Chapter 6 – Proterozoic and Lower Cambrian Strata of the Western Canada Sedimentary Basin

Introduction

Proterozoic Lower Cambrian strata of the Western Canada Sedimentary Basin are exposed within the Canadian Cordillera (Fig. 6.1). All exposures have been transported northeastward from their original site of deposition by structures that formed during Late Jurassic to Eocene deformation of the eastern Canadian Cordillera. This chapter deals with three major unconformity-bounded successions: Middle Proterozoic (~1.5 – 1.2 Ga), Upper Proterozoic (~0.78 – 0.54 Ga) and Lower Cambrian (0.54 – 0.35 Ga). Each succession is dominated by clastic strata and is notable for great thicknesses: up to 11 km for the Middle Proterozoic, 9 km for the Upper Proterozoic, and 4 km for the Lower Cambrian. Upper Proterozoic and Lower Cambrian strata form part of a narrow, sinuous belt of correlative rocks that extends for over 6000 km, from Alaska to northern Mexico (Stewart, 1972). Underlying Middle Proterozoic strata lack this longitudinal continuity (Fig. 6.1). These successions record multiple extensional events in the early history of the western margin of the North American craton and the Western Canada Sedimentary Basin. In this chapter each succession (Middle Proterozoic, Upper Proterozoic, Lower Cambrian) is discussed separately.

Middle Proterozoic

Introduction

Two Middle Proterozoic assemblages are recognized – the Purcell (Bell) Supergroup in southeastern British Columbia and southwestern Alberta, and the Muskwa assemblage in northeastern British Columbia (Fig. 6.1). Both assemblages were deposited some time within an 800 million year interval bracketed by the age of the unconformably underlying Proterozoic crystalline basement (1.57–1.77 Ga) and the unconformably overlying Upper Proterozoic Windermere Supergroup (0.73–0.77 Ga). Each assemblage consists predominantly of fine-grained clastic and carbonate rocks that form successions several kilometres thick. The Purcell Supergroup hosts one giant and numerous smaller Pb-Zn (Ag) deposits. Many thick basic sills (Moyie sills) intrude the basal part of the supergroup. U-Pb zircon dating indicates that most of these were intruded between 1.45 and 1.33 Ga (Zartman et al., 1982; Hoy, 1989). Local lithostratigraphy and sedimentology are generally well known. However, the paucity of reliable radiometric dates and the absence of biostratigraphic control has hindered correlation within and between the assemblages and precluded accurate dating of each assemblage. Interpretation of geological, geochronological, and paleomagnetic data suggests that the Purcell and Muskwa successions occurred between 1.5 and 1.2 Ga (cf. McMechan and Price, 1982a), although not all workers agree. The isotopically undated Muskwa assemblage has been correlated with the Purcell (Bell, 1968) or Mackenzie Mountains (Bell, 1962, 1963; Eschbocher in Hoffman, 1986) supergroup.

In this chapter we focus on eastern and central exposures of the Purcell Supergroup. Information on northern and western assemblages, where the sediments are commonly intensely deformed, can be obtained from the references cited below.

Previous Work

Recent summaries of the lithologies, ages and tectonic settings of the Purcell and Muskwa assemblages are included in Rose et al. (1989) and Atkin and McMechan (in press). These include recent stratigraphic descriptions and assignments from western exposures of Purcell strata suggested by Reesor (1984, pers. comm.). Numerous workers have examined the Purcell Supergroup in the course of bedrock mapping and mineral exploration studies. Important regional stratigraphic and tectonic syntheses are presented in McMechan (1981) and Price (1964), Hoy (1982) and Morton et al. (1973) summarized the main mineral deposit types and occurrences. Details of the giant Sullivan Pb-Zn (Ag) mine are described in Hamilton et al. (1962). Bell (1966, 1968) is the only geologist to have published significant information on the Muskwa assemblage.

Geological Framework

Two different interpretations of the tectonic setting of the Bell-Purcell basin have been proposed. Canadian geologists have generally suggested a subsiding delta environment in a continental-margin setting (Walker, 1976; Reesor, 1982; Price, 1984) with the succession representing the initiation and formation of a passive margin (McMechan, 1981). Recently, increasing evidence for a west side to the Bell-Purcell Basin in the United States (e.g., Finch and Baldwin, 1984; Winston et al., 1984) has led to the reconsideration of an intracratonic basin setting (e.g., Winston et al., 1984), an idea initially proposed by Walcott (1910) and then abandoned. Chemical trends from Moyie Sills exposed in the southern Purcell Mountains are typical of basic volcanism in an incipient rift environment, or the early stages of continental rifting (Hoy, 1989).

The quartzite and carbonate strata forming the lower part of the Muskwa assemblage were derived from the northeast and deposited on a shallow-water shelf. The deeper-water strata that make up the upper part were transported to the northwest, possibly along the axes of linear troughs developed parallel to the margin of the craton (Bell, 1968).

Stratigraphic History

The thick, fine-grained clastic- and carbonate-dominated succession forming the Purcell Supergroup can be divided into four broad divisions (basal, lower, middle carbonate and upper) on the bases of distinctive rock types and readily correlatable sequences (Fig. 6.5; McMechan, 1981). Variations in thickness and facies are most pronounced in the basal division, with a thinner, platformal carbonate succession in the east and a thick, clastic, basinal succession in the west. Facies variations in the fine-grained clastics of the lower division reflect the embayed configuration of the basin margin and the transition between sources of detritus to the east and south. The middle carbonate division is a thin, platformal facies along the northeast limit of exposure and a thicker, more basinal facies elsewhere. The upper division represents a variety of subsaline and shallow-water environments (Fig. 6.5). The only widespread discontinuity recognized within the Purcell succession occurs within the upper division at the base of the Sheppard Formation. However, if Phanerzoic successions serve as an analogue for Middle Proterozoic strata, there surely must be many unrecognized discontinuities within the Purcell Supergroup. Important lithological changes in the upper part of the upper division occur near the eastern limit of exposure and rather than near the northeastern limit of exposure as in the underlying units. These changes (summarized in Atkin and McMechan, in press) may reflect the influence of source areas to the west (Root, 1987).

Figure 6.1 Distribution of Middle and Upper Proterozoic strata in the Western Canada Sedimentary Basin (after Hoffman, 1986).

Figure 6.2 Generalized stratigraphy of the Middle Proterozoic Muskwa assemblage. Based on descriptions by Bell (1966). Symbols as in Figure 6.4.
Regional Cross Section

The regional cross section (Fig. 6.4) clearly illustrates the great thickening of the Purcell Supergroup away from its eastern margin and its predominantly fine-grained clastic and carbonate composition. Rocks of the Purcell Supergroup are generally brightly colored.

The obvious change in the basin division from platformal carbonates near the basin margin to basin turbidites and argillites contrasts with the subtle lithological changes in overlying divisions. The section is oriented across the reticulate basin margin (see inset Fig. 6.4). The Sage Creek-Palace Atlantic Flathead section represents a more basinal locality than the adjacent sections and forms the key section for correlation of basin division platformal and basin fill facies (see McManus, 1987; Feniuk and Price, 1986, for details).

Two different lithostratigraphic correlations proposed for this important section are illustrated.

The great variation in the stratigraphic position of the overlying sub-Middle Cambrian or sub-Denman unconformity is largely a function of the northwestern uplift of the lower Paleozoic (Montana) high (Norton and Price, 1966), complicated by pre-Denman block faulting near its crest, which apparently reactivated fault structures formed during extension of the Purcell volcanics (McManus and Price, 1986b). The upper Purcell synsedimentary block faulting occurred between the Mount Baker and Steeples sections (Fig. 6.3).

Reference Logs

Petroleum exploration wells drilled in the 1980s provide excellent reference logs for the eastern facies and the western, basin turbidite facies of the Purcell Supergroup (Fig. 6.6). Thick mafic strata intruded into the turbidite succession are clearly recognized in the OSG Meyre well by their blocky, low gamma-ray response. The relatively high conductivities found in the unnamed and Tombstone Mountain formations in the Shell Grouse well may be due to the presence of hydrocarbon layers such as those that occur in equivalent strata exposed nearby.

Structure and Thickness

The present structure of the Purcell Supergroup reflects its distribution on thrust sheets of the Rocky Mountain Thrust and Fold Belt. In Canada, all sections have been transported over 100 km northward from their site of deposition. Thickness variations in the lower and also the middle carbonate division of the Purcell outline a reticulate basin margin with a prominent northeast-trending re-entrant near the northwest corner of the basin (Fig. 6.5b). The almost 200 km east-west jog in the shape of the basin margin is mirrored by the northeast limit of Purcell exposure, suggesting that the thrust faults carrying Purcell strata upstep toward the margin of the basin. The pattern of thickness variation for the upper division (excluding the Roswell Formation) is different from that of the underlying divisions. These changes suggest a reorganization of the basin. This reorganization was associated with extension of volcanic rocks and the development of a fault-controlled sub-basin (Fig. 6.7; McManus, 1981).

The northeast-trending re-entrant, apparent on all topographic maps, is a graben structure that formed during Middle Proterozoic extension (McManus, 1981). It appears to be the western extension of a buried, graben-like structure in the basement of southern Alberta (Kananwisch et al., 1969).

Upper Proterozoic

Introduction

Within the Upper Proterozoic Windermere Supergroup it is not yet possible to correlate individual beds or events on a basin-wide scale, with the possible exception of the 'marker', which is discussed below. In the southern Canadian Cordillera, strata of the Windermere Supergroup unconformably overlie the Middle Proterozoic Purcell Supergroup in the central Purcell and southern Selkirk mountains, and nonconformably overlie the Deserters Group (782 ± 8, 7 Ma; Evanchik et al., 1984) in the Deserters Range, and Malton and associated gneisses south of Valemont, B.C. (Murphy, 1990); elsewhere the base of the Upper Proterozoic is not exposed (Fig. 6.8). The Windermere Supergroup consists predominantly of coarse-grained, feldspathic conglomerate and pebbly sandstone ('grits') and pelitic shale, and lesser carbonates. These strata were deposited some time between 1.2 to 230 million year interval bracketed by the age of the basal Windermere Supergroup (770 Ma; Evanchik et al., 1984; Devlin et al., 1988) and the overlying Lower Cambrian Gog Formation (540 Ma).

Isolated studies have established the local stratigraphy and lithostratigraphic correlations; however, the lack of biostratigraphic markers and the paucity of radiometric age determinations have hampered detailed time-stratigraphic correlations within and between the various assemblages. In this chapter we focus on exposures of the Windermere Supergroup south of 57°N.

Previous Work

Detailed structural, stratigraphic and sedimentological studies have been conducted locally in areas of the southern Canadian Cordillera. Recent preliminary syntheses of the lithologies, ages and tectonic setting of the Windermere Supergroup are given in Ross et al. (1989), Aitken (1990), Aitken and McDonough (1990), and Campbell and Gabrielse (in press). Bond and Kominiak (1984) discuss a possible tectonic evolution and subsidence history for the Upper Proterozoic and the overlying lower Paleozoic succession of the Canadian Cordillera.

Geological Framework

In the southern Canadian Cordillera, most of the Windermere Supergroup comprises deep-water (below wave base) mass-flow deposits emplaced as part of a rift-margin and/or continental margin succession. Locally, glaciation strongly influenced sedimentary facies and sequence patterns at the base of the succession in the south and in the middle part of the Windermere succession between 54° and 57°N. By contrast, concurrent with glaciation in the adjacent highlands, equivalent strata in eastern and central Idaho were deposited in deep to shallow water in an active volcanic rift-basin (Link, 1983; Elston et al., in press).

The top of the Windermere generally is eroded. In parts of the southern Rocky Mountains, 2 to 3 km of strata are identified beneath the sub-Lower Cambrian unconformity (Aitken, 1989; Simony and Aitken, 1990). Deposition was locally affected by small- and large-scale structures. Large-scale structures are called 'Windermere High', a northwest-trending offshore high that developed south of 57°N, and which extended southeastward to the more prominent Montana high.

There are many problems concerning the geological framework of the Windermere Supergroup (see Simony and Aitken, 1990). The issues include: 1) the involvement of rifting; 2) structural controls on sedimentation; 3) intra-Windermere correlation; 4) the replacement of thin and extensive deep-water, coarse-grained feldspathic 'grits' with little or no apparent facies changes; 5) the source of carbonate detritus (the "vesicated" carbonate platforms); and 6) the role of glaciation both in sedimentation and as a possible control on eustatic sea-level variation. The coarser grained lower parts of the Windermere Supergroup have been interpreted as having been deposited either within a single rift basin or in a complex of rift basins (e.g., Stewart, 1979). This was followed by development of a passive margin, resulting in the deposition of the upper, finer grained, more uniform continental succession (Gabrielse, 1972). The timing of the rifting events and their relation to the subsequent breakup and drift of the margins of the proto-Pacific ocean remain controversial (Thompson et al., 1987; Devlin et al., 1988; Gabrielse, 1972; Stewart, 1979; others).

Stratigraphic Nomenclature

A number of different stratigraphic names have been applied to the various units within the Windermere Supergroup (Fig. 6.8). Some of these formations most likely are time-correlative but the exact details of the correlations are uncertain and controversial.

A distinctive sedimentary unit, informally known as 'the marker', occurs within the main coarse-grained grits of the Windermere. This marker is characterized by a pelitic succession, dominated by rhythmic marble-siltite pelite and siltite pelite in the Cariboo Mountains (Ross and Murphy, 1988) and is interpreted as correlating with distal turbidites and hemipelagites in the Bain Brook division of the Windermere Supergroup (Kubik, 1989) and with shallow-water resedimented carbonates and pelites in the Old Fort Point Formation, near Jasper (Dechoore, 1990). The 'marker' and its equivalents have been interpreted as relative sea-level highstand deposits and have been tentatively correlated on a basin-wide scale for over 35,000 km² (Ross and Murphy, 1988). In some sections, such as at Cushing Creek (Fig. 6.9d), there is more than one carbonate and pelite horizon similar to the 'marker', suggesting that the Old Fort Point and other limestone breccias correlated with the 'marker' may not be unique. The use of the 'marker' as a basin-wide time-correlation tool remains equivocal, but with the lack of any other suitable biostratigraphic or isochronous age data within the Windermere, the 'marker' and its equivalents are used as a time line in the correlation chart (Fig. 6.8) and the regional cross sections. Primitive trace and body fossils in the East Twin, Isaac and Byng formations may assist in correlating the upper part of the Windermere (see biostratigraphy).
Figure 6.4 Regional cross section for the Purcell Supergroup. Stratigraphic columns are based on section descriptions from the following sources: Moyie Lake - McEachen (1980); Huy (1984); Mount Baker, Steeples, Sand Creek - McEachen (1980); N.W. Galton Range - Laich (1958, 1960), Selkirk (1914); North Kootenay Pass - Price (1965); Ferner and Price (1963); Cape Creek-O., B.C. - Pett et al. (1963); Sage Creek-Pacific Atlas No. 1 - Price (1962, 1964); Ferner and Price (1963); Shell Grouse - unpublished Shell Canada Ltd. well logs; East Waterton - Douglas (1952), Huy (1984).
The succession may have originated as subaqueous debris flows at the base of tilted fault blocks, and that part of the succession was affected by syndepositional faulting (Root, 1987). Near-volcaniclastic debris (Irene, Fig. 6.8) locally overlie the Toby in the southern Selkirk Mountains (Ibb, 1998; Aitken, 1999).

The next succeeding units within the windermere, comprising much of the Horned Chief Creek, Miette and Kazza groups, consist predominantly of coarse-grained, feldspathic, pebbly sandstone along with greywacke shale, graphite, silcrete, and arkose. Locally, there are argillites and siltstone (Fig. 6.9d). The argillites locally contain thin interbeds of siltstone and fine-grained sandstone, many of which show Bouma sequences typical of deep-water fluviatile shales. Less commonly, the argillites have siltstone and fine-grained sandstone interbeds that may represent bottom current or contourite deposits (Ros, pers. comm. 1996; Karbi, pers. conn, 1996). Local stratigraphic sequences (i.e., the grays) occurred as submarine channels on small, tilted fault blocks (Arnott and Hein, 1986), or as larger submarine-channel complexes that flowed between fault blocks (McDonough, 1989). Locally, fine-grained strata (argilite and deep-water limestone, Cushing Creek Formation) are exposed beneath the main mottling units in central exposures (Fig. 6.9d).

The greys are most notable for their uniform character along depositional strike and lack of obvious, well-defined vertical facies patterns. One interpretation is that they represent relict subaqueous fan facies (Carey and Simms, 1985; Ross et al., 1988; among others). A problem with this interpretation is accounting for midfan facies occurring in apparently continuous zones for over 700 km along strike, and 400 km across strike (Simms and Aitken, 1988). Some of the channel fills show northwest trends parallel to the northwest-dipping faults. Lechwood (1989), and other channel fills have north to northeast transport directions perpendicular to the strike of the palaeoslope (Arnott and Hein, 1986). An alternative interpretation is that they are submarine channels on coalescing deep-water slope aprons along graben margins (cf. Hein, 1989; for example).

In the central Rocky Mountains, a thick succession of diamictite (Vreeland Formation, Fig. 6.9c) occurs in a stratigraphic interval equivalent to the lower part of the middle Miette McKee Formation. This diamictite includes a large proportion of pliocene and volcanioclastic clastics, derived from crystalline basement, set in an argillaceous matrix (Ross et al., 1989). Diamictites of the Vreeland Formation are overlain by siltstone, argilite, calcsiltstone and grey and rare gunit of the Paskus Formation in exposures near Paskus Pass, and by an unnamed succession of quartzite chloritic greywacke, quartzite (Bromhead et al., 1977; little; Devlin and Bond, 1988). Both units have been identified as Late Proterozoic or Early Cambrian in age by various authors. On Figures 6.8 and 6.9c, we refer to these units as the Leduc Formation, locally, feldspathic sandstones of the base of the Hamill and Gog groups. In the Cariboo Mountains, the top of the Upper Proterozoic conglomerate of the lower section of Miette McKee Formation (Fig. 6.8) is also exposed in the carboon overlain by the Yankie Creek Formation, the Little Cariboo Formation, and the McKee Formation (Fig. 6.8). This unit is probably younger than the upper Miette McKee Group and is disconformably overlain by the sandstone-dominated Yanks Peak Formation, which is equivalent to the basal Gog Group to the southeast.

Biontrollography

In the Mackenzie and Wernecke mountains, Northwest Territories, the Lower Cambrian Members of the Aivurose Proterozoic is divided into the Aivurose Fossil Member and the Lower Cambrian Members. The Aivurose Fossil Member contains intertidal shelf fossils and the Ediacaran megafossils throughout the topmost 2.5 km of section (Narbonne and Hofmann, 1987). The first trace fossils and Ediacaran megafossils occur in the deep-water units below a tilting, indicating significant colonization of the deep seafloor in the Late Precambrian and may relate to warming glaciation (Aitken, 1989a). Ediacaran-bearing limestones also occur near Japer (Byng Formation, Fig. 6.9d; Hofmann et al., 1987) and mudrocks forming assemblages of Ediacaran fossils have been reported from the upper Isis Formation in the Cariboo Mountains (Ferguson and Simons, 1991). Diversity and complexity of trace fossils in the Cariboo, however, are not widespread throughout the Precambrian boundary, commonly marked by the abrupt occurrence of complex two- and three-dimensional forms in the Cambrian (Narbonne et al., 1987). These changes, however, may be largely attributable to the Precambrian-Cambrian boundary.
Figure 6.8 Reference logs for the Purcell Supergroup. Lithology logs generalized from unpublished litho logs provided by Shell Canada Limited. Vertical scale (1:6000) is condensed from Atlas standard for reference logs (1:3000).
Stratigraphic Nomenclature
A number of formations are recognized within the Lower Cambrian succession of the southern Canadian Cordillera. Many of these formations are very uniform throughout the area, although in general, they become more shaly toward the west. Because of the fairly uniform nature of most of the units, correlations are more certain than in the underlying Windermere, and are summarized in Figure 6.8. Two sedimentary units are used as datums. These are the base of the archeocyathid-bearing Mural Formation, and the base of the Olenellus-bearing Peyto Member/Hota Formation (Figs. 6.8, 6.9). The Mural correlates regionally with the archeocyathid-bearing limestones of the Donald, Michigan/Badshot formations of the Dogtooth and Purcell Mountains, and with the Old Dominion Limestone of northwestern Washington (Fig. 6.9b,c).

Stratigraphic History and Regional Cross Sections
Initial deposits of the Lower Cambrian are feldspathic, poorly sorted, conglomeratic or pebbly sandstones. In the basal McNaughton, very thick successions of massive conglomerate were emplaced by fan deltas and possibly braided rivers in the central Rocky Mountains (Fig. 6.9a; Young, 1979). Further south, feldspathic conglomerates are generally absent. Devlin and Bond (1988) interpreted the Three Sisters Formation as an Early Cambrian fluvial succession, which may be equivalent to the basal McNaughton. However, we have followed the pre-Hamill Group interpretation of Little (1960) on our regional cross section (Fig. 6.9c). In the northern Selkirk Mountains, the lower sandstone within the Hamill Group (Fig. 6.9b) is unchannelled and uniform along strike, and has features indicating a shallow-marine origin (Devlin, 1989). The next unit in this area is a greenstone and graded sandstone unit, which is interpreted as representing a period of volcanism, creation of a deep-water paleoslope or fault scarp, and the emplacement of large volumes of submarine mass flows along the base-of-slope. Sedimentation is interpreted to have been strongly influenced by syndepositional faulting. With warming tectonic activity and filling of the fault basin, shallow-marine deposition returned and the upper sandstone unit resulted (Fig. 6.9a). Finally, as clastic supply dwindled, carbonate sedimentation associated with a possible transgression ensued, resulting in deposition of the Badshot limestone (Fig. 6.9b). Lateral equivalents to the upper sandstone in the northern Selkirks are very well exposed in the Kicking Horse Pass area, where they have been studied in detail (Hels, 1987; Hels et al., in prep.; Fig. 6.9b, c). Here, the tidally-dominated Fort Mountain Formation consists of quartzite and less common shale. This is succeeded by the shaly, shallow-marine Lake Louise Formation which, in turn, is overlain by shelf sandstone ridges of the St. Piran Formation. As with the clastic successions in the Selkirk Mountains, clastic supply diminished through time, with the capping limestone of the Peyto Formation completing the sequence.

To the northwest, in the central Rocky Mountains, sandstones of the lower McNaughton are shallow marine and strongly tidally influenced (Fig. 6.9a). In the Robertson Trough (Walker Creek and Bastille Creek, Fig. 6.9a) the middle and upper McNaughton formations are shallow-marine successions. Laterally equivalent strata to the west, over the McBride Arch, are subtidal (Yanks Peak Formation; Mt. Cochran and Dome Creek, Fig. 6.9c; Young, 1979). During deposition of the Midas Formation, sand supply was greatly diminished, and weak tidal currents moved material in the Robertson Trough and to the west. Finally, the Robertson Trough was infilled and an iron-rich, calcareous green shale, interpreted as a lateritic paleosol (Young, 1979), was deposited above the McNaughton, forming the basal unit of the Mural. Shallow-marine carbonates of the Mural Formation record a transgression. Overlying quartz sandstones of the Mabto Formation (Fig. 6.8) record two large-scale sandstone-shale successions deposited in shallow-marine to alluvial environments. The Mural Formation thins and becomes sandier to the south and east (Fig. 6.9c,d). Where the Mural is no longer recognized, the Mabto is not distinguished from underlying strata. Clastic supply diminished and limestones of the Hota Formation (Peyto Member) occur at the top of the group.

Biostratigraphy
The clastic successions within the Gog Group lack body fossils but contain a diverse trace fossil assemblage (McKerwood, 1988). Some of the common traces documented in the Kicking Horse Pass/Lake Louise area include: Bergnaturia, Craziana, Skolithos, Ditylum, Stenothecus, Asaphus, Ophiomorpha, Planulites, Orthocladus, Phycodes, Trichichnus and Zoophycus, plus others. Most of these forms and their abundance suggest that these traces belong to the Craziana ichnogenera. Concentrations of Skolithos (called "pipetone rock" locally) occur in coarser grained, and higher energy deposits (Fig. 6.9e). The presence of well developed Craziana and Asaphus within the Gog Group in the Lake Louise area indicates it is Albian in age (McKerwood, 1988). This is supported by the presence of the Olenellus index fossils in the Peyto Member, which also are Albian in age. Elsewhere, lower Gog Group strata contain more simple traces and a less diverse ichnospecies (Young, 1979).

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Crystoclastic Platform uplift. Devonian to Carboniferous strata exposed along the Rundle Thrust above Banff, Alberta. Viewed along strike from the northwest. The Cambrian to Jurassic Crystoclastic Platform succession of the Western Canada Sedimentary Basin is preserved in an undisturbed state throughout the plains where it is well known from in excess of 100,000 borehole penetrations. Thrust belt deformation allows for surface examination of virtually all of the same-aged strata, in the Rocky Mountains. Photograph by G.D. Mosop.