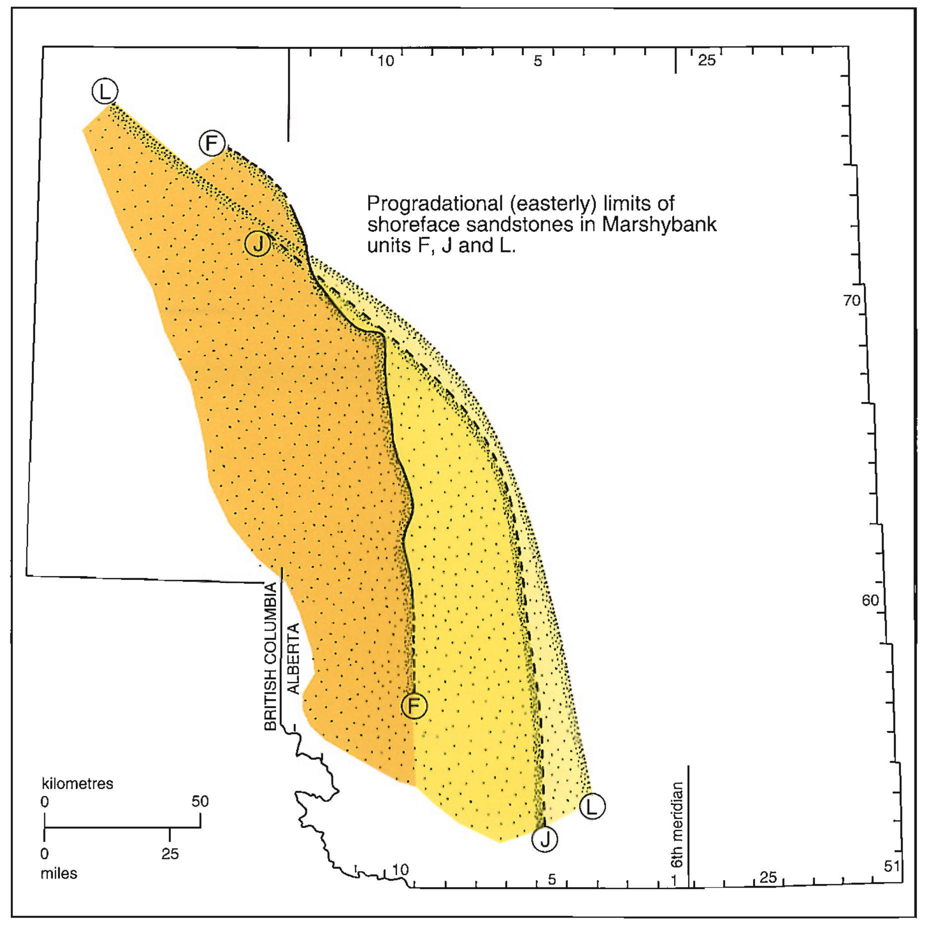

Figure 20.24 Map showing progradational limits for shoreface sandstones in Marshybank units F, J and L (see Fig. 20.23), based on data in Plint and Norris (1991).

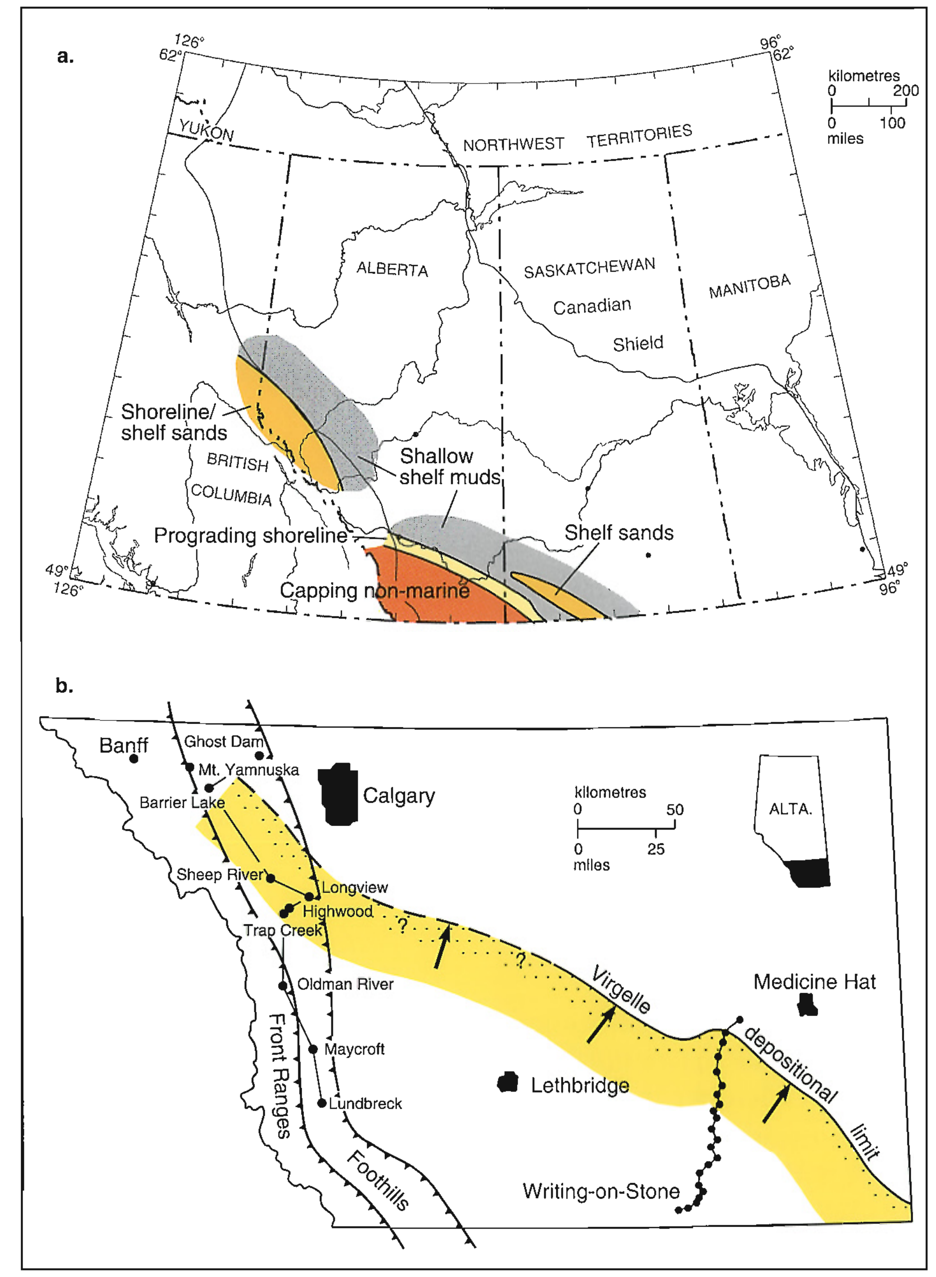

Figure 20.25 Location maps. **a.** Generalized paleogeography of prograding shorelines of the Chungo, Milk River, and Chinook. Shelf sandstones of the Alderson Member are probably younger than the Milk River shoreline sandstones farther south (Braman, pers. comm.). **b.** Northern limit of Milk River/Chungo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

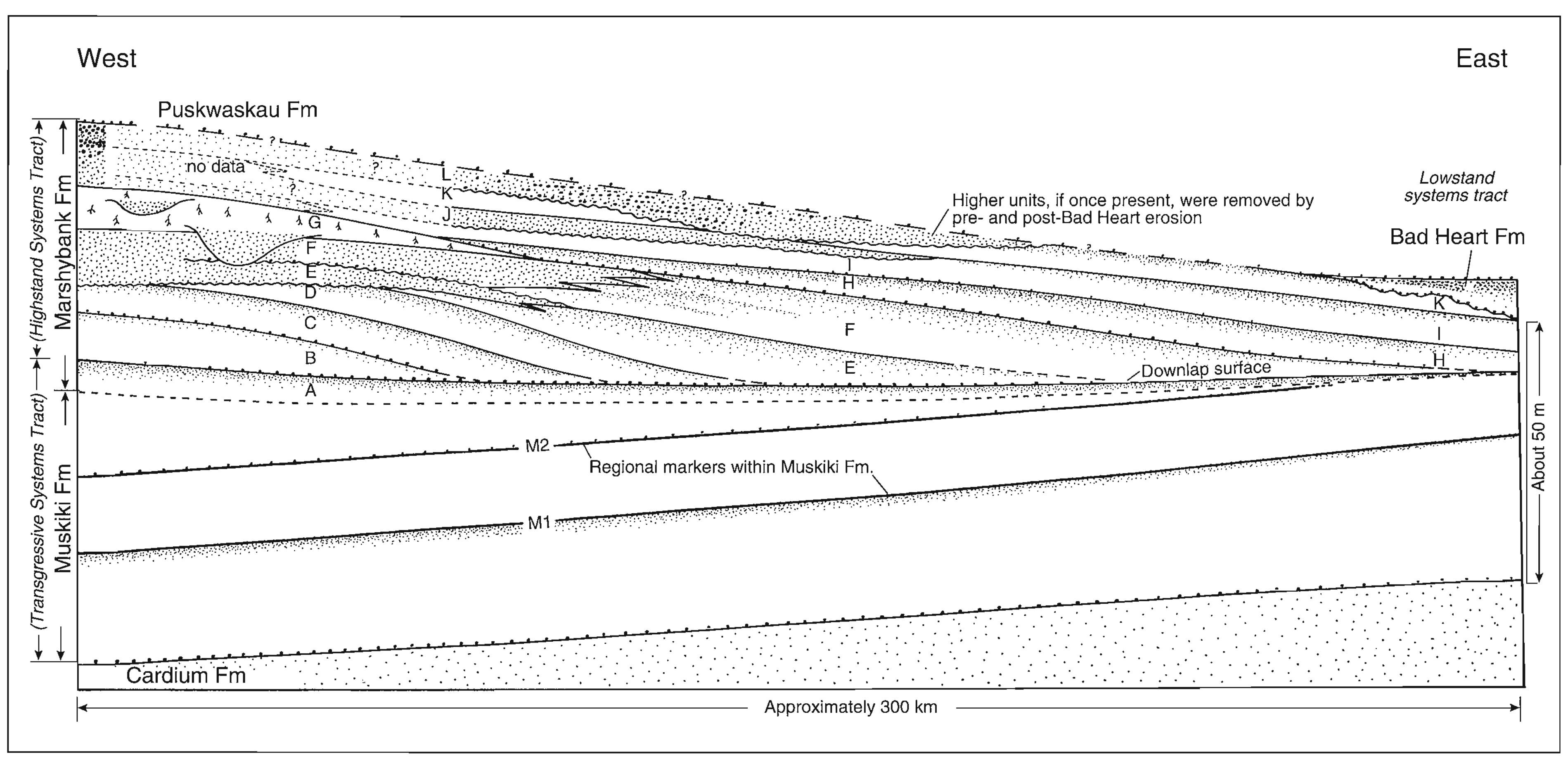

Figure 20.23 Summary stratal geometry of the Muskiki and Marshybank formations. In sequence stratigraphic terms, the Muskiki plus Marshybank unit A make up a transgressive systems tract, Marshybank units B through L make up a broadly progradational highstand systems tract that downlaps onto the top surface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

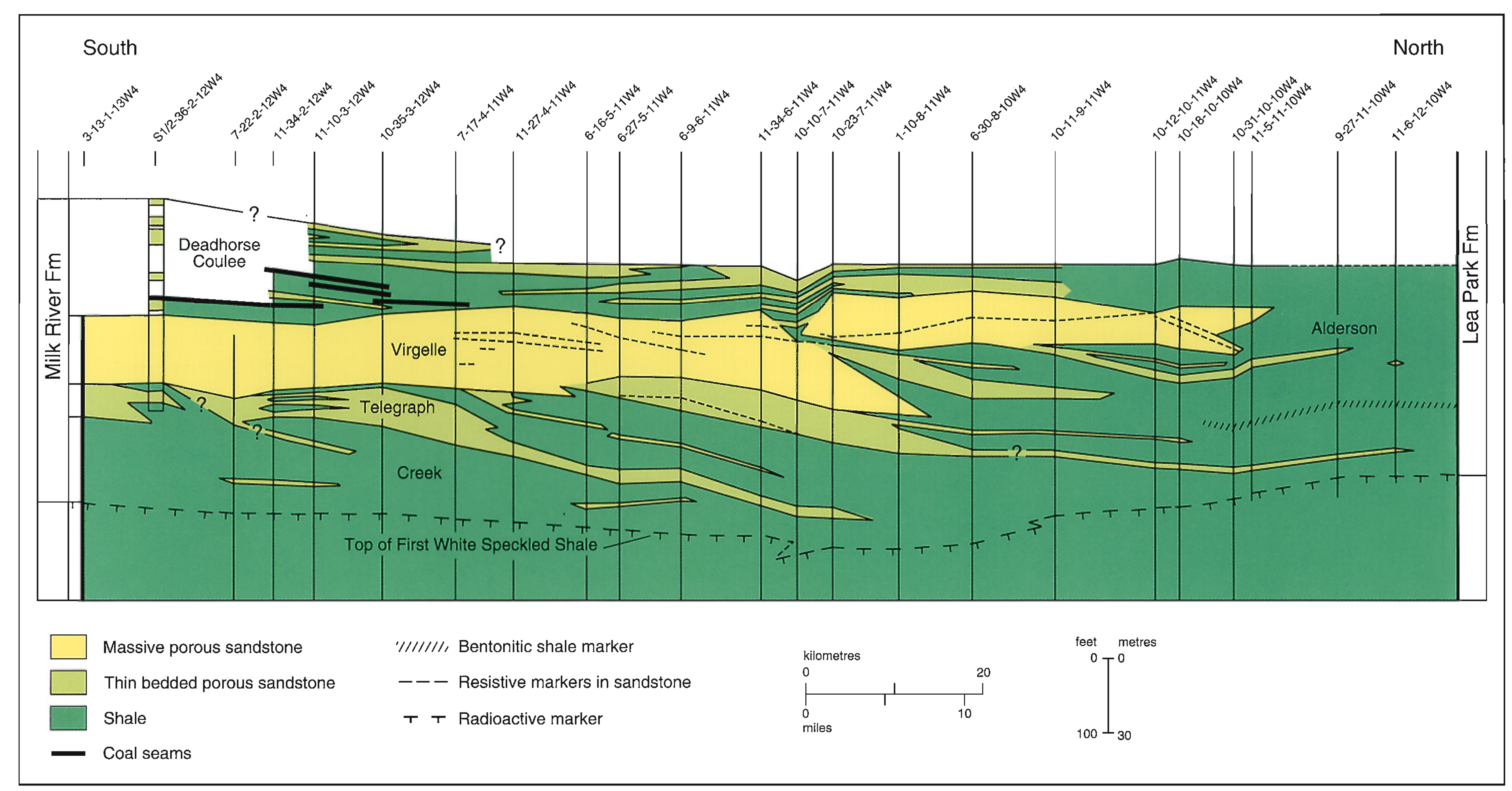

Figure 20.26 Cross section through Milk River based on well logs (after Meijer Drees and Myhr, 1981). The cross section emphasizes the downlapping nature of the Milk River onto the First White Speckled Shale and shows the interfingering nature of the Milk River with the Alderson Member. The Virgelle sandstone is diachronous, with indication of at least two offlapping shorefaces. Cross section located on Figure 20.25b.

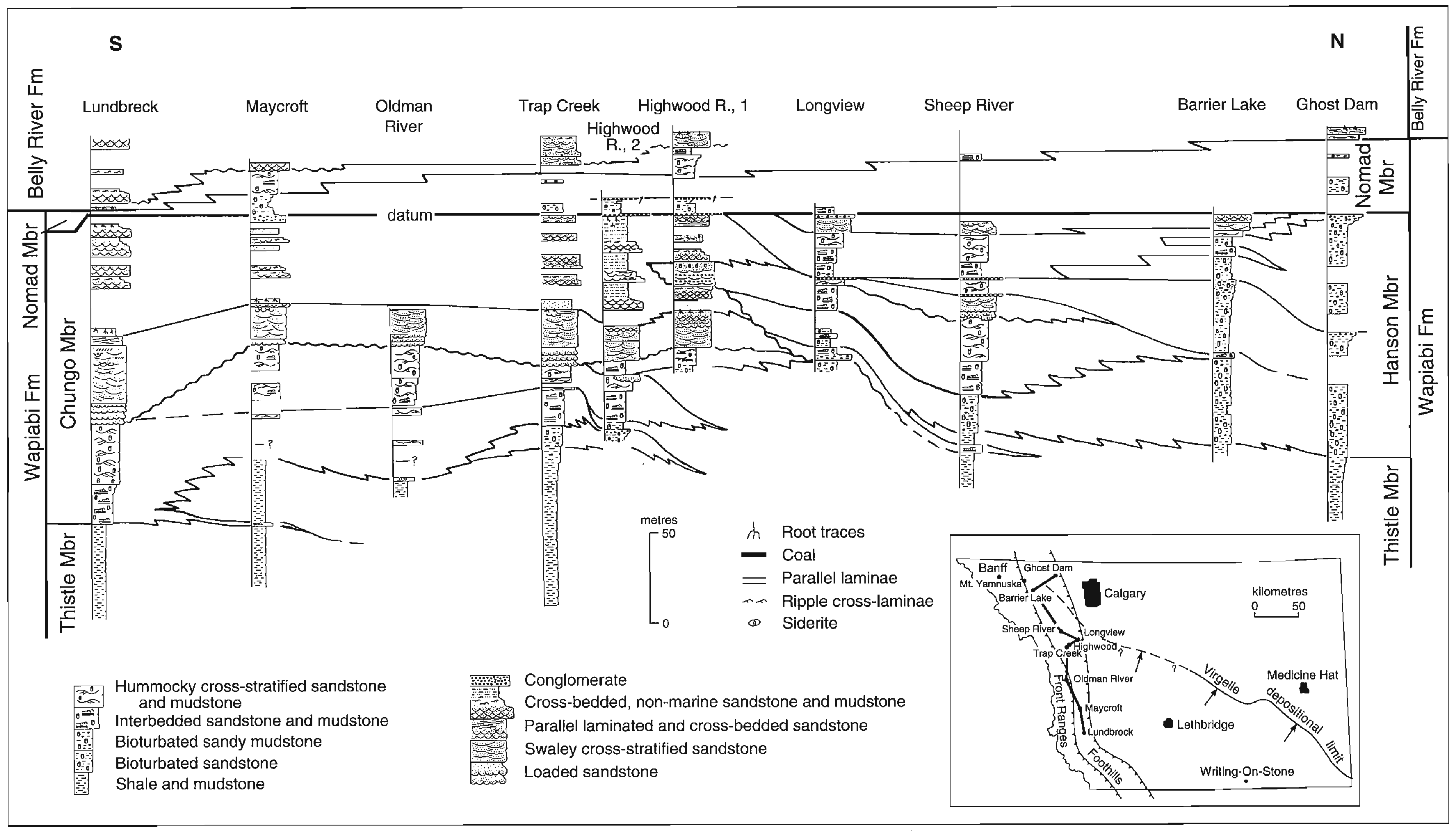

Figure 20.27 Cross section through Chungo Member (outcrop sections taken from Rosenthal and Walker, 1987). The Chungo consists of three offlapping shoreface sandstones that pass landward (south) into non-marine facies and interfinger north with the Hanson and Thistle members. Bioturbated sandy mudstones of the Hanson Member, at Ghost Dam, correlate with non-marine facies of the Chungo farther south. This is also supported by the biostratigraphy (Sweet and Braman, 1990). The base of the Nomad represents a transgressive unconformity, indicated by the chert-pebble horizon and shown by the biostratigraphic relations (Sweet and Braman, 1990). This is used as the datum.

The Dunvegan Formation represents a major progradational event and a provenance in the Yukon Territory and northern British Columbia. The Dunvegan Formation consists of numerous stacked depositional cycles that prograded as wave, fluvial and mixed-influence deltas (Bhattacharya and Walker, 1991). The progradation, though attributed to global lowering of sea level at 94 Ma, also 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 (Haq et al., 1987; Caldwell, 1984). It resulted in basin-wide deposition of the coccolithic Second White Speckled Shale (Vimy Member) within which the Cenomanian-Turonian boundary occurs (Stelck and Wall, 1954). The Second White Speckled Shale is represented by the argillaceous, highly calcareous Favel Formation in Manitoba (McNeil and Caldwell, 1981). The calcium carbonate content of this interval generally increases eastward 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 Cardium sedimentation is represented by the First White Speckled Shale. Planktonic faunas in this unit indicate a warm-temperate 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 biogenic 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 Virgelle Member (Milk River Formation) and the Chungo Member (Wapiabi Formation) which extend from southeastern Alberta and northern Montana to the central Alberta Foothills. The shoreline prograded as a sheet of wave-dominated sandstone up to 59 m thick; it extended along strike for at least 350 km. The Virgelle and Chungo members exposed in outcrop grade laterally northward into interbedded sandstone, siltstone and shale of the Alderson Member (of the Lea Park Formation) in the subsurface (Miejer Drees and Myhr, 1981; Rosenthal and Walker, 1987). In west-central Alberta, the shoreface sandstone of the Chinook Member is slightly younger than the Chungo Member, although Stott (1967) included the Chinook within the Chungo 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 (Cheel and Leckie, 1990). During early to early late Campanian time, sea level rose again and the marine shales of the Pakowki Member/Nomad Member were deposited.

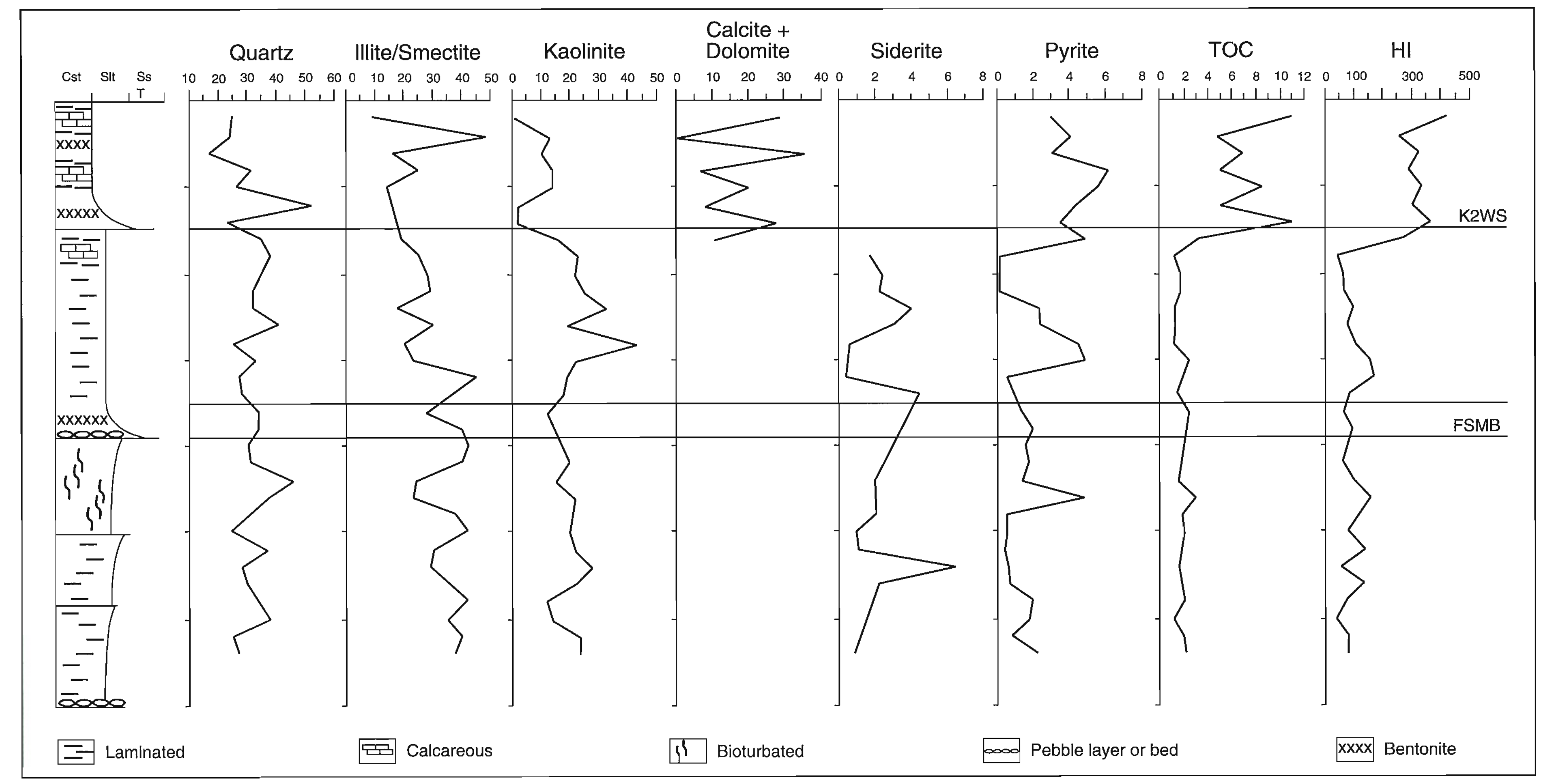

Figure 20.28 Generalized geochemical characteristics of the shales of the Colorado Group. K2WS refers to Second White Speckled Shale; FSMB refers to Fish Scales Zone; TOC is Total Organic Carbon content, based on Rock-Eval pyrolysis; HI is Hydrogen Index, based on Rock-Eval pyrolysis.

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