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EVOLUTION OF FLUVIAL LANDSCAPES IN THE WESTERN CANADA FORELAND BASIN: LATE JURASSIC TO THE MODERN

By

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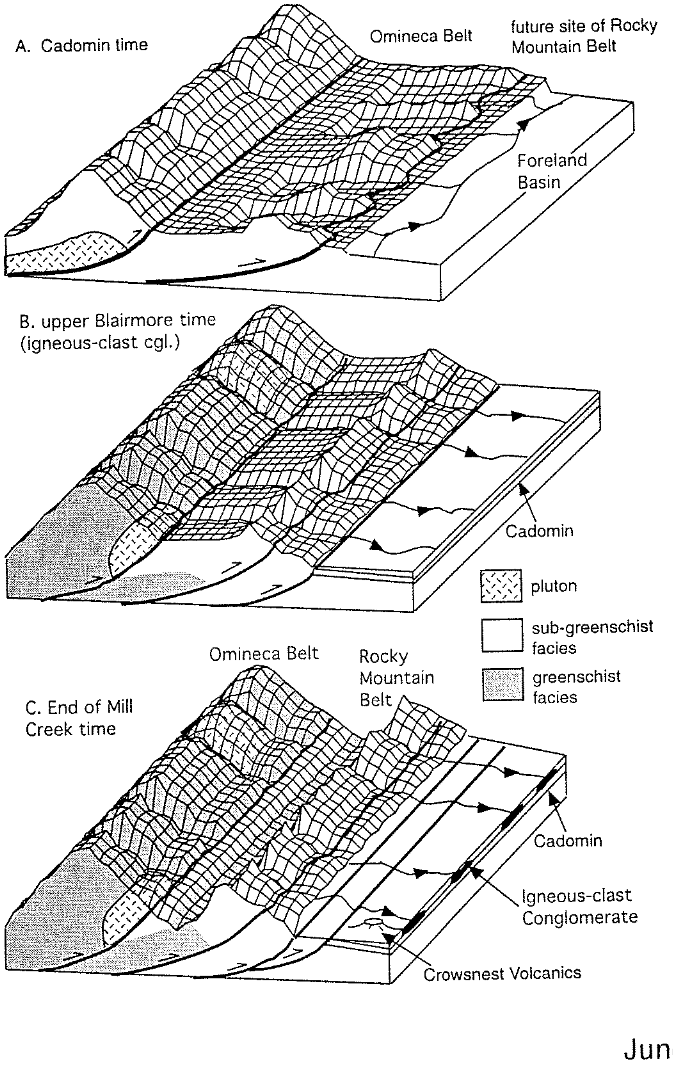

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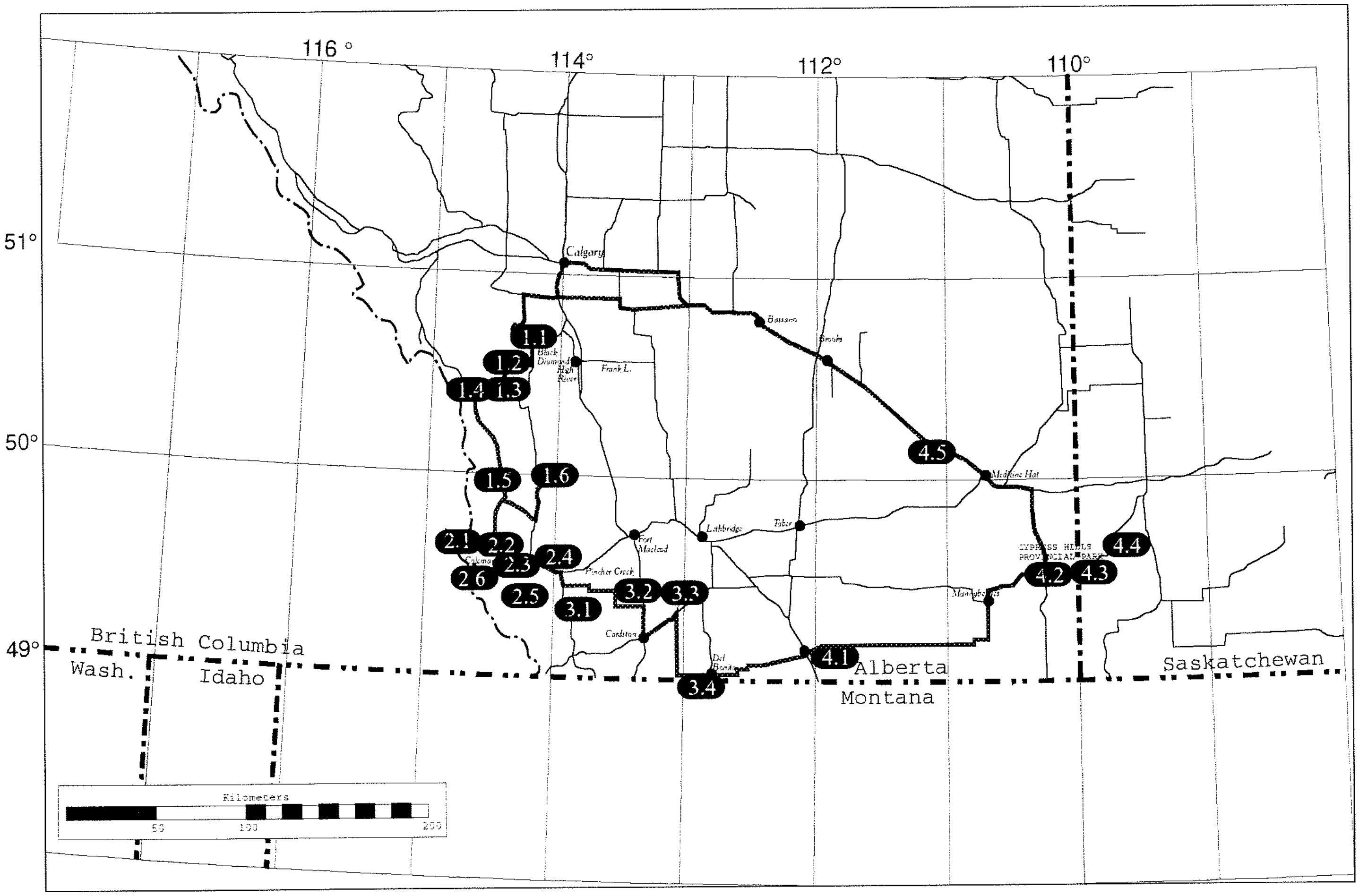


Figure 1. Field trip route.

INTRODUCTION

The purpose of this field trip (Figure 1a) is to provide an overview of variations in fluvial style through the evolution of the Western Canada Sedimentary Basin. The strata we will examine span approximately 140 my, from the Jurassic to the middle Tertiary (Figure 1b) and into the modern environment.

The format of the guidebook is to present an overview of some of the main tectonic, climatic and eustatic factors that controlled the fluvial styles in southern Alberta. This is followed by an individual site description for each outcrop. We hope these outcrops provide the basis for discussions that can enhance our understanding of the processes controlling the distribution of nonmarine facies within the Western Canada Sedimentary Basin in particular and foreland basins in general.

During the field trip we will present our evidence and observations for the following features related to the evolution of fluvial landscapes in Western Canada:

- types of river deposits
    - meandering
    - anastomosing
    - braided:
        - a) sheets
        - b) incised
- excellent exposures of facies geometries associated with anastomosed fluvial deposits
- several different types of paleosols and exposure surfaces:
    - caliche and calcrete
    - inceptisols, Vertisols, Alfisols(?)
    - organic soils (peats)
    - permanently frozen ground (permafrost)
    - silcretes
- significant and radical climate change:
    - warm and humid
    - arid to semi-arid with seasonal rainfall (savanna-like)
        - a) spring/summer wet
        - b) fall/winter wet

  - warm to cool temperate
  - periglacial

- two major continental drainage divides:
  - one extreme with profound relief
  - the other subtle with subdued relief

With these fluvial styles, we have observed certain features which can provide information on evolution of the nonmarine landscape. It is one of the reasons for running the field trip and hopefully generate discussion. Some of the features that we see include the following.

- braided sandstone and conglomerate sheets
  - overlie profound unconformity
  - regional in nature
  - basin parallel drainage
  - coincides with a compressional tectonic hiatus
  - commonly subsequently dissected as uplift continued
  - preserved as erosional remnants in parts of the basin
  - multicyclic
- braided channels
  - incised
  - no indication of significant unconformity
  - basin perpendicular
  - probably result of compressional tectonic activity in the hinterland
  - associated with shifting of drainage divides
- meandering rivers
  - abundant mud deposited in system
  - in some situations subsidence approximates sedimentation rate
- anastomosed rivers
  - low gradients
  - high suspended load

- rapid aggradation
- high subsidence rates
- basin perpendicular

A CAVEAT

Our ideas on fluvial styles and implications on basin evolution (the Greg and Dale view of the world) are in a state of flux and just starting to gel. One of the reasons for running this field trip are to present these ideas and generate discussion.

However, if you don't like some of our points of view, remember, it is only a guidebook and a field trip. Enjoy the view.

ACKNOWLEDGMENTS

This field trip is the result of discussions and work with many people over the years. Some of these individuals include Jan Bednarski, Doug Cant, Rick Cheel, David Craw, Bob Dott, Rudy Klassen, Lee Krystinik, Paul McCarthy, Andrew Miall, Lorne Rosenthal, Derald Smith and Art Sweet.

WHY STUDY FLUVIAL DEPOSITS OF THE WESTERN CANADA FORELAND BASIN?

Rust and Koster (1984) depicted a braidplain as an environment in which coarse-grained sediment was shed off an upland, perpendicular to the trend of the source area. Their interpretation was based, in part, on ancient fluvial examples from western Canada. One of their ancient analogs for the braidplain concept of the model was based on published apparent paleocurrents from the Cadomin Formation. In contrast, Leckie and Cheel (1997) show that sediment dispersal for the Cadomin was largely axial, and not directly out onto the craton. Thus, it appears that a foreland trough acted as a conduit for sediment transport throughout the period of initial uplift by thrusting as well as the period of uplift due to post-orogenic erosion. The "braidplain" model of Rust and Koster (1984) was also partially based on the Cypress Hills Formation. However, Leckie and Cheel (1989) demonstrated that those coarse-grained deposits were also not simply shed off the upland but were transported out onto the craton through a series of pulses related to thrusting, relaxation, and igneous intrusion. Consequently, alternative interpretations for the two ancient analogs used by Rust and Koster (1984) suggest that the "braidplain" concept as initially proposed should be treated with some caution.

Elsewhere, the limited, previously published descriptions of the Cadomin have also played a role in developing conceptual ideas on the nature of sedimentation in foreland basins (e.g., Heller and Paola, 1989).

FLUVIAL STYLES

We divide nonmarine strata into the three basic fluvial channel styles (Figure 2):

- braided
    - braided conglomerate/sheet overlying a major unconformity
    - braided incised conglomerate
- meandering

- anastomosing

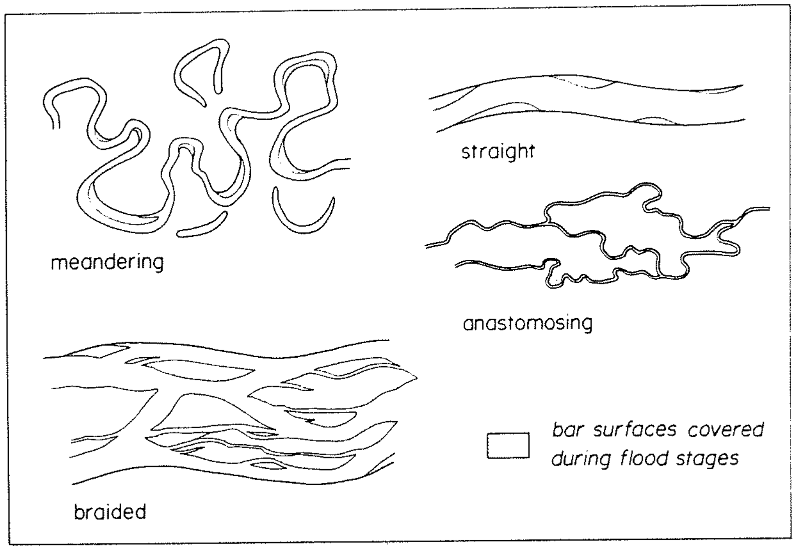


Figure 2. The main fluvial styles (from Miall, 1977).

Braided

Braided rivers are high energy, anabranching bedload systems in which the banks and channel floor have more or less equal potential for erosion (Nanson and Croke, 1992). Valley gradients are generally high and discharges commonly vary markedly during the year. The wide range in stream power and available sediment size creates a broad spectrum of channel morphologies and deposits (Miall, 1996).

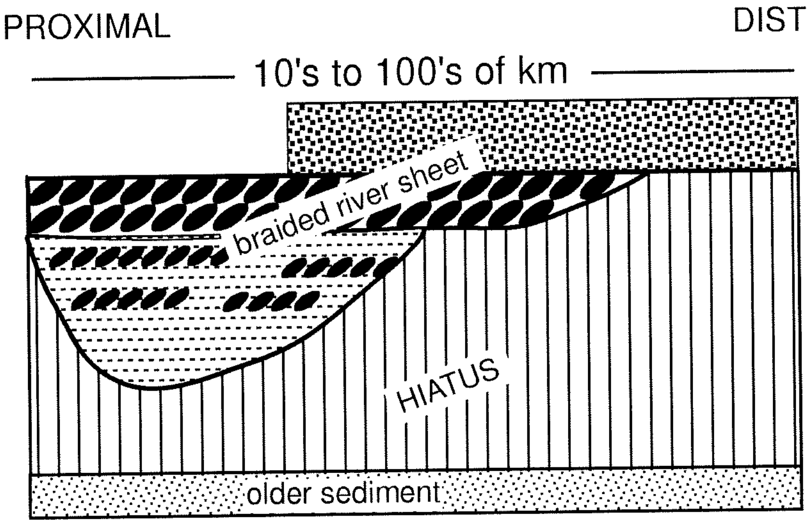
Two markedly different styles of braided-river deposits are recognized on this field trip (Figure 3). The first variant is the basin-wide sheets of conglomerate and sandstone which overlie a significant unconformity (Figure 3a). The oldest of these was deposited during the earliest Cretaceous (Cadomin Formation) and the second, during the Tertiary (Cypress Hills Formation). The formation of the basal unconformity and deposition of the overlying braided river deposits resulted from a lull in tectonic compression during the Early Cretaceous and later in the early Tertiary. The result was regional uplift and basinwide beveling. This in turn is followed by an episode of major erosion, leaving erosional remnants of the sheet.

The second style of braided river deposit is those deposited within confined, incised valleys (Figure 3b). An example is represented by middle Cretaceous igneous-clast conglomerates within the Blairmore Group. Although the channels are erosionally based, we have not recognized an associated significant unconformity.

Meandering

Meandering fluvial systems are characterized by a single thread channel carrying a mixed sediment load and intermediate valley gradients. These systems can carry a wide range of grain sizes depending on the source material and the slope. The increased energy results in a

A. BRAIDED SHEET OVERLYING MAJOR UNCONFORMITY



B. BRAIDED INCISED CHANNELS

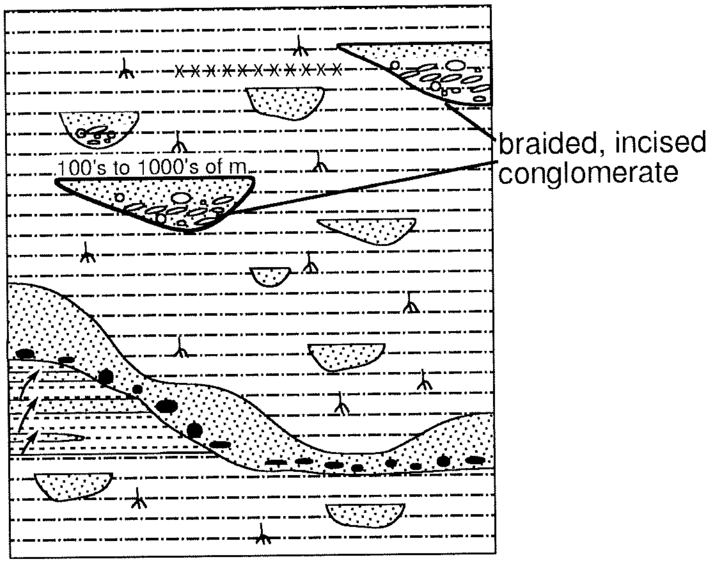


Figure 3. Two styles of braided river systems in the Western Canadian Foreland Basin. A) Braided river sheet deposits overlying a major unconformity. B) Braided incised channels.

meandering thalweg that produces the characteristic point bar and cut bank couplets. Plan views of meandering systems show that the floodplain is commonly marked by scroll bars and oxbow lakes. Cross-sectional views of such systems show that natural levees are small and mainly restricted to the cut bank side of the point bar. Flow in the channels is generally common year round although bankfull flows generally have a 1.5 year recurrence interval.

Meandering fluvial deposits are composed of sandstone sheets that span the width of the meander belt. Preservation of floodplain deposits occurs when subsidence rates are high enough to prevent reworking of the deposits during lateral migration of the channel. The assignation of a meandering fluvial origin to all sandstones that fine upward and contain evidence of lateral accretion results in an overestimation of these deposits in the stratigraphic record (Miall, 1996). We will see records of meandering systems in the Blairmore and basal Belly River Groups.

Anastomosing

An anastomosed fluvial system is one of a continuum of anabranching channel morphologies that form in response to low gradients, high suspended loads, and seasonal water flow (Smith and Smith, 1981; Nadon, 1994). There is considerable debate regarding the genesis of these systems and their products in the stratigraphic record.

In plan view, anastomosed systems consist of interconnected channels, which vary from relatively straight to highly sinuous, separated by floodplains that contain lakes, ponds, and crevasse splay deposits. Cross-sections show that channels are flanked by levees that have relief of up to 1.5 m and are separated from adjacent channels by topographic lows. During periods of low flow there is commonly only one or two channels that carry running water. The remainder may contain ponds or sloughs or dry up completely. High flow inundates the entire floodplain.

Modern anastomosed systems are characterized by rapid vertical aggradation over short time periods (several thousand years) (Smith and Smith, 1981, Smith, 1976; 1986). This rapid aggradation, which is commonly attributed to a base level rise, results in numerous channel avulsions through levee breaks. The result is numerous, short-lived channels that are separated by floodplain sediments.

The stratigraphic expression of anastomosed fluvial systems is one of highly lenticular sandstone channels separated by floodplain mudstones and sandstones. The sandstones are commonly thin, rippled, and may be heavily rooted or bioturbated. Mudstones rarely preserved evidence of thin laminations produced by lacustrine deposition. Instead the mudstones generally record a wide range of intensity of paleosol development formed during the periods of subaerial exposure during low flow.

On this field trip the upper Belly River Group, the St. Mary River Formation and much of the Willow Creek Formation provide examples of these mud-dominated anastomosed fluvial deposits.

CONTROLS ON FLUVIAL STYLE

Fluvial sedimentation is a complex function of interrelated variables that are the result of autocyclic (*e.g.*, levee crevasse and avulsion) and allocyclic controls (*e.g.*, changes in climate, source area, and base level) that cannot always be easily differentiated from each other. In addition, the response of rivers, like most geomorphic systems, to any perturbation is strongly nonlinear (Phillips, 1992). Fortunately, despite the wide range in possible variations of input only two broad categories of fluvial styles recur in modern settings; single thread and anabranching (Nanson and Knighton, 1996). The anabranching systems, in turn, form a spectrum of styles with two end-members, braided and anastomosing. The lateral and temporal distribution of these styles, all of which we can recognize in the stratigraphic record, combined with an understanding of how various controls may affect these systems, provides an opportunity to more accurately reconstruct evolution of the landscape, both in the source area and depocentre. Models have illustrated how variations in subsidence rate (Beaumont, 1981, Cant and Stockmal, 1993, Stockmal *et al.*, 1992), sedimentation rate (a proxy for climate) (Flemmings and Jordan, 1989; Beaumont *et al.*, 1993), and rate of sea level rise or fall (e.g., Jervey, 1992) can each produce similar cyclicity in fluvial deposits over a range of scales. We therefore present below a brief overview of the tectonic, climatic, and eustatic variations that affected the southern Alberta region since the middle Jurassic.

THE RESPONSE OF FLUVIAL SYSTEMS IN FORELAND BASINS

The three main controls on basin sedimentation — tectonism, eustasy, and climate — have been invoked to explain lateral and vertical patterns of sediment accumulation in foreland basins. Although many authors choose between tectonics and eustatics and hold climate constant, they generally include the caveat that climate may play a role.

Tectonic forces have a three-fold impact on nonmarine foreland basin sedimentation. First, the loading of a plate by allocthonous terranes and associated thrust sheets forms the foreland basin (Beaumont, 1981). Variations in crustal parameters, pre-existing structural patterns within the crust, and in the deforming wedge all contribute to the size and shape of the subsequent basin and therefore the fluvial patterns within them (Miall, 1996). Second, the isostatic uplift resulting form the stacking of thrust sheets creates a source area and the slope necessary for sediment to be transported. Finally, the uplift of mountains has an important feedback reaction to local, regional and sometimes global climate regimes (*e.g.*, Beaumont *et al.*, 1993).

Eustatic changes affect ultimate base level, thereby impinging upon the style and distribution of fluvial sediments. However, there is considerable discussion on the magnitude and processes involved (*e.g.*, Miall, 1996). A change in sea level affects a river system through 1) a change in sinuosity, and 2) incision (Schumm, 1993). The magnitudes of the changes are a function of the amount and, more importantly, the rate of sea level change. Schumm (1993) illustrated how a meandering river system first responds by changes in sinuosity and then by incision to a sea level fall. However, these examples referred only to magnitude of base level change and did not consider the rate of change.

High-frequency changes in relative sea level affect will influence fluvial aggradation and incision only a few hundred kilometres inland from the coast. Even the high magnitude (100+ m) late Pleistocene sea level fluctuations only resulted in incision of the Mississippi River only as far as present-day Baton Rouge (Saucier in Autin *et al.*, 1991). Blum (1994) found that fluctuations in sea level had affected the Colorado River in Texas for only 100 km upstream. Both examples are consistent with modeling studies which indicate that the distance upstream to which sea level fall can affect a river is approximately the square root of the duration of the event (Paola et al., 1991). A sea level drop that lasts for 100,000 years can be expected to produce incision approximately 350 km upstream. The combination of a diminution of the magnitude of the incision as the knickpoint migrates upstream and the presence of local base levels effectively isolates the headwaters of all but the small coastal river systems from the effects of rapid base level change.

Longer term (*i.e.*, several million years), high magnitude sea-level changes will affect more of a basin than the high-frequency events. These changes will be manifest in the migration of facies belts rather than in the formation of single event surfaces or beds. The headward damping of base level perturbations therefore eliminates sea level as a cause of conglomerate deposition. Changes in tectonism or climate, not sea level, are required to produce the slopes and flows to transport clasts to form conglomerates.

Variations in climate, specifically precipitation, also impact the evolution of fluvial systems at all scales. The amount, duration and timing of rainfall events in the mountains directly impacts the amount and type of sediment produced as well as how efficiently the sediment is flushed into a basin (Paola *et al.*, 1992). Variations in precipitation are capable of producing clastic wedges in foreland basins at the same physical and temporal scales as either tectonics or long-term eustatic variations (Beaumont *et al.*, 1993). The distribution of styles of fluvial deposition within a basin are also affected by the amount and distribution, both temporal and spatial, of the rainfall. This control of fluvial style is partly the result of the impact of precipitation on plant growth in post-Silurian strata (Schumm, 1968) and partly a function of the response of a fluvial system to seasonal variations in discharge. Rivers in basins with seasonal rainfall will produce different fluvial styles if the rainy season comes in the winter rather than the summer.

Interpreting the controls of fluvial deposition is therefore seldom possible from a single section. It is possible to deposit gravels in response to either an increase in precipitation, slope, or source rock, in the proximal portions of a river while mudstones and lenticular channels, suggesting a rise in base level are being deposited at the distal end of the same fluvial system. The problem is further compounded by the generally coarse nature of correlations possible between even closely spaced fluvial outcrops. As a result we refer to "relative base level change" as a nongenetic term to describe either lateral or vertical changes in fluvial styles. For example, a vertical change in fluvial style from braided to meandering in a single outcrop or local area is commonly interpreted as a decrease in depositional gradient but examination of data from modern rivers (Leopold and Wolman 1957) shows that there might well be an increase in gradient but a change in another variable that would result in the same change. Rather than immediately assigning a specific causal mechanism to individual outcrops it seems more appropriate to describe the setting as one in terms of relative base level. This view will reduce bias until comparison of all possible causes can be attempted.

LANDSCAPE OF SOUTHERN ALBERTA

The landscape of the southern Saskatchewan and Alberta prairies is complex, ranging from the mature, unglaciated landscape of the Cypress Hills uplands, to the highly-sculpted and glacially-modified drift-covered plains. The unglaciated topography has been modified by arid to semi-arid, mass-wasting and fluvial processes since the Late Tertiary as well as permafrost processes during glacial periods (Westgate *et al.*, 1972). The Cypress Hills uplands are the erosional remnants of more extensive plateaus and pediments.

Cypress Hills

The Cypress Hills were originally called the “Katewius Netumoo” or “Pine Hills”. Early French Canadian explorers mistook the pine trees capping the hills as “cyprès”, calling the area the “Montagne de Cyrès” which later translated into Cypress Hills. The Cypress Hills have an area of ~2600 km^2, are 40 km wide, and about 140 to 160 km long. Elevation of the Cypress Hills decreases from 1466 m ASL in the west to 1067 m near Eastend in the east. The 1466 m elevation is the height of land between the Rocky Mountains and Labrador. This Cypress Hills were never glaciated above ~1371.6 m (Klassen, 1992). A cross sectional profile across the Cypress Hills is shown in Figure 4.

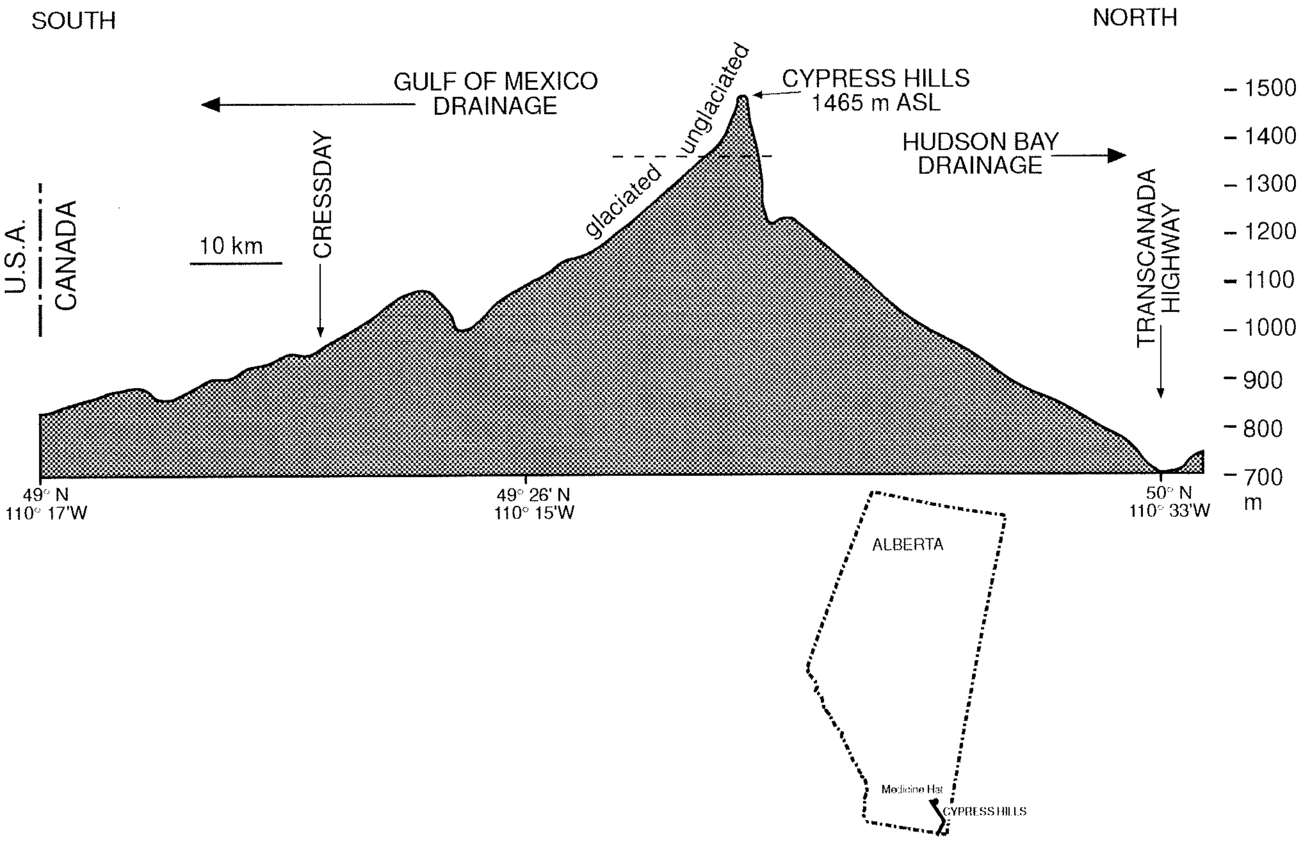


Figure 4. Cross sectional profile across the Cypress Hills. South of the Cypress Hills divide, drainage is into the Gulf of Mexico. North of the divide, drainage is to Hudson Bay. Elevations above 1371.6 m were not glaciated.

The Cypress Hills are capped by the Oligocene to Miocene Cypress Hills formation. The youngest ages recovered from sediments capping the Cypress Hills are middle Miocene (Storer, 1975), indicating deposition roughly 16.3 - 10.4 Ma ago. Nurkowski (1984) estimated, using moisture values in coal from the Ravenscrag Formation, that approximately 1000 m of sediment was eroded from the top of the Cypress Hills. Much of this material was probably eroded in association with the regional unconformity between the Ravenscrag and Cypress Hills formations.

Subsequent to deposition of the Cypress Hills Formation, degradation and downcutting took place in southern Alberta and Saskatchewan. Four erosion surfaces have been recognized downcutting from the Cypress Plain (Figure 5; Vreeken, 1996) which forms the top of the Cypress Hills Formation. These surfaces and the Cypress Hills Formation are mantled by the Late Miocene Davis Creek Silt which has been dated using tephras and paleomagnetism as having been deposited between 9.3 to 8.3 Ma (Vreeken *et al.*, 1989; Vreeken and Westgate, 1992; Barendregt *et al.*, in press). The oldest erosion surface may have started to form prior to 10 Ma (Vreeken and Westgate, 1992); three younger, erosion surfaces formed between 10 and 8.3 Ma. The implication is that the landscape of southern Alberta, with its major uplands along the drainage divide had already developed much of its relief by Late Miocene.

EVOLUTION OF CYPRESS HILLS: MORPHOLOGY AND STRATIGRAPHY

- Maastrichtian: deposition of nonmarine, coal-bearing sediments of the Ravenscrag Formation.
- between post Maastrichtian to Oligocene: regional uplift and erosion to form the unconformity at the top of the Ravenscrag Formation; up to 1000 m eroded
- Oligocene to Miocene (16.3 to 10.4 Ma): deposition gravels of the Cypress Hill Formation — the Cypress Plain
- 10.4 to 9.3 Ma: continued uplift and erosion of the Cypress Hills; multiple denudation surfaces downcutting from the Cypress Plain; it was at this time that much of the regional landscape was formed
- 9.3 to 8.3 Ma, Late Miocene: deposition of the Davis Creek Silt on landscape
- Quaternary: glaciation(s); uppermost Cypress Hills remain ice free

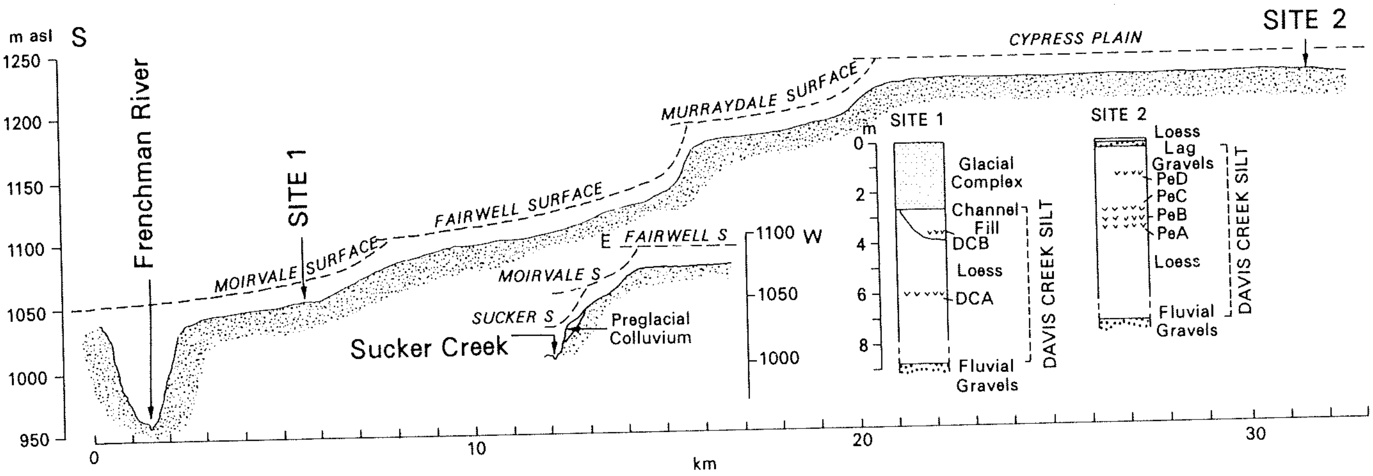


Figure 5. Geomorphic surfaces downcutting from the Cypress Hills (from Vreeken, 1996).

SUBGLACIAL FLOODS AND LANDSCAPE EVOLUTION

Recently, a new and controversial model has recently emerged regarding the development of modern landscape of the glaciated terrains of North America (Shaw 1996 and references therein). A major premise of the model is that many of the landforms through which we will be driving were the result of Late Wisconsin subglacial outburst floods from the base of the Laurentide ice sheet (Rains *et al.*, 1993; Shaw *et al.*, 1996).

The basic interpretation is that at least one, short-lived megaflood differentially eroded pre-existing substrates (Rains et al, 1993; Shaw, 1994) across the prairies. Of interest to this field trip is the map illustrating the axes of principal flow paths in Alberta of the Livingstone Lake sheetflood (Figure 6). These flow paths skirt the Cypress Hills and the Del Bonita uplands, two regions to be visited. In the area between the Del Bonita uplands and Cypress Hills, sheetflood-derived water and sediment was to flow upslope into Montana. Shaw *et al.* (1996) show the sheetflood as having impinged on the Cypress Hills and Del Bonita uplands however, they do not specifically state that the floods eroded these landforms.

Compare the continental glacier flow patterns (Figure 7) for eastern Alberta (Gravenor and Bayrock, 1961) with the flow lines proposed for the Livingston Lake event. The flow lines, in each case are similar, based on the interpretations of the surficial geomorphology. It is the inferred erosion versus depositional process that is different. One question that the field trip participants should consider is evidence of the subglacial flooding and timing of the landscape evolution of the Cypress Hills and Del Bonita uplands as dated paleomagnetically and radiometrically. Are they compatible?

TWO CONTINENTAL DRAINAGE DIVIDES

The route of this field trip occurs over what can be considered as the apex of the North American continent. The actual apex is situated 46 km south of the border, in the Lewis Range, Montana. As part of the field trip, we will travel to two distinct and separate drainage divides (Figure 8). The border between southern Alberta and British Columbia occurs at the continental drainage divide of the Rocky Mountains. To the west, rivers flow to the South Saskatchewan River and then to the Pacific Ocean; to the east, rivers flow to the Hudson Bay. The mountains along this divide are rugged, with several passes such as the Crowsnest.

In southernmost Alberta, a drainage divide stretches from the Cypress Hills westwards to Milk River Ridge and then towards Waterton Lakes National Park. To the south, rivers eventually flow into the Missouri and then the Mississippi River and the Gulf of Mexico. To the north, the rivers flow into Hudson Bay.

TECTONIC AND PALEOGEOGRAPHIC SETTING OF THE WESTERN CANADA FORELAND BASIN

The regional tectonic and paleogeographic setting of the Western Canada Foreland Basin has been summarized in detail in two recent publications edited by Caldwell and Kauffman (1993) and Macqueen and Leckie (1992). A detailed discussion of the regional setting, evolution and depositional cycles of the foreland basin is in Leckie and Smith (1992).

The Mesozoic western North American foreland basin was an elongate trough that developed between a continental-margin magmatic arc and the North American craton. Two collisional events, the Early Jurassic to Cretaceous Columbian Orogeny and the Late Cretaceous to Paleocene Laramide Orogeny, resulted in the formation of five tectono-stratigraphic zones in western Alberta and British Columbia. These include the Rocky Mountain, Intermontane and Insular belts, consisting primarily of non- to weakly-metamorphosed volcanic and sedimentary

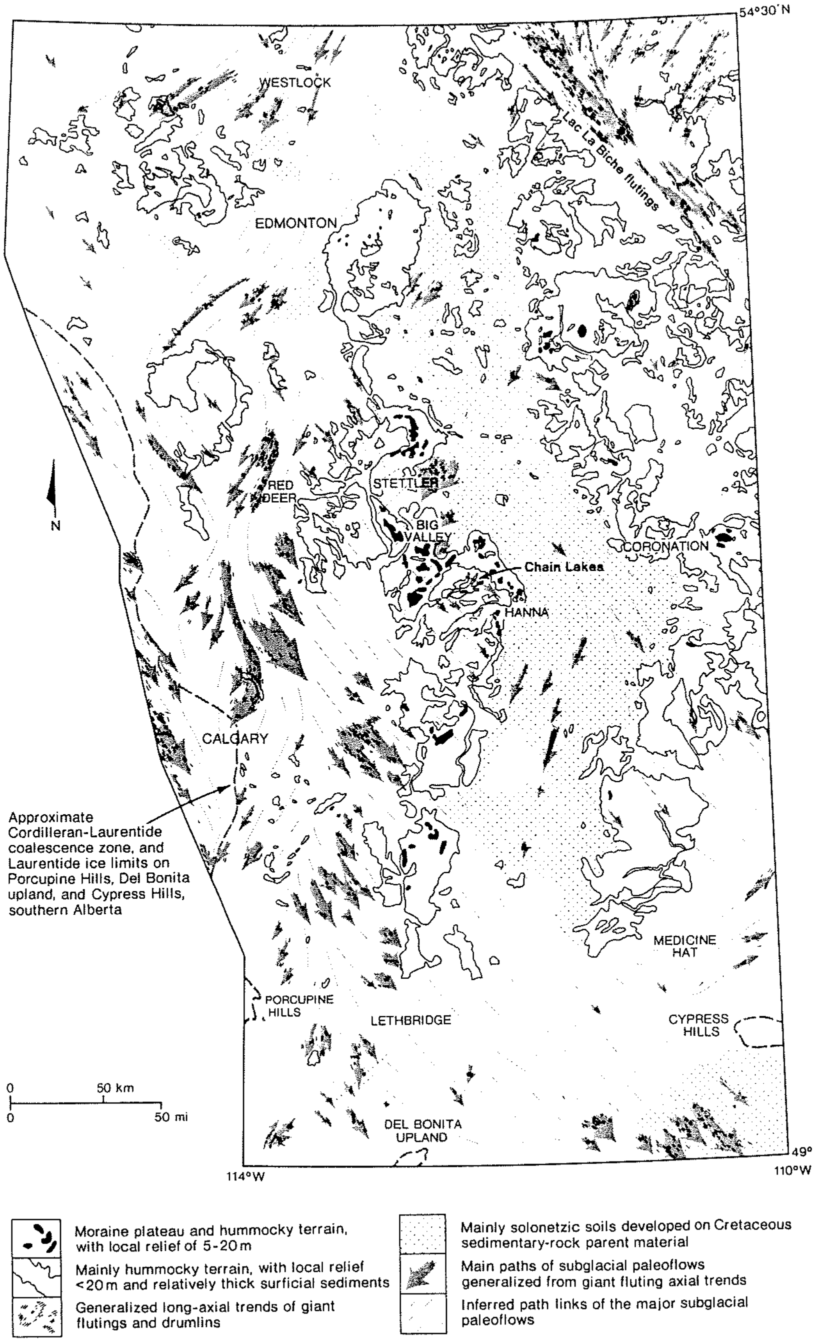
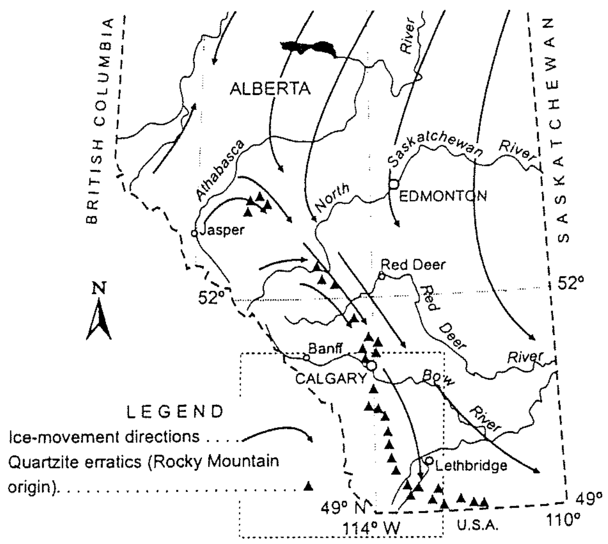


Figure 6. Axes of principal flow paths in Alberta of the Livingstone Lake sheetflood (Shaw, 1994).



Generalized ice-advance directions in Alberta

Figure 7. Continental glacier flow patterns for eastern Alberta (Gravenor and Bayrock, 1961). Compare with Figure 6.

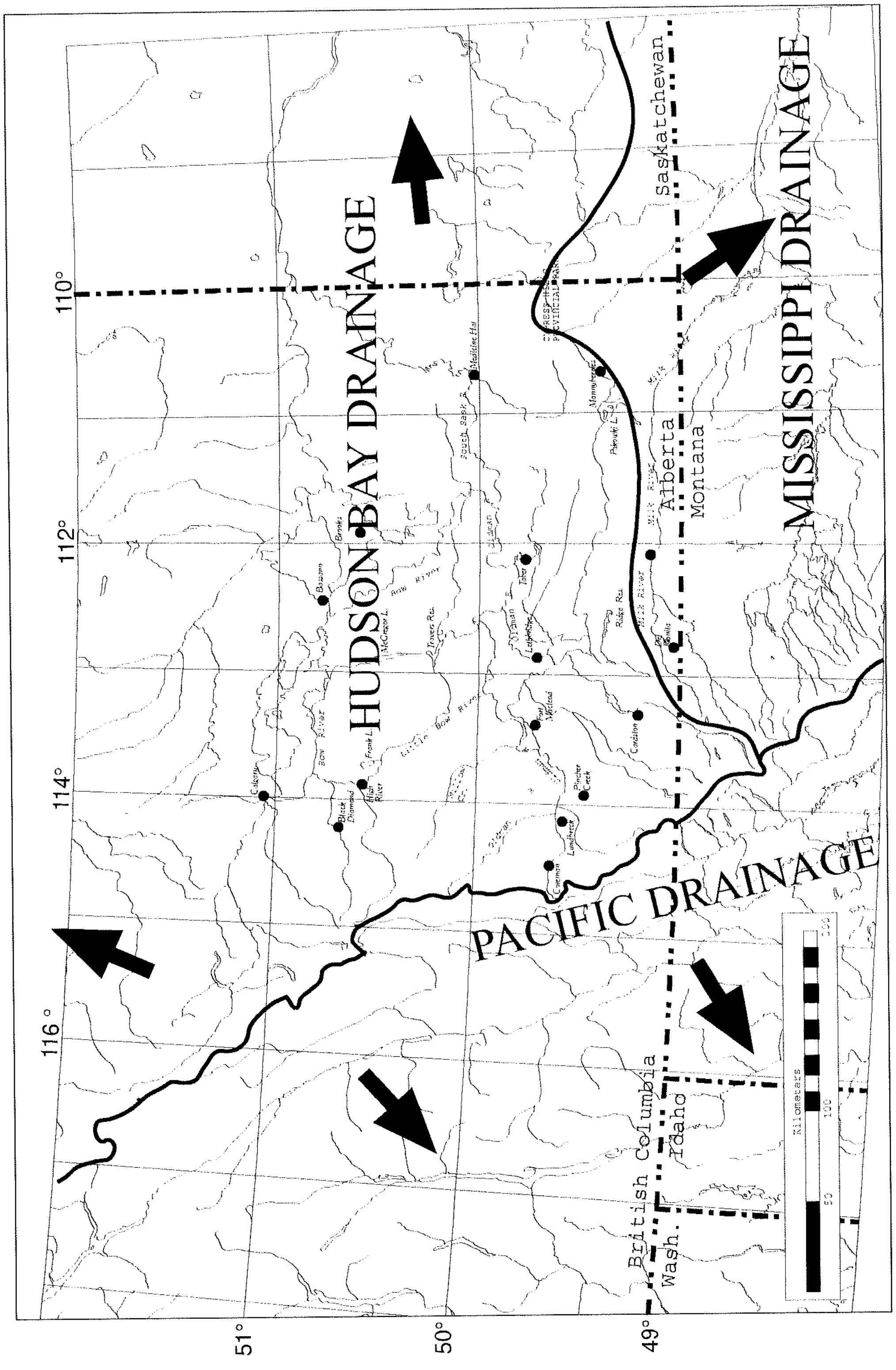


Figure 8. Drainage systems and divides of western Canada.

strata. These three belts are separated by two sutural complexes, the Omineca Belt and Coast Plutonic Belt, comprising high-grade metamorphic and plutonic rocks. The clastic sediments of the foreland basin form a westward-thickening wedge of unmetamorphosed detritus.

During latest Paleocene or middle Eocene time, Cordilleran tectonics changed from transpressional deformation to large-scale extension. Uplift resulted in development of a basinwide Eocene unconformity and deposition of extensive boulder-gravel sheets across the western part of the basin. Modern drainage patterns probably became established during this time. Uplift and erosion continued during the Neogene and early Pleistocene, recycling the Paleocene to Oligocene gravels into preglacial valleys such as those now containing the Saskatchewan Sands and Gravels. During the Pleistocene, Cordillera-derived glacial outwash gravels were transported eastward from valley glaciers and piedmont lobes in the Rocky Mountains. This post-Paleocene period is unnamed in Western Canada geological literature, but for discussion purposes, we refer to it as part of the foreland basin.

Paleogeographic reconstructions from six time periods are shown in Figure 9 (Leckie and Smith, 1992) to illustrate the regional evolution of the Western Canada Sedimentary Basin. Stratigraphy is shown in Figure 10.

Eustatic

The eustatic variations in sea level that occur from 140 my through to the Miocene of Haq *et al.*, 1988 are illustrated in figure 4. The long-term changes have an estimated magnitude of 180 m and duration (based on the Haq *et al.* curve) on the order of 30 million years. There are five third-order maxima and minima over the same time span. The third-order variations show 5 minima and maxima with magnitude of 60 - 90 m and durations of 10 million years. The fourth order excursions are up to 90 m in magnitude and last 0.25 to 1 million years.

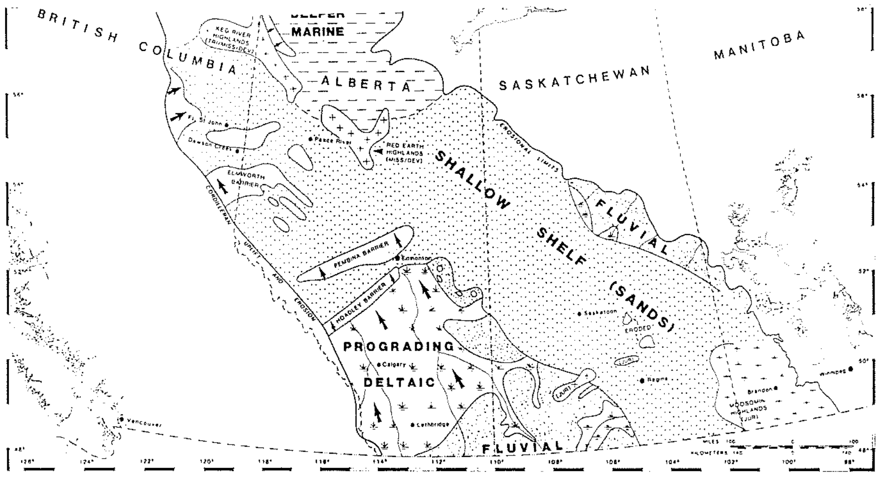
The theoretical maximum upstream incision of the fluvial systems of the fourth order fluctuations should be 300-1,000 km upstream and as much as 3,000 km for the third order variations such as that occurring from 25-30 Ma. However, as noted above, the presence of local base levels makes it improbable that this maximum distance can ever be achieved.

Climate

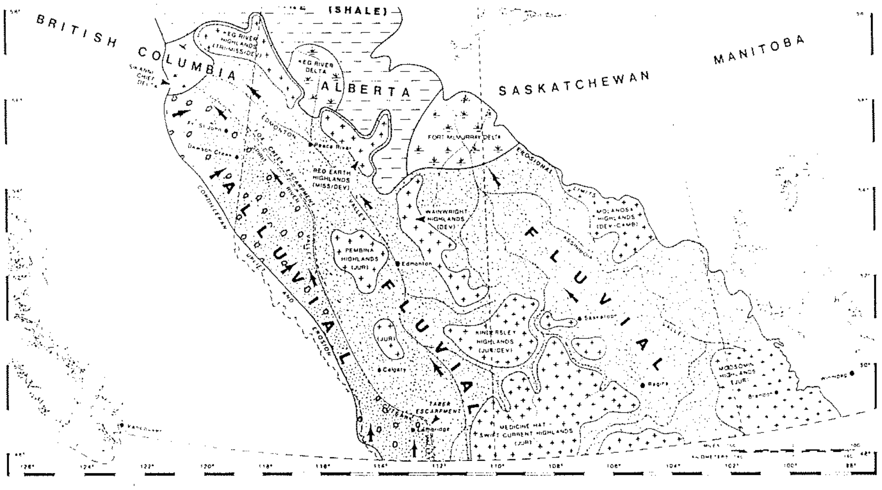
Climatic indicators from the Jurassic through to the modern are derived from a sparse and disparate data set. During this time period, the climate of the foreland basin has ranged from warm, humid to semi-arid to periglacial. Paleo-reconstructions of the positions of the North American craton over the last 140 m.y. show that southern Alberta has migrated south approximately 10° and rotated clockwise 20° (Scotese *et al.*, 1989). World-wide climate variations, as marked by marine isotopic records indicate a generally warm and equitable climate throughout the Jurassic, Cretaceous and Paleocene. The onset of a major cooling trend occurred in the mid-Eocene and accelerated in the Miocene. The various paleoclimatic signatures from southern Alberta and southeastern British Columbia are summarized in Figure 9.

During the Oxfordian and Kimmeridgian of the Late Jurassic, paleoclimate was warm and humid, subtropical (Gibson, 1985), with the water table being relatively high. Moisture was likely provided from the epicontinental Western Interior Seaway. The result was the thick and economic coal seams of the Mist Mountain Formation. Climate may have been changing and becoming dryer, but still seasonally wet, as indicated by the needle coal (Kalkreuth, 1982; Snowdon *et al.*, 1986; Gibson, 1985) in finer-grained deposits of the Elk Formation. The red beds and caliche of the Pocaterra Creek Member indicate a possible climatic shift to warmer and drier climate with seasonal wet periods. Discharge was flashy with braided rivers probably being channeled rather than sheetlike. Uplift to the west may have caused a partial rainshadow effect.

Paleosol successions from the upper Blairmore Group have micro- and macro-facies similar to recent alluvial soils, Brunisols, Luvisols, hydromorphic soils and vertic soils (McCarthy *et al.*, press). The paleosols indicate a warm to cool temperate (5-20°C) paleoclimate with seasonal precipitation. This is consistent with paleobotanical interpretations



Paleogeographic reconstruction of the Glauconite, Bluesky, Wabiskaw, and Lloydminster units during deposition of Cycle 2.



Paleogeographic reconstruction of the Cadomin, Ellerslie, Gething, and Dina formations during deposition of Cycle 2.

Figure 9. Paleogeographic reconstructions from six times periods, showing evolution of the Western Canada Sedimentary Basin (continued overleaf).

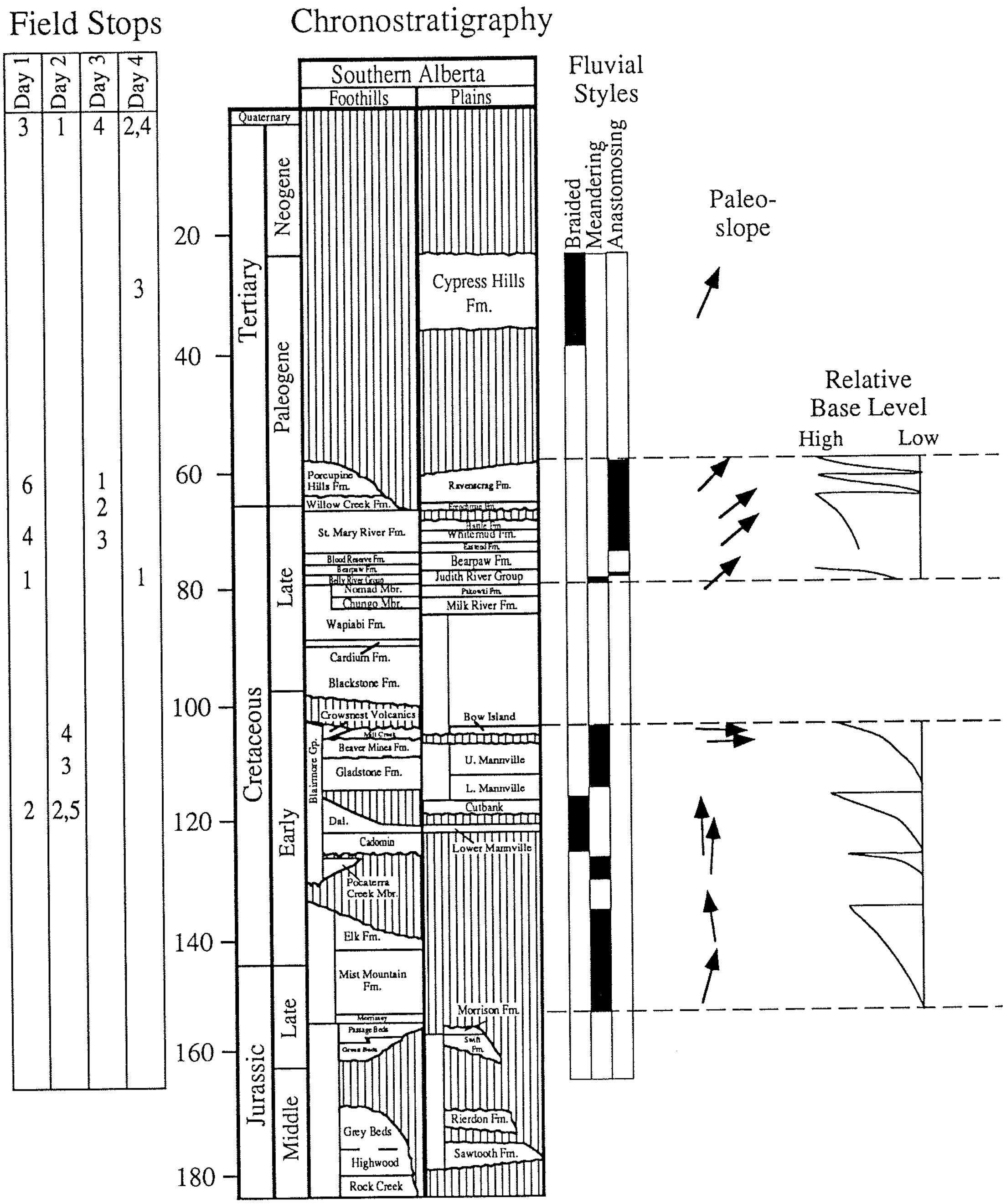
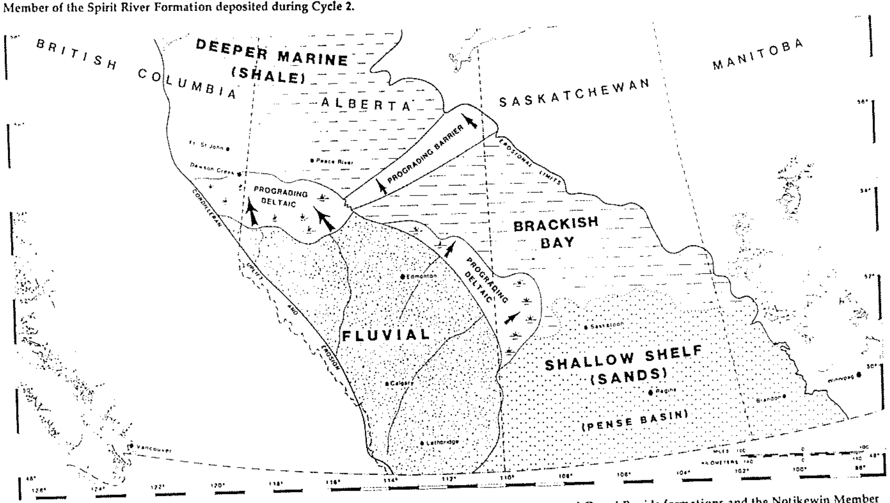
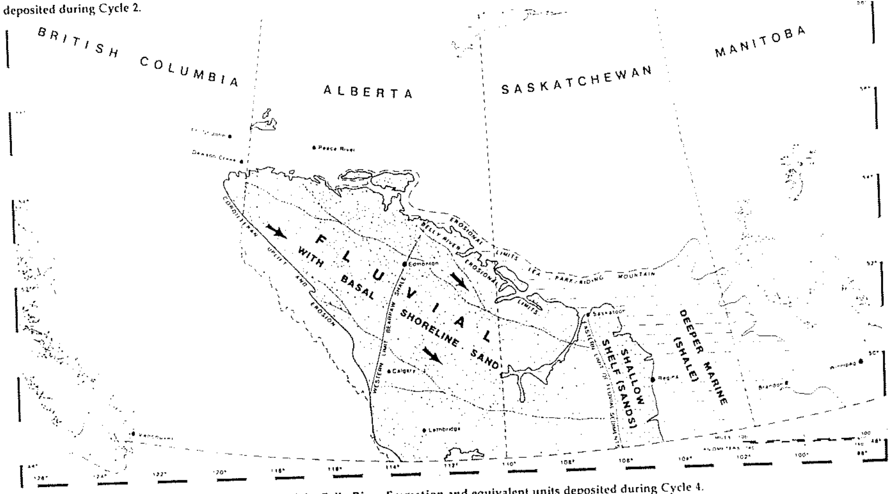


Figure 10. Field trip stops, eustatic sea level curve, climate and tectonism associated with sediments deposited from the Jurassic through to the modern (continued overleaf).

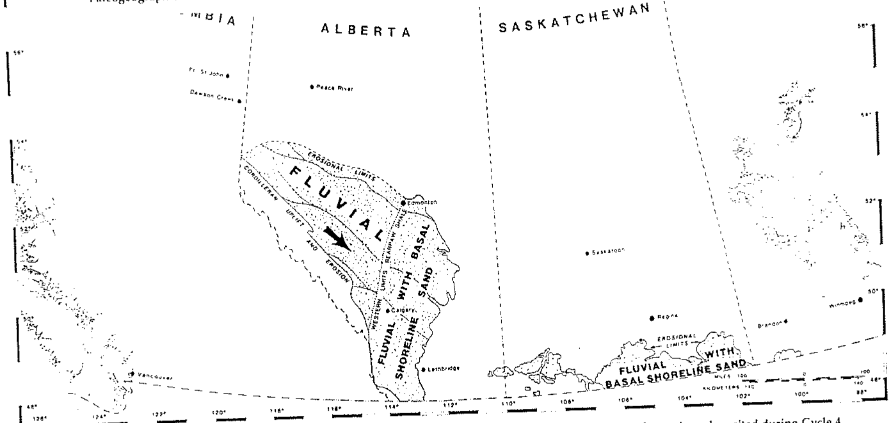
Paleogeographic reconstruction of the Upper Mannville, Rex, General Petroleum, Waseca, Gates, and Clearwater formations and the Falher Member of the Spirit River Formation deposited during Cycle 2.



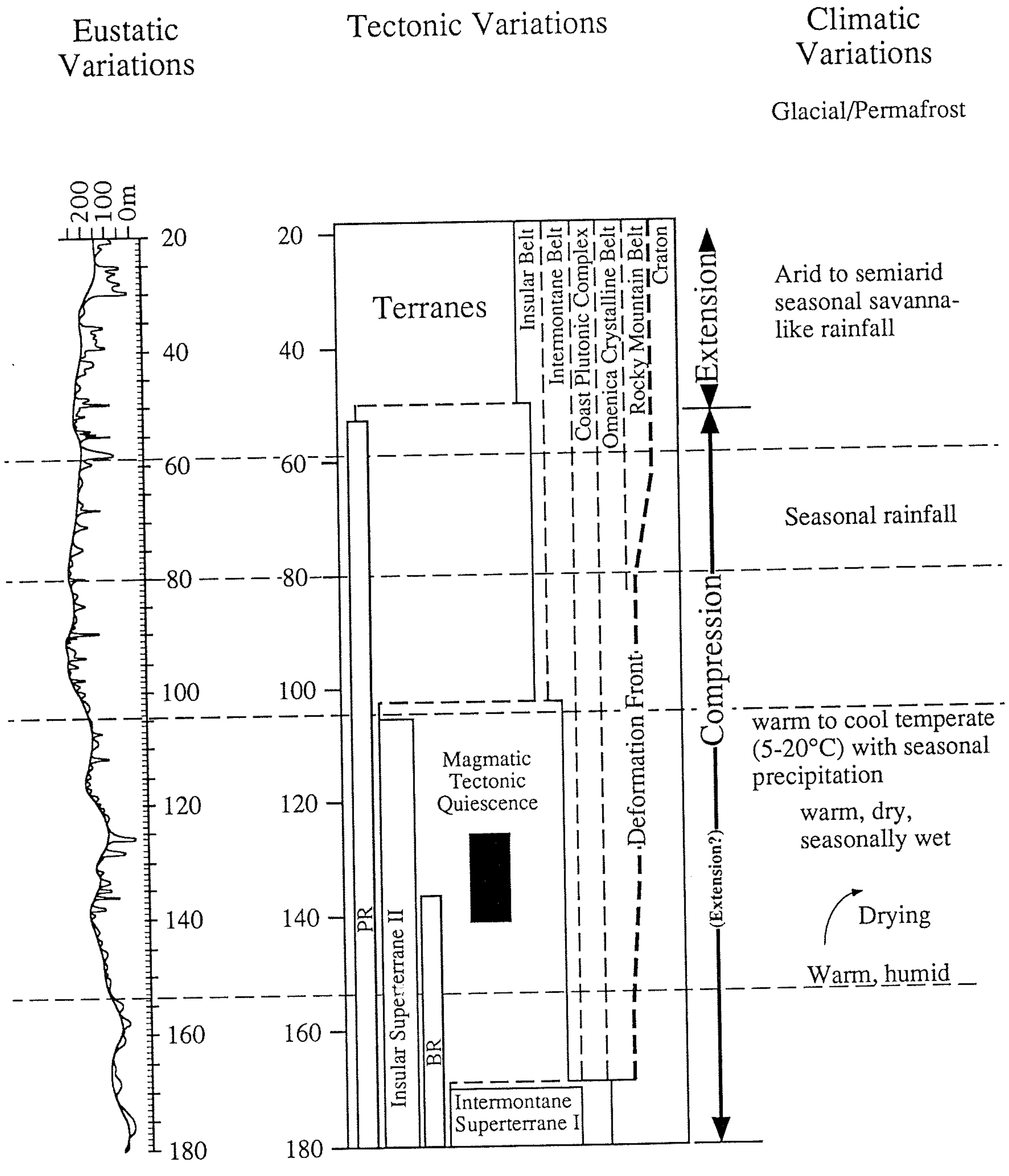
Paleogeographic reconstruction of the Upper Mannville, Colony, McLaren, Pense, and Grand Rapids formations and the Notikewin Member deposited during Cycle 2.



Paleogeographic reconstruction of the Belly River Formation and equivalent units deposited during Cycle 4.



Paleogeographic reconstruction of the Edmonton, Willow Creek, Brazeau, Wapiti, and Paskapoo formations deposited during Cycle 4.


Eustatic Variations
Tectonic Variations
Climatic Variations
Glacial/Permafrost
200
100
0m
20
40
60
80
100
120
140
160
180
Terranes
Insular Belt
Intermontane Belt
Coast Plutonic Complex
Omenica Crystalline Belt
Rocky Mountain Belt
Craton
Extension
Compression
(Extension?)
Deformation Front
Magmatic Tectonic Quiescence
PR
Insular Superterrane II
BR
Intermontane Superterrane I
Arid to semiarid seasonal savanna-like rainfall
Seasonal rainfall
warm to cool temperate (5-20°C) with seasonal precipitation
warm, dry, seasonally wet
Drying
Warm, humid

which indicate warm temperate to subtropical climate with the precipitation:evapotranspiration ratios being > 1.2; a seasonal drop in precipitation during the growing season, and a low seasonality of temperature (Bell, 1956; Vakrameev, 1982; Upchurch and Wolfe, 1993).

Climatic conditions during deposition of the Belly River Group were generally similar to those of the Blairmore Group. Less has been published on the paleosols of the Belly River Group, however, the presence of numerous caliche profiles indicate that semi-arid conditions were present. Variations in colour and caliche content between the basal Connelly Creek Formation and the Lundbreck Formation have interpreted to be a result of an increase in aridity but could equally well be due to a shift in yearly precipitation patterns from summer to winter-wet.

The climate of the St. Mary River Formation climate was also semi-arid. This interpretation is based on modern anastomosed fluvial analogs (Smith, 1983;1986; Nadon, 1994). Seasonal moisture, which we interpret as spring/summer wet, allowed the growth of lush vegetation in the floodplains (roots are common in all of the sandstones) and small lakes that dotted the landscape. Trees were rare. The degree of paleosols formation within the St. Mary River Formation is seldom intense. Well developed caliche is rare but small calcite concretions (rhizoliths) are common in many areas. B_t horizons of Vertisols, Mollisols, and Alfisols (*sensu* Retallack, 1990) are most common. The grey and green colours of the paleosols indicate high water table conditions that are also found in modern anastomosed fluvial systems in seasonal tropical climates such as the Llanos of South America (Clemente et al., 1983) and the semi-arid desert climate of central Mali. The wet season in both examples is summer.

The reds and purples of the Willow Creek Formation mark a dramatic contrast in colour from the drab greys and greens of the St. Mary River Formation. However, grey and green mudstones are still present throughout the formation (Douglas, 1950; Jerzykiewicz and Sweet, 1988). Caliche and calcretes, both the product of rhizoliths are common as a paleosol in intervals within the formation. The climate is still open to discussion. The fluvial style is the same as the underlying St. Mary River Formation suggesting a seasonal water environment. Jerzykiewicz and Sweet (1988) argue that the impoverished palynofloral assemblage is indicative of xerophytic assemblage. and therefore a more arid climate than before. However, the change may have been in the timing rather than the quantity of the rainfall. A fall/winter wet season (Mediterranean in modern climate regimes) also lead to a lower water table and hence both rubification (Xeralfs) and the formation of the biologically mediated caliche and calcrete layers.

The Porcupine Hills Formation is largely a return to the condition prevalent in the St. Mary River time. Floodplain sediments are greys and greens as opposed to reds indicating gleyed soil profiles. Rhizoliths common in some horizons but caliche is rare (Jerzykiewicz, 1997).

The climate of the Oligocene Cypress Hills Formation in southeastern Alberta and southwestern Saskatchewan was arid to semi-arid, savanna-like probably with seasonal wet periods. This interpretation is indicated by silcretes, vertebrate fauna, absence of palynomorphs and sedimentological relationships (Leckie and Cheel, 1989, 1990).

The Quaternary, fluvial gravels exposed on the Del Bonita uplands show a complex relationship of ice-wedge casts and pulses of fluvial gravel. The ice-wedge casts indicate permanently frozen ground with mean annual temperatures of -6 to -8° C in a periglacial setting and surficial permafrost temperatures of -15 to -20°C (c.f. French, 1976).

GENERAL BACKGROUND DESCRIPTION OF NONMARINE STRATA SEENON THE FIELD TRIP

During this field trip, nonmarine strata from several intervals will be examined. In the discussion below, we describe some of the regional background for each of these intervals. This description will be followed by more detailed descriptions of each of the stops on the field trip. A stratigraphic section is presented in Figure 10.

a) Jurassic Kootenay Group

Mist Mountain Formation

The Tithonian Mist Mountain Formation was deposited in a deltaic (lower Mist Mountain) to fluvial/alluvial (upper Mist Mountain) environment, which became increasingly distal upwards from the shoreline facies of the Morrisey Formation. Rare occurrences of pyrite, dinoflagellates and ostracodes suggest an episodic marine to brackish-water flooding during deposition, consistent with a deltaic interpretation. The high water table, thick peat accumulations and dominance by fine-grained sediments point to a low gradient. Limited paleocurrent data (Figure 9) from the Fernie Basin suggest that the paleoslope may have been towards the ENE.

Elk Formation

The Berriasian to Tithonian Elk Formation is a westward-thickening succession of nonmarine sandstone, mudstone, conglomerate and coal. Thick beds of medium to coarse-grained sandstone and conglomerate are locally abundant. In the underlying Mist Mountain Formation, coals are thicker (up to 18 m) and more common, whereas coarse sandstones and conglomerate are less common (Gibson, 1985). The conglomeratic sand bodies in the Elk Formation have previously been interpreted as the deposits of braided rivers and distal alluvial fans, largely due to their coarse nature and some of their coarse nature and some of the facies. However, the conglomeratic bodies are discontinuous and encased in finer sediments (sandstone, siltstone and shale), generally fine upwards from conglomeratic sandstone, contain lateral accretion surfaces and grade laterally into mud plugs (oxbow lakes?). These are point-bar deposits of coarse-grained meandering rivers which were up to 20 m. Given the abundance of conglomerate, paleoslope likely increased with deposition of the Elk Formation, compared to that of the underlying Mist Mountain Formation. The base of the amalgamated conglomerate may represent the nonmarine expression of a significant sequence boundary. The facies change to more conglomerate and less coal is fairly abrupt. Paleoflow was predominantly northwards.

b) Cadomin and Dalhousie Formations

The Cadomin Formation is a relatively thin, but laterally persistent conglomerate, extending for >1000 km along the length of the Rocky Mountain Foothills and Front Ranges. Other units associated with deposition of the Cadomin Formation include the underlying and locally occurring Pocaterra Creek Member (Berriasian) of the Cadomin Formation, and overlying Dalhousie Formation, each separated by unconformities. The Berriasian Pocatera Creek Member of the Cadomin Formation occurs as a conglomeratic wedge below the upper unit and above the Kootenay Group. These units each become more extensive laterally to the east with younging and each unconformity becomes more regionally extensive.

The Pocatera Creek Member is finer grained (mean diameter 2 cm) and contains fewer green cherts and quartzites than the coarser (mean diameter 5 cm) remainder of the Cadomin Formation (Rickets and Sweet, 1986). Red beds and caliche are common. The paleoslope may have been relatively steep and fluvial discharge was episodic; accounting for the abrupt introduction of gravels into the otherwise fine-grained depositional environments. The preservation of red shale and caliche suggests that the gravels were channeled rather than sheet deposits. The dryer and warmer conditions may have been the result of a rain shadow effect on the eastern side of the cordillera. The increase in conglomerate upwards from the Mist Mountain Formation to the Elk Formation likely indicates uplift in the source area which may have heralded possible rain shadow conditions of the Pocaterra Creek Member.

The Cadomin Formation represents deposition of a sheet of gravel on a north-dipping paleoslope. The fluvial style was braided as indicated by the absence of fine-grained material, the sheet-like geometry, multiple erosion events, and no or little fining upwards. Channels were continuously shifting by avulsion and bank cutting. The angular siliceous sandstone clasts at Adanac Mine are similar to rooted, grey, silcretes cemented with amorphous silica cement found within the Mist Mountain Formation at Coal Creek and elsewhere. The angular nature of the silcrete clasts indicate that lithification occurred and a short transport distance. The coal clasts at Adanac Mine and elsewhere were eroded from Mist Mountain peat mats which likely floated downstream, became water logged and sank.

The Dalhousie Formation has the characteristics of sandy, braided fluvial deposits. Parts of the section that are dominated by trough cross beds likely represent channel deposits. Most of the deposits are similar to those of sand flats or the side bars and middle channel bars. Planar tabular crossbeds were formed by straight-crested 2D dunes in shallow channels and on bar tops.

Interpretation

Deposition of the Elk, Cadomin and Dalhousie formations and their related unconformities correspond with an episode of magmatic and tectonic quiescence in the Canadian Cordillera from 140 to 125 Ma (Figure 10) and, generally, around the world (references in Leckie and Cheel, 1996). Over this same period, global relative sea level was also low (Haq *et al.*, 1988). Tectonic compression associated with the Columbian Orogeny may have decreased or changed directions, thereby allowing uplift and rebound of the craton. The uplift and rebound is first recorded in deposition of the Elk Formation conglomerates. The gradient was relatively steep as indicated by the abundance of gravels, and the fluvial style appears to have been initially meandering and later changed to braided. The unconformities are the result of regional erosion and beveling, rather than deep valley incision, as there is no evidence of major Cadomin or Dalhousie infilled paleovalleys. Uplift from unloading progressed basinwards (eastwards), resulting in truncation of older strata eastwards, by the compound unconformity which also youngs eastwards.

The Cadomin and Dalhousie formations were deposited in northerly flowing braided-rivers, the former was dominated by gravel, the latter by sand. There is not a significant downstream or along-strike fining of sediment in either the Cadomin or Dalhousie Formation. A depositional analog for the Dalhousie Formation may be the modern sandy braided deposits of the Kosi megafan (Figure 11). The reconstruction is based on channel patterns of streams flowing from the Himalayan Mountains into the Indo-Gangetic plains, India. Rivers flow out of the mountains into the foreland basin, more or less orthogonal to the mountain front and then veer to flow parallel (longitudinally) to the mountains.

Blairmore Group

Sediments of the Blairmore Group represent deposition in an alluvial plain setting with a shallow north or northeast-dipping slope and characterized by sandy and muddy point-bar and overbank deposits.

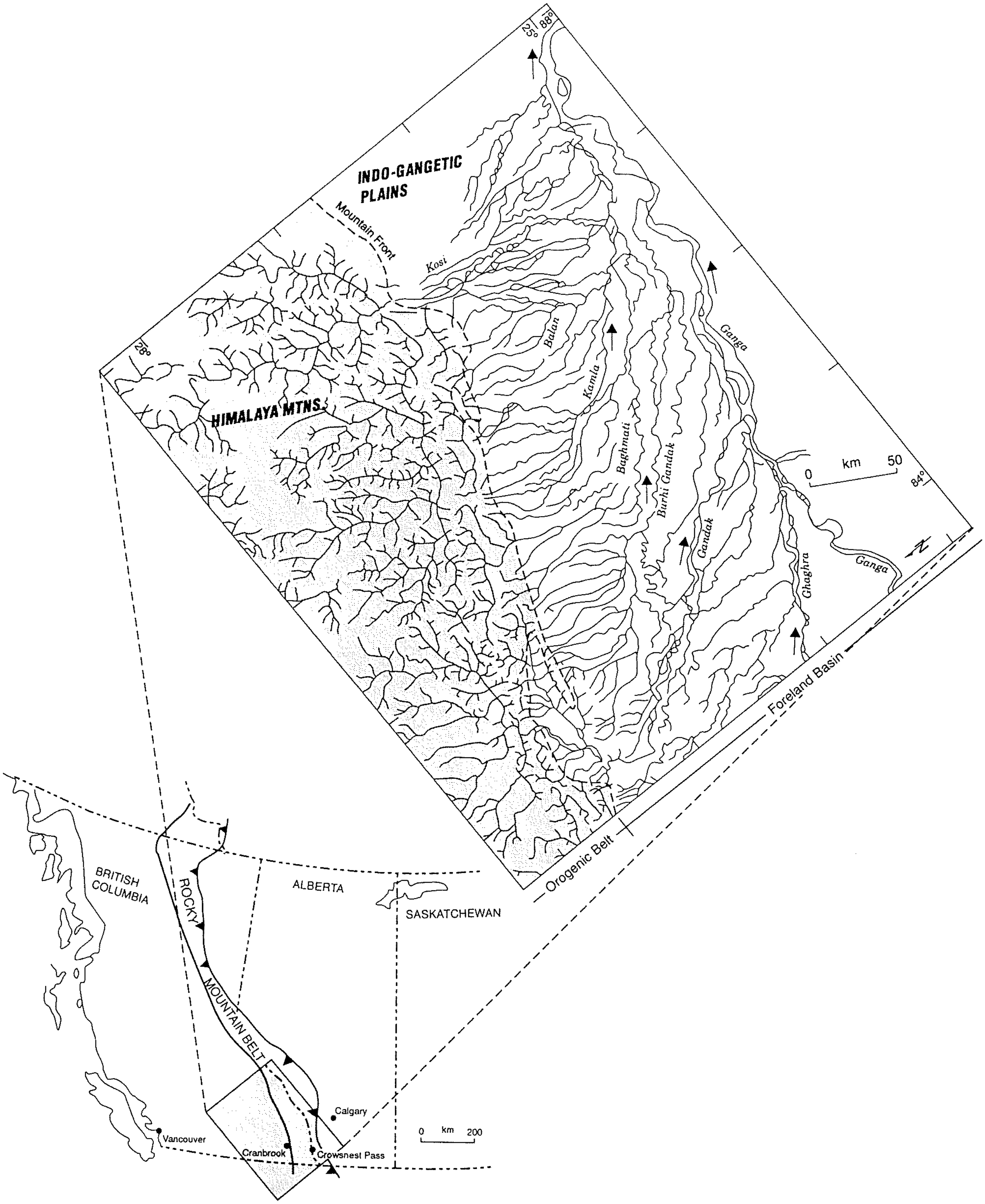


Figure 11. A possible interpretive analog for the Cadomin and Dalhousie formations in a foreland basin setting.

Several Albian-aged, igneous pebble to cobble conglomerate channels are entrenched into finer grained sediment of the Mill Creek and Beaver Mines Formation (Blairmore Group) in the Rocky Mountain Foothills and Main Ranges in southwest Alberta and southeastern British Columbia. The conglomerate was deposited as a series of ten east-flowing subparallel channels (Figure 11) which flowed into the foreland basin perpendicular to the mountain front, from a source terrain 350 to 400 km away. The channels can be traced eastwards in several adjacent thrust slices for up to 66 km. Individual conglomerate bodies are up to 60 m thick and can be traced laterally for up to 3 km. The largest conglomerate-filled channel, Bruin Channel (Figure 12), was ~ 22 km wide. The conglomerates were deposited in low-sinuosity, braided rivers. There is no indication in the underlying or adjacent sediment to herald the introduction of the conglomerate into the basin. After its deposition, sedimentation returned to medium-grained sandstone or finer detritus.

Sediment was introduced into the foreland basin due to westward shifts in the drainage divide, so that river headwaters tapped into high, steep plutonic sources (Figure 12). Paleocurrent data show that the conglomerate was derived from the west, and the conglomerate-filled channels trend east or northeast. Clast petrography implies a provenance which includes granitoids, mafic volcanics, low-grade metamorphic rocks and shallow level (ca. 7 km depth) post-metamorphic quartz veins formed from meteoric fluid. The conglomerate was derived from igneous and volcanic source terrains in the southern Omineca Belt of British Columbia prior to the rise of the Rocky Mountains.

This conglomerate contains detrital gold grains up to 150 microns across, and chemical analyses (up to 910 ppb Au) indicate widespread anomalous gold concentrations in conglomerate matrix. Less pronounced but persistent As anomalies (up to 260 ppm) occur also. Gold enrichment in the igneous-clast conglomerate contrasts strongly with background gold concentrations in the underlying conglomeratic Cadomin Formation. The gold concentrations demonstrate that paleoplacers derived from the Canadian Cordillera have formed in the Western Canadian foreland basin, a sedimentary sequence previously dismissed as a detrital gold host.

The levels of enrichment detected in this study are locally comparable to modern economic placers which contain at least 200-300 ppb Au, and preferably around 1000 ppb Au, in unconsolidated gravels (Boyle 1979). The gold is very fine grained, due to its distance from the presumed source (about 250 km, not palinspastically restored), and probable post-depositional mobility.

Tectonic implications

If the igneous pebble conglomerate was derived from the Omineca belt to the west, the drainage pattern must have been very different from today (Fig. 13). In particular, the continental divide must have been farther to the west, probably within the Omineca belt, and the Rocky Mountains either did not exist or were minor sources of sediment. The Early Cretaceous sequence of Alberta records the initiation of deformation and uplift in what is now the eastern Cordillera. The Cadomin and related sediments record an early uplift and removal of miogeoclinal rocks, possibly as far west as the Omineca Belt. These were overtaken by unroofing of the deeper, higher grade parts of the Omineca, including Jurassic-Cretaceous plutons. Gold-bearing veins were eroded from the Omineca Belt and gold was transported to the east to be deposited in the igneous-clast conglomerate. The sudden influx of detritus from miogeoclinal rocks represents the end of this eastward transport of gold, and may record the rise of the Rocky Mountains as a continuous high mountain chain. Thereafter, Omineca gold was shed westwards, and no more reached Alberta.

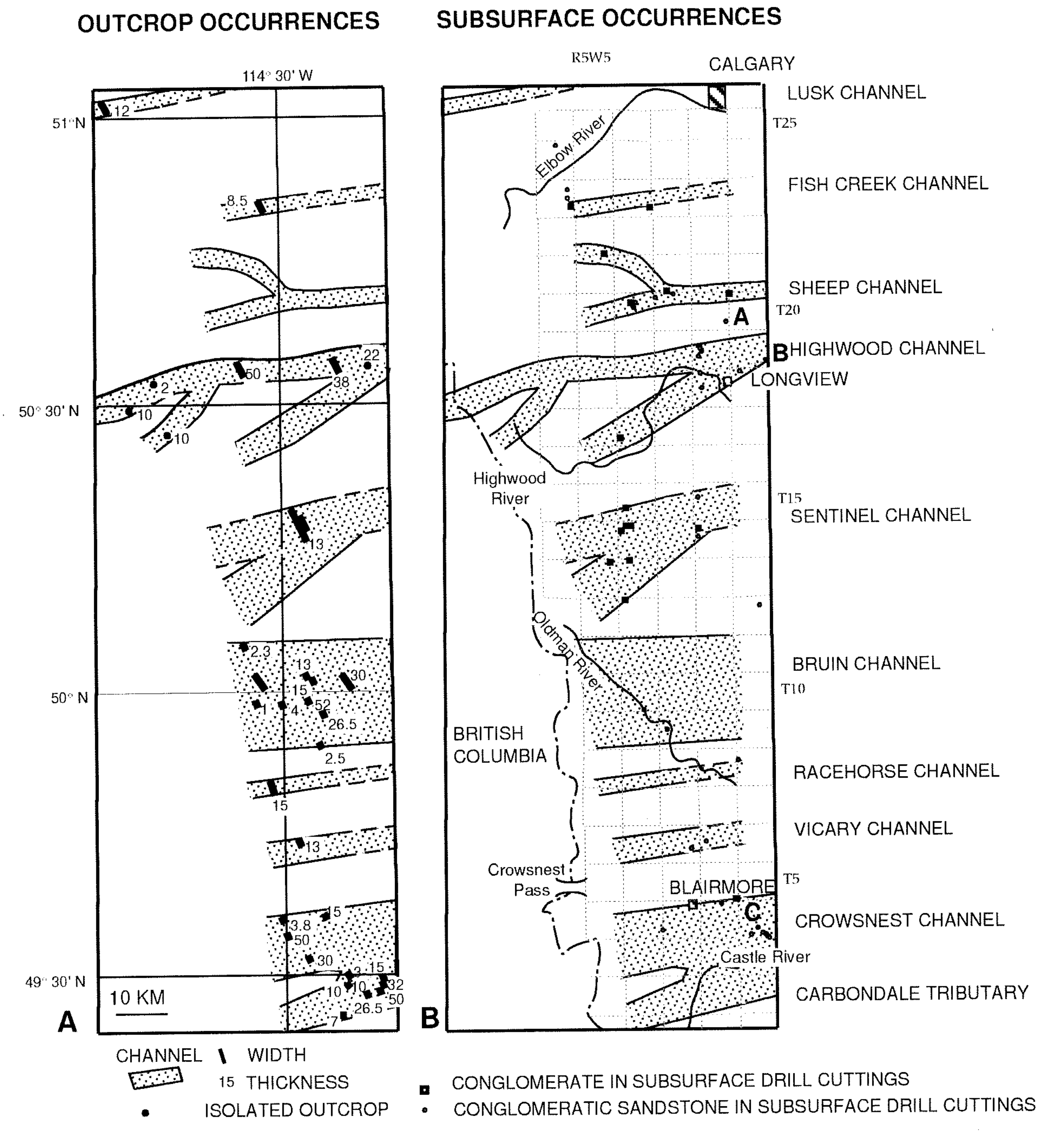


Figure 12. Multiple channels of igneous clast conglomerated as mapped from outcrop and subsurface data.

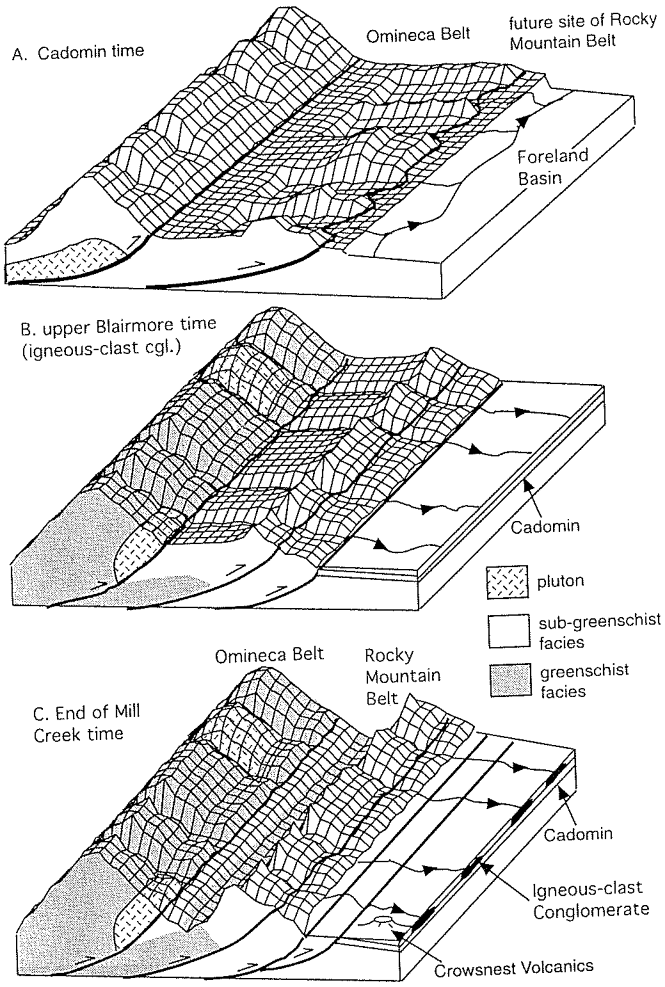


Figure 13. Three-dimensional reconstruction of the inferred geometry of the Omineca Belt mountain ranges to the west of the Western Canada Foreland Basin in the early Cretaceous. Vertical exaggeration is enhanced. A) Cadomin time, with initial uplift and mainly eastward drainage into north-flowing rivers in the Alberta Basin. B) Igneous-clast conglomerate deposited, with central Omineca Belt unroofed, exposing plutons intruded into mainly greenschist facies host, and shedding detrital gold to the east through rising east Omineca ranges. C)East Omineca ranges have risen to allow capture of the central Omineca streams (and detrital gold) to drain ultimately to the west. The Western Canada Foreland Basin again receives only shallow-level debris from the rising eastern Ranges.

Belly River Group

The Belly River Formation in the Foothills, which was considered to be equivalent to both the Foremost and Oldman Formations in the Plains, was divided into three informal members by Douglas (1951). The upper member, which comprised the fluvial component, was described as 594 m (1950 ft) thick and subdivided into five units that were recognizable on the basis of sandstone thickness and frequency, color, and abundance of carbonate concretions (Figure 14).

Jerzykiewicz (1997) formally subdivided the interval corresponding the upper two members of Douglas (1951) into three formations and raised the rank of the Belly River to Group status. Maximum thickness of the Group varies from 1,000 m under the Lewis Thrust to 800 m in the vicinity of Lundbreck to 300 m in the Plans. Paleocurrent measurements indicate flow to the east or northeast (Rahmani and Lerbekmo, 1975; Jerzykiewicz, 1997).

The Connelly Creek Formation (Jerzykiewicz, 1997) is equivalent to both the middle sandstone member and much of the basal sandstone-shale unit of the upper member of the Belly River Formation of Douglas (1951), and to the Foremost Formation of the Judith River Group in the Plains (Figure 15). The sediments in the type area, which unconformably overlie the marine shales of the Pakowki Formation, are described as over 400 m of mainly sandstone with interbedded dark to greenish grey mudstones, coaly shale, and rare coals. In addition there are minor redbeds (the Drywood Creek section). The upper contact is placed at the facies change to greyish green to pale yellowish green, caliche-bearing mudstones. The descriptions of the laterally extensive, ridge-forming sandstones in Douglas (1950) suggest this portion of the unit is a meandering fluvial deposit.

The overlying Lundbreck Formation is broadly equivalent to the concretionary member of Hage (1943) and Douglas (1951) and recognized only in the southern Foothills. Jerzykiewicz (1997) states that this unit wedges out between the Oldman and Foremost Formations in the Plains, however, the stratigraphic position and the correlation of the units above and below indicates that it is homotaxial with the Oldman Formation. The unit is up to 250 m thick and characterized by caliche-bearing mudstones and micritic limestones. The formation is interpreted as an alluvial fan and playa complex by Jerzykiewicz (1997). The caliche beds are formed by rhizoliths occurring in variable densities. The beds of amalgamated rhizoliths are interpreted by as hardpans equivalent to stage III to IV calcretes of Gile *et al.*, (1981). This interpretation implies significantly reduced sedimentation rates for periods of more than 50,000 years. The micritic limestones were interpreted as playa deposits.

The upper Drywood Creek Formation is equivalent to the upper sandstone-shale member of Hage (1943), Douglas (1951) and the Dinosaur Park Formation of the Judith River Group in the Plains. The formation contains dark grey to black organic mudstones, bentonites, coaly shales, coals, and caliche-bearing mudstones. The fauna are fresh to brackish fauna and the sandstones, which are less than 2 m thick and contain oyster shells, are not fluvial in origin. The Drywood Creek is 55 m thick at the type section but is described as 160 m in the subsurface near the axis of the Alberta Syncline (Jerzykiewicz, 1997).

St. Mary River Formation (Maestrichtian)

The St. Mary River Formation is present in extensive lateral exposures in the river valleys of the Plains and in vertical profiles in the thrusted strata of the Foothills of the Rocky Mountains. Subsurface isopach data show a general westward increase in thickness from approximately 230 m in the Plains to over 900 m in the Foothills (Douglas 1950), but reliable thickness estimates are difficult to confirm because of the low and

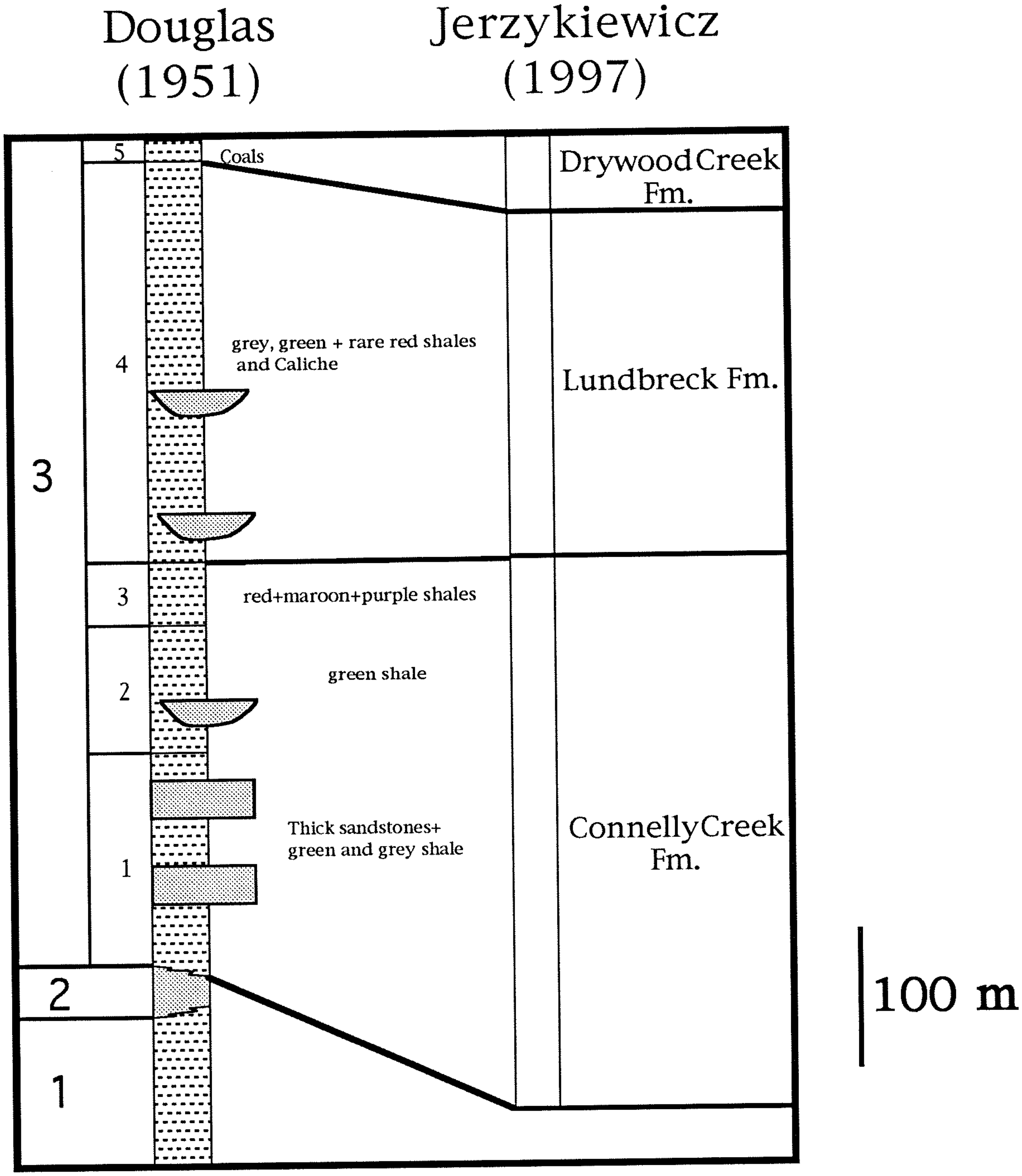


Figure 14. Belly River stratigraphy according to Douglas (1950) and Jerzykiewicz (1997).

Correlation of the Belly River and Judith River Groups

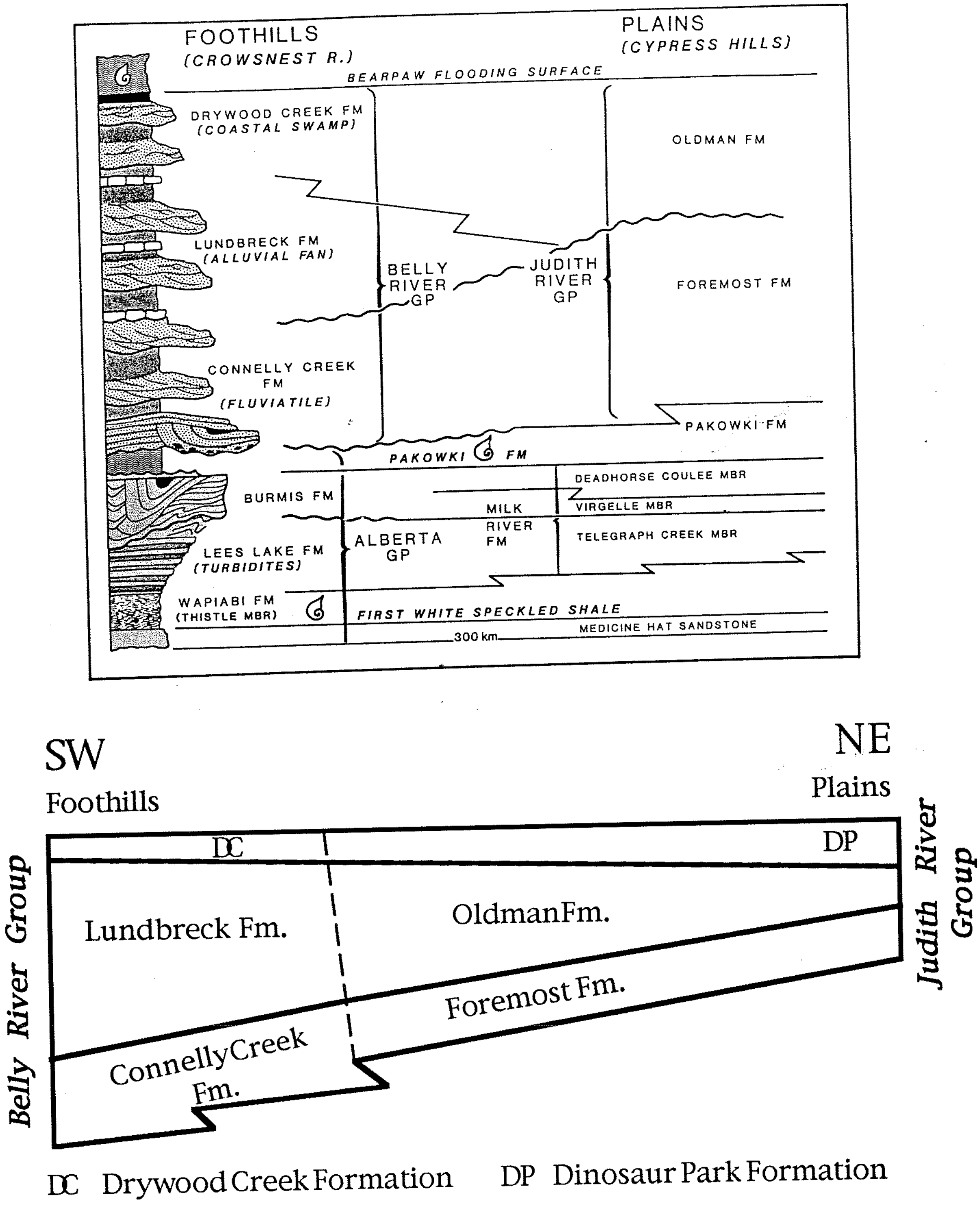


Figure 15. Correlation of the Belly River an Judith River Groups. Upper figure from Jerzykiewicz and Norris (1993)

variable dips in the Plains and the possibility of undetected thrusts within the Foothills and subsurface. Palynomorph data indicate that the St. Mary River Formation is uppermost Campanian to upper Maastrichtian (A. Sweet, personal communication 1991).

The St. Mary River Formation consists of lenticular bodies of medium sandstone surrounded by thin sheets of sandstone, siltstone, and shale. Detailed sections measured in the Foothills yield the lowest sandstone/mudstone ratios, between 0.51 and 0.60. The St. Mary River Formation sediments display significant lateral and vertical heterogeneity but can be divided into four recurring facies associations (Nadon, 1994), which represent channel and levee, splay-channel, crevasse-splay, and floodplain environments.

Facies Association 1 consists of large winged lenses composed of medium to fine sandstone 2.5-9.0 m thick, that have width/thickness (W/T) ratios of 8-27. These lenses are either simple or have at the most two stories. The basal contact varies from erosional with flutes and grooves in the center, to sharp and flat or slightly undulatory at the margins. Directly above the base at the margins of the lenses the sediment is massive to horizontally laminated sandstone to trough cross-bedded, medium to fine sandstone. Tree trunks were found in growth position at the base of a lens margin in two locations.

Above the erosional base is a lag, up to 0.6 m thick, composed of shale/siltstone intraclasts, caliche nodules, pelecypod shells, logs, and, less commonly, dinosaur bones and teeth. The overlying sandstone varies from fine to medium and is mainly trough crossbedded with minor horizontal lamination at or near the base and planar-tabular cross-beds toward the top. The lenses are capped by rippled and climbing rippled siltstone to very fine sandstone. The tops of the lenses are flat. Lateral accretion (LA) and inclined heterolithic stratification (IHS) surfaces, which are both uncommon, are 2-3 m high. Paleoflow was toward the north or northeast.

The margins of the lenses vary from concave to stepped. The stepped margins contain beds that dip at a steep angle from the sandstone into adjacent shales and siltstones of Facies Association 4. The wings of the sandstone bodies are composed of 3-15 amalgamated sandstone and siltstone beds that fine laterally over a few tens of metres away from the lenses. Proximal to a lens, the wings show offlap into the adjacent floodplain with a maximum preserved relief of 0.5-1.0 m. At several locations the beds of one wing can be traced directly into the wing of an adjacent lens (Nadon 1993, Figure 1).

Roots, present as thin, straight to irregularly curved carbon traces, are common throughout the sandstone lenses and wings. Branching in the roots is not common, but where preservation is exceptional, smaller rootlets perpendicular to the main traces are visible. Other carbon traces appear similar to the roots but are infilled with sandstone or siltstone.

Facies Association 2 are smaller channels composed of medium to fine sandstone with sharp, undulatory bases but no basal lag; LA surfaces are commonly delineated by intraclasts. The LA surfaces show symmetrical or vertical accretion but no sustained lateral migration. The lenses are rooted throughout and surrounded by siltstone and sandstone beds of Association 3 and shales and siltstones of Association 4. Paleocurrent directions obtained from these smaller lenses are generally perpendicular to Association 1 trends for a particular stratigraphic level.

Facies Association 3 are siltstone to medium sandstone sheets 0.3-2.5 m thick that extend 10-500 m laterally. The thicker sheets are generally coarser and fine upward whereas the thinner sheets are finer and are equally likely to fine upward, coarsen upward, or show no change. The base of individual beds vary from flat to slightly undulatory to highly irregular with as much as 0.8 m of relief. Sedimentary structures in the thicker sheets include trough crossbeds, horizontal laminations, ripples and climbing ripples; thinner beds are massive or rippled. The tops of beds are flat to slightly irregular and are commonly wave-rippled. Fresh exposures generally appear massive with thin (0.001-0.002 m), long (0.2-0.8 m), straight, and evenly spaced roots. Weathered talus debris shows that these beds are commonly heavily bioturbated. The traces range from monospecific assemblages of open burrows of equal size to complicated networks of intertwined burrows and trails. Paleocurrent directions from ripples are commonly unimodal with a relatively low dispersion, but some beds do show a significant variation from base to top. Paleoflow directions from climbing ripples are commonly perpendicular to those from adjacent major sandstone lenses.

Facies Association 4 is a complex assemblage of gray, brown, and green siltstones and shales that are exposed between the Association 3 sheets. All the shales and siltstones contain varying percentages of expandable clays and are interbedded with many bentonites. Basal contacts of beds vary from flat to highly irregular and are commonly sharp but may also be slightly gradational. The lateral persistence of individual beds varies from tens to hundreds of metres.

All facies in this association contain a variable amount of thinly laminated beds. These beds are most common in dark-brown and dark-gray siltstones and shales and least common in the light-green and dark-green facies. The rest of the beds in each facies type show no preserved sedimentary structures. Disseminated organic debris, roots, bioturbation, and shell material are found in varying proportions (Nadon, 1994). The shell material is mainly fragmented gastropod shells and rare *Unio* bivalve remains. Although roots are common, coals are rare and thin (< 0.4 m thick).

Each of the fine-grained floodplain facies also contains varying amounts of beds with post depositional structures: granular, blocky and blocky with slickensides (Bt; Retallack 1988). Irregular-shaped carbonate nodules are also present.

Discussion

The overall facies distribution of the St. Mary River Formation shows that the unit is dominated by crevasse-splay (Association 3), marsh, and lacustrine (Association 4) sedimentation with rare main channel (Association 1) and splay channel (Association 2) sandstone bodies. The variations in grain size, paleocurrent direction, and textural trends in the crevasse-splay sediments are consistent with those described from Holocene anastomosed fluvial deposits (Weerts and Bierkens, 1993). The geometry and internal structures of the fluvial and splay channels show that they are the products of vertical aggradation and very limited lateral scour, an effect noted also in both modern and Holocene studies (Smith and Smith 1980; Smith 1983, 1986; Törnqvist 1993; Törnqvist *et al.* 1993).

Although coals are rare, the overall facies distribution nevertheless places the St. Mary River Formation as a deposit of an organic-rich, anastomosing river floodplain (suborder C2a) of Nanson and Croke (1992). Smith and Smith (1980) suggested that anastomosed river deposits would be likely sites for coal formation because the channels do not rework the floodplain through lateral migration and because abundant vegetation can grow in the interchannel wetlands. The presence of coal has been used by some as a criterion to support the interpretation of a deposit as anastomosed fluvial. However, recent studies of modern systems show that peat deposits are absent or very minor even in tropical areas such as in the Magdalena River region of Columbia (Smith 1983, 1986). This corroborates the view held by McCabe (1984) that one of the main prerequisites for coal formation is an area isolated from clastic input. With certain exceptions discussed below, the floodplain of a suspended-load river is not such an area. The many crevasses in the levees inundate the floodplain with clastic detritus.

The St. Mary River Formation is interpreted as the deposit of anastomosed rivers that flowed northeastward over a broad, low-gradient plain (Nadon, 1994). In the case of the St. Mary River Formation a low-gradient slope existed over an area larger than 10,000 km^2 for almost 9 m.y. in a region with a seasonal climate.

Waterton River - Willow Creek Formation (Maastrichtian-Paleocene)

The Willow Creek Formation, which overlies the St. Mary River Formation and is capped by the Porcupine Hills Formation, was initially described by Dawson (1884) on the basis of colour. The formation varies in thickness from 320 m along the Oldman and Belly Rivers in the southern Plains to 1,400 m Oldman River upstream of Cowley (Jerzykiewicz and Sweet, 1988). Douglas (1950) divided the formation into five informal. Jerzykiewicz (1997) used the K/T boundary to divide the section into two informal members (Figure 16). Paleocurrent evidence suggests a continuation of the northeasterly paleoflow present in the St. Mary River Formation (Mack and Jerzykiewicz, 1989).

Douglas (1951) described the lower and upper contacts as erosional, however, the presence of the K/T boundary shows that the section is equivalent to the Coalspur Formation in the central Foothills and the Scollard Formation in the central Plains based on the presence of the K/T Boundary in all three units. The basal contact with the St. Mary River Formation was defined by Hage (1943) and Douglas (1950) as the base of the lowest soft grey sandstone that is more quartzose than those in the St. Mary River Formation. Douglas (1950) noted major variations in both colour or lithology between the different units. Units A and B are predominately mudstones with variable amounts of sandstones, however, unit C consists of a conglomerate 4.6-9.1 m thick composed of chert and quartzite pebbles. Unit D is a return to the red mudstones while unit E has an increasing amount of sandstone and is transitional into the overlying Porcupine Hills Formation along the Crowsnest River.

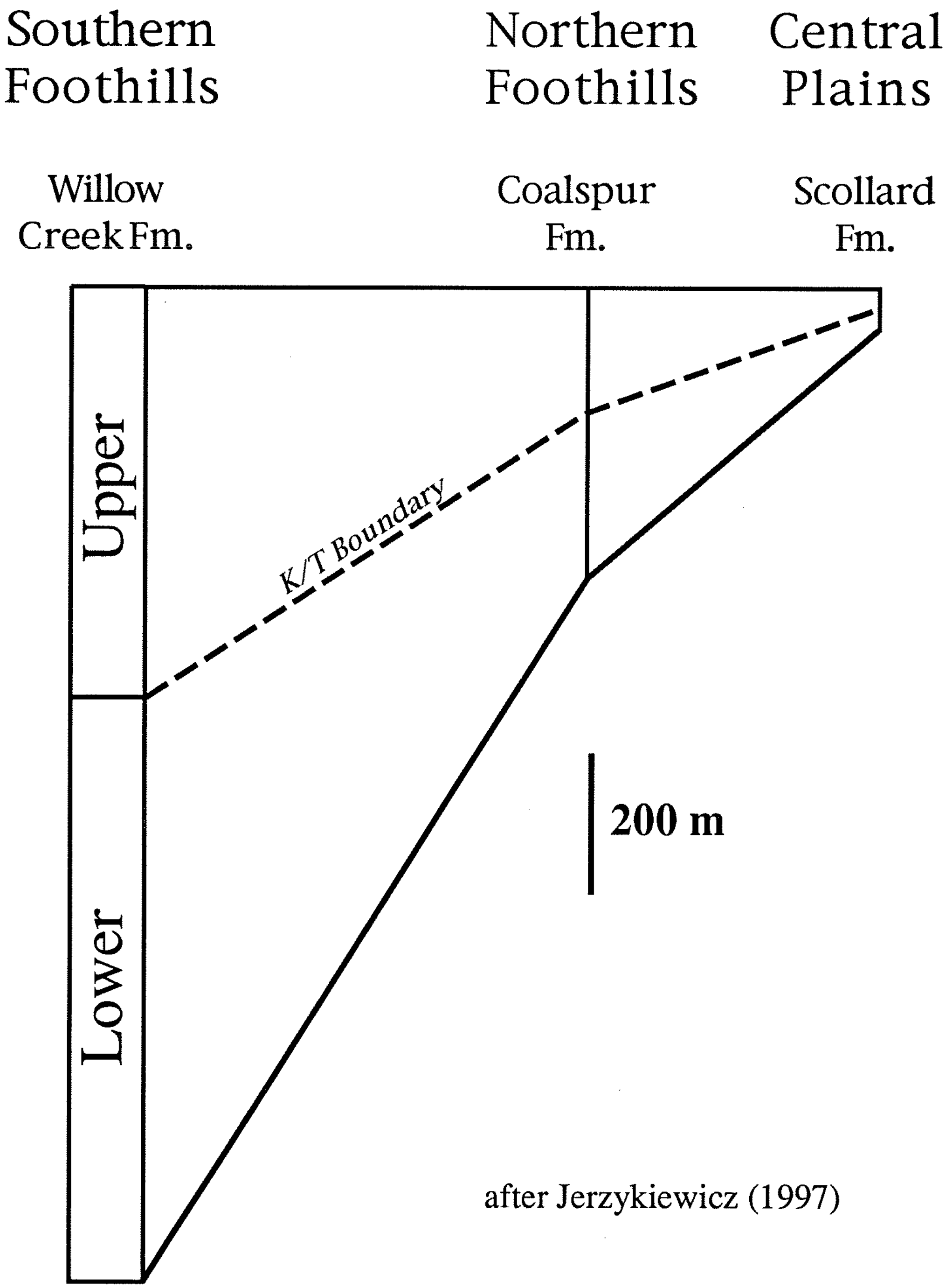
Jerzykiewicz (1997) described his lower unit as mainly pink to red mudstone with greyish olive-green and brown common. The mudstones are described as structureless but also contains caliche (rhizoliths) as "float" in a muddy matrix. Fauna recovered from the Willow Creek are all nonmarine. Thicker channel sandstones are highly lenticular. The upper member is a mostly dark grey mudstone with sandstones that increase in abundance up section. Jerzykiewicz (1997) interpreted the rhizoliths as indicative of annual rainfall of 400-600 mm and suggested that the sediments of the lower member were deposited in a mid to distal alluvial fan setting. The upper member was interpreted as lacustrine deposits (p. 64, fig 73).

Porcupine Hills Formation - Paleocene

The Porcupine Hills Formation (Paleocene), which is exposed primarily in the axis of the Alberta Syncline, is equivalent to the Paskapoo Formation of the central Foothills and Plains. Jerzykiewicz (1997) placed the base of the unit beneath a prominent sandstone underlain by a thick caliche and divided the interval into two informal members at the base of a laterally persistent sandstone best exposed in the Beaver Creek Valley. The Porcupine Hills Formation is primarily grey to green mudstones with interbedded siltstones and thin sandstones up to 50 m thick. The floodplain facies in cores from the Oldman River Dam site are described as structureless mudstones interbedded with laminated siltstones and fine-grained sandstones. Caliche (*i.e.*, rhizoliths) are present but coals are absent. Small micritic calcite nodules are found dispersed within the mudstone and fine-grained sandstones facies (and occasional as lags) that (Jerzykiewicz, 1997) interpreted as possibly from deposition in hypersaline lakes.

Channel sandstones, which are up to 30 m thick, are of two types; 1) laterally discontinuous multistory complexes and 2) laterally continuous complexes. Both contain paleocurrent readings indicating flow was toward the northeast (Jerzykiewicz, 1997). Type 1

Correlation of the Willow Creek Formation with formations to the north and east



after Jerzykiewicz (1997)

Figure 16. Correlation of the Willow Creek Formation with formations to the north and east.

channels have width/thickness ratios as low as 4 and are described as of either braided or anastomosed origin. Type 2 sandstones are described as flash-flood deposits.

Oligocene Cypress Hills

The foreland basin succession of Saskatchewan and Alberta is locally overlain by remnant Tertiary gravels of varying ages, ranging from Eocene to Pliocene.

The Upper Eocene to Miocene Cypress Hills Formation is one such unit that crops out on the plateau crest of the Cypress Hills (Figure 17). The Cypress Hills Formation is made up primarily of gravel with minor sand and silt lenses. An angular unconformity separates the base of the Cypress Hills Formation from the underlying Ravenscrag Formation. The basal contact is irregular and is marked by incision with fluvially-scoured potholes and channels. The east — west distribution of outcrop exposes facies representing lateral variation across the slope of the braidplain. Overall, the average gravel clast size decreases from west to east, with the western area sediments dominated by boulder-sized gravels deposited on longitudinal bars. The eastern outcrops contain deposits of braided channels cut into and interbedded with finer interchannel material including lacustrine marlstones, silcretes, and debris-flow deposits, the latter commonly containing abundant fossils. Local recycling is indicated by debris-flow deposits interlayered with the braided river sediments.

The gravel consists of well-rounded clasts up to 40 cm maximum dimension of quartzite, chert, arkose, limestone, and dolomite. Minor but important igneous clasts include porphyritic basalt and andesite, trachyte, phonolite, flow-banded rhyolite and obsidian, and porphyritic and equigranular granitoids. Rare metamorphic clasts include argillite, granite gneiss and metaquartzite.

The Cypress Hills Formation is interpreted as a northeast-flowing braidplain deposit, with multicyclic gravels that were originally derived from the western ranges of the Rocky Mountains during Laramide orogenesis (Figure 18). The gravels were subsequently shed farther into the basin during rebound due to unloading of the Laramide thrusts by erosion. Most recent transport resulted from uplift by intrusive activity of the Sweetgrass Hills, the Bearpaw Mountains, and the Highwood Mountains in northern Montana. Transport from the uplifted source areas was largely restricted to valley-confined rivers with the braidplains beginning beyond the valley termini. Minor reworking of the top of the formation occurred on the Cypress Hills plateau during the middle Miocene.

Siliceous nodules within the Cypress Hills Formation are similar to silcretes described elsewhere in the literature but their morphology and occurrence suggests that they are of a rare variety. The silcretes are discrete equant to disc-shaped nodules, 1-3 cm thick, and up to 15 cm long. The silcretes form horizontal, discontinuous layers parallel to bedding within the an unweathered profile. Void spaces and fractures within the nodules are lined or filled with druzy quartz. The silcretes are filled with less than 0.07% TiO_2. The $TiO_2/SiO_2/Al_2O_3$ and $TiO_2/SiO_2/Fe_2O_3$ ratios are similar to values obtained from nodules formed in an arid to semi-arid environment based on comparison to modern silcretes. This interpretation is confirmed by sedimentological and paleontological climatic evidence form associated deposits.

Del Bonita Periglacial, Pleistocene

Many of the upland surfaces in western Canada have not been glaciated but remained as nunataks during the last glaciation. These uplands are erosional remnants mantled with Tertiary Gravel. During glacial periods, periglacial conditions resulted in the formation of ice-wedge

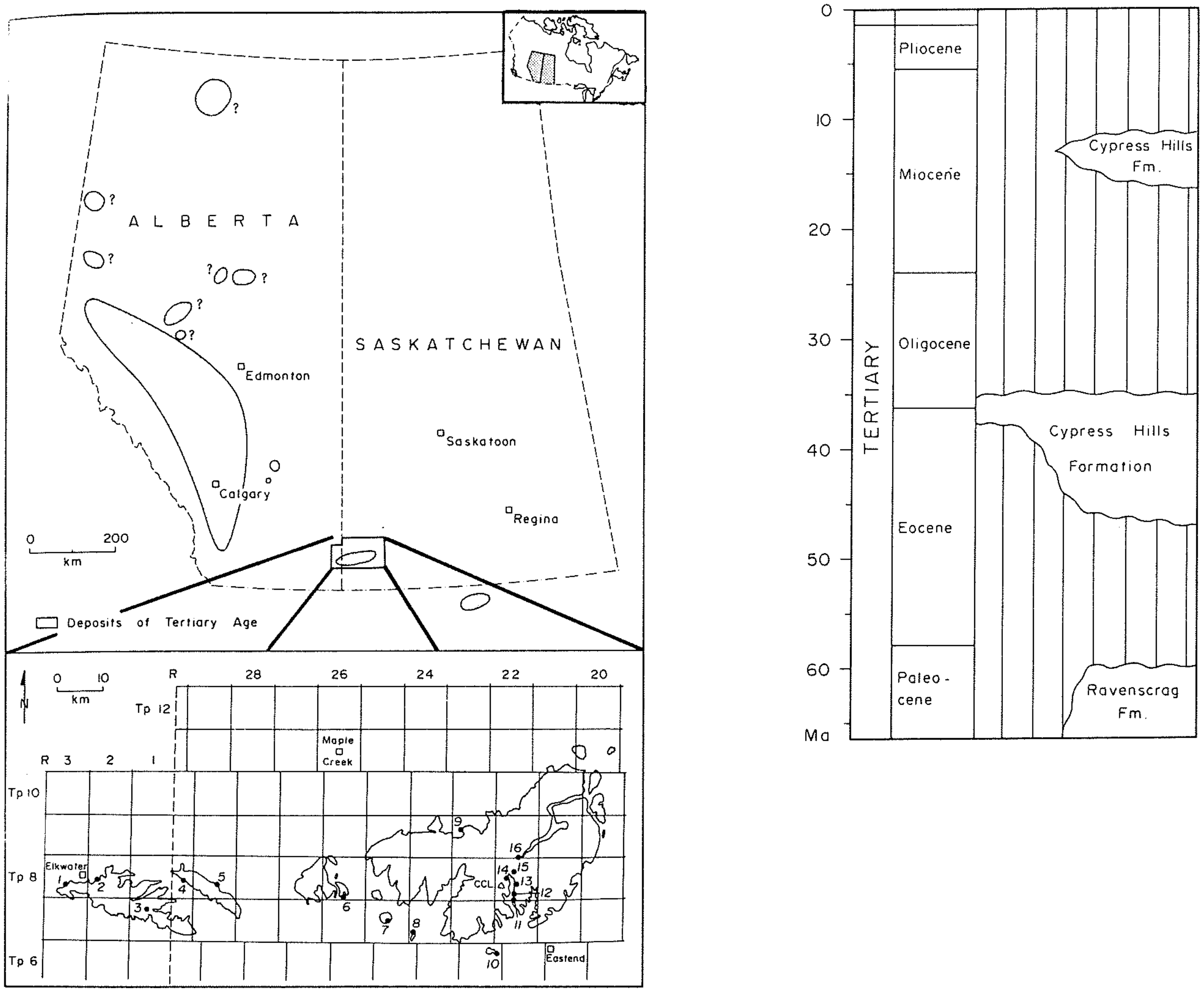
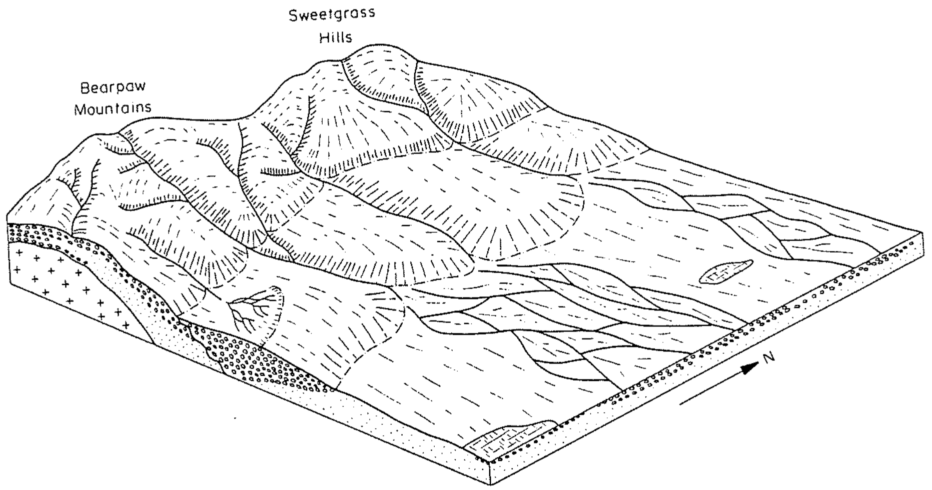


Figure 17. Location and stratigraphy of Cypress Hills Formation outcrop and other Tertiary gravels in the plains.



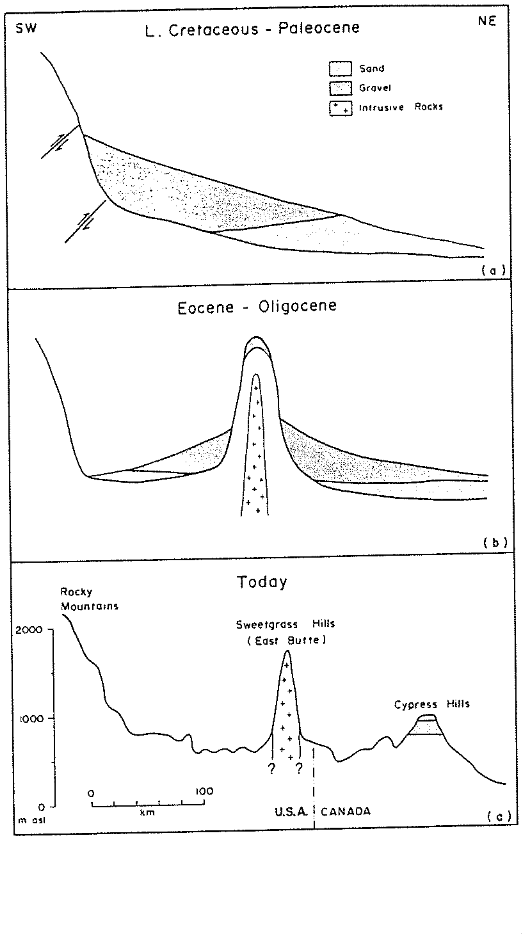


Figure 18. Reconstruction of environment of deposition of the Cypress Hills Formation and sequence of events to account for the origin and provenance of the Cypress Hills Formation.

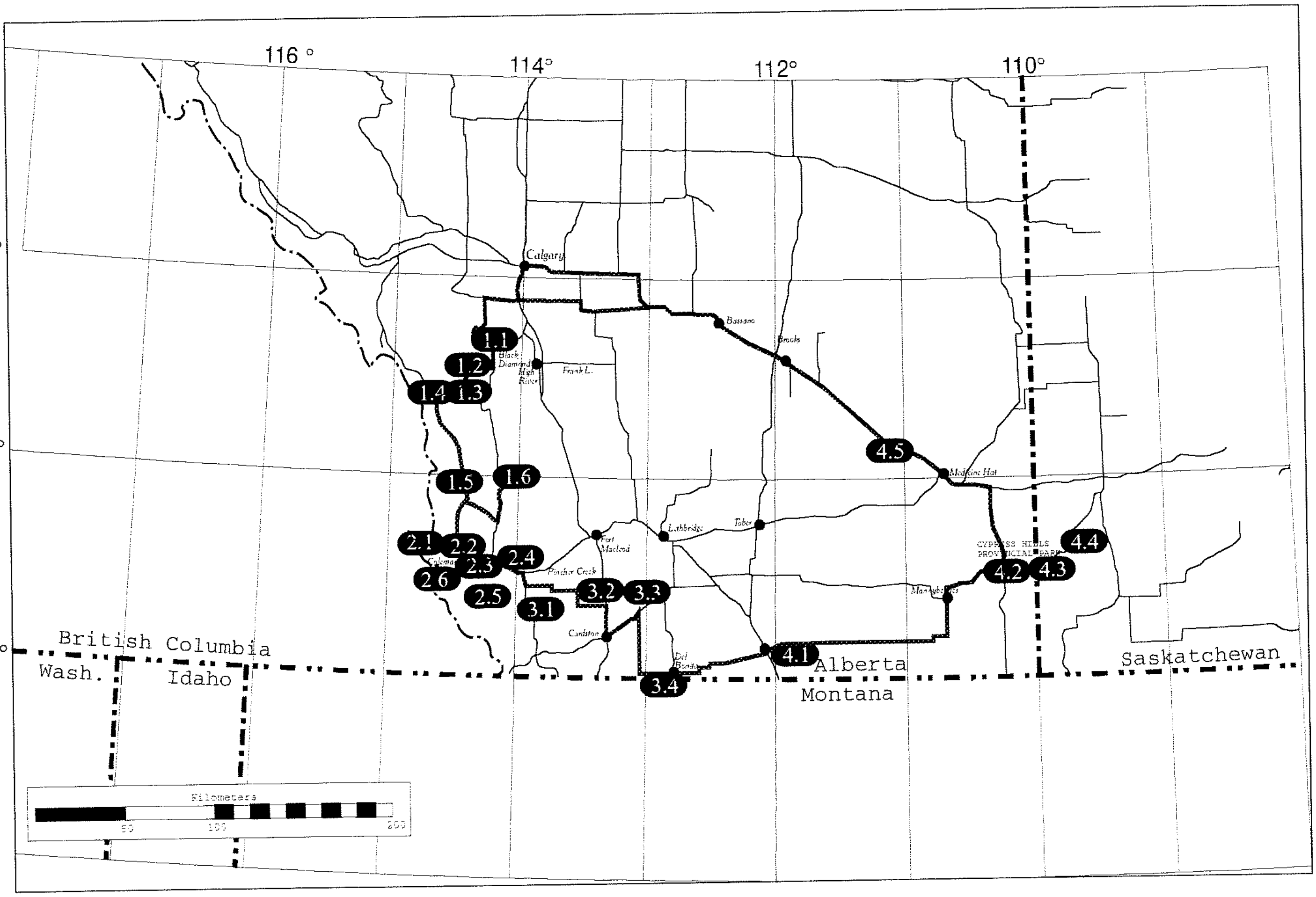
casts, frost boils and patterned ground. We will see examples of these on the Del Bonita uplands and across the province, at the Cypress Hills.

Crowsnest Pass Modern Drainage Divide

Minor uplift and faulting in the Foothills continued at least into the Paleocene (McMechan and Thompson 1993). The drainage divide remained within the Rocky Mountains, near the present divide position, since the end of the Paleocene, when modern drainage systems became established (Stalker 1968a). There has been over 100 m of downcutting by some outboard rivers over the past million years (e.g., Bow River; Stalker, 1968b). Uplift is sufficiently slow that the rivers can erode and keep pace with it, so stream capture and divide shifting was limited. However, the position of the present divide is tenuous, such that if major compression had continued, some parts of the divide would have undergone another eastward shift. Only about 250 m of net uplift in the Front Ranges is now required to allow westward capture of all the drainage of the Main Ranges through Yellowhead, Howse, Kicking Horse, and Crowsnest Passes (Figure 3). This capture would cause the drainage divide to step to the Front Ranges for the whole length of southwestern Alberta.

FIELD STOPS

We have attempted to present data in a generally oldest to youngest sense; however, there will be necessary departures from this trend imposed by the locations of outcrops relative to roads. Time, floods, snow or weather constraints may prevent us from visiting some of the outcrops and the field trip will be modified accordingly.



Field Trip Route

Day 1

Stop 1.1:

Location: Black Diamond, Sheep River, Highway 7

Formation: Connelly Creek (Belly River Group)

Age: Campanian

Fluvial Style: Meandering

Climate: Seasonal rainfall, savanna-like

Important Points: Meandering fluvial deposits with associated floodplain facies.

Description:

This outcrop provides an example of fine to medium-grained meandering fluvial channel sandstones interbedded with floodplain mudstones, siltstones and fine-grained sandstones (Fig. 1.1.1). Channel sandstones occur as tan to light grey, resistant bodies up to 8 m thick and generally form persistent ridges. Stratification consists of trough crossbeds, ripple cross lamination and parallel bedding. Scale of crossbedding thickness decreases upwards in some units. Low-angle (12-17°) dipping surfaces (lateral-accretion surfaces) commonly cut through the sandstone bodies and may be draped by a thin clay layer. Bases of the sandstone beds are sharp-based and contain abundant clay-pebble intraclasts, woody plant fragments and (rarely) scattered chert pebbles and dinosaur bones. Trough crossbeds within the channel sandstones indicate paleoflow towards 55° and 83°. Two sets of lateral accretion surfaces on different sandstone bodies dip towards 158° and 316°, roughly orthogonal to the crossbeds.

The non-channel facies consists of olive-green to grey, recessive-weathering sandy mudstones with 10-60% interbedded tan to light grey sandstones. The mudstones are carbonaceous, rooted, and interbedded with thin coals. Pedogenic slickensides are common within mudstones. The sandstone interbeds are typically sharp-based, laterally discontinuous and may show evidence of loading at their base. Climbing ripples within one thin sandstone at ~40 m indicate paleoflow towards 316°, perpendicular to the trend of the thick sandstones.

The lateral extent of the sandstones within the Connelly Creek Formation combined with the lateral accretion surfaces suggest they were formed by a northeasterly flowing meandering fluvial system. The amount of mudstone preserved between channel sandstones suggests rapid subsidence of this portion of the basin. The sharp-based sandstone beds are crevasse splay deposits that generally flowed perpendicular to the main channels. Loading at the base of the sandstones may be dinosaur tracks.

Paleosols contain stacked cumulative, multiple soil events which are metres thick. The roots, peds, and clayskins show that paleosols formed between ongoing flood events. Comparing with results obtained by P. McCarthy for the Blairmore Group (pers. comm., 1997), the soils suggest a near balance between subsidence and sedimentation rates. The grey and green coloration of the mudstones is indicative of gleyed (high water table) conditions on the floodplain. Some of the macroscopic pedogenic indicators include:

- roots
- blocky structure
- illuvial clay coatings
- pedogenic slickensides.

Key References: Douglas (1950); Rosenthal et al. (1984); Currie et al., (1991)

Basal Belly River Group - Black Diamond

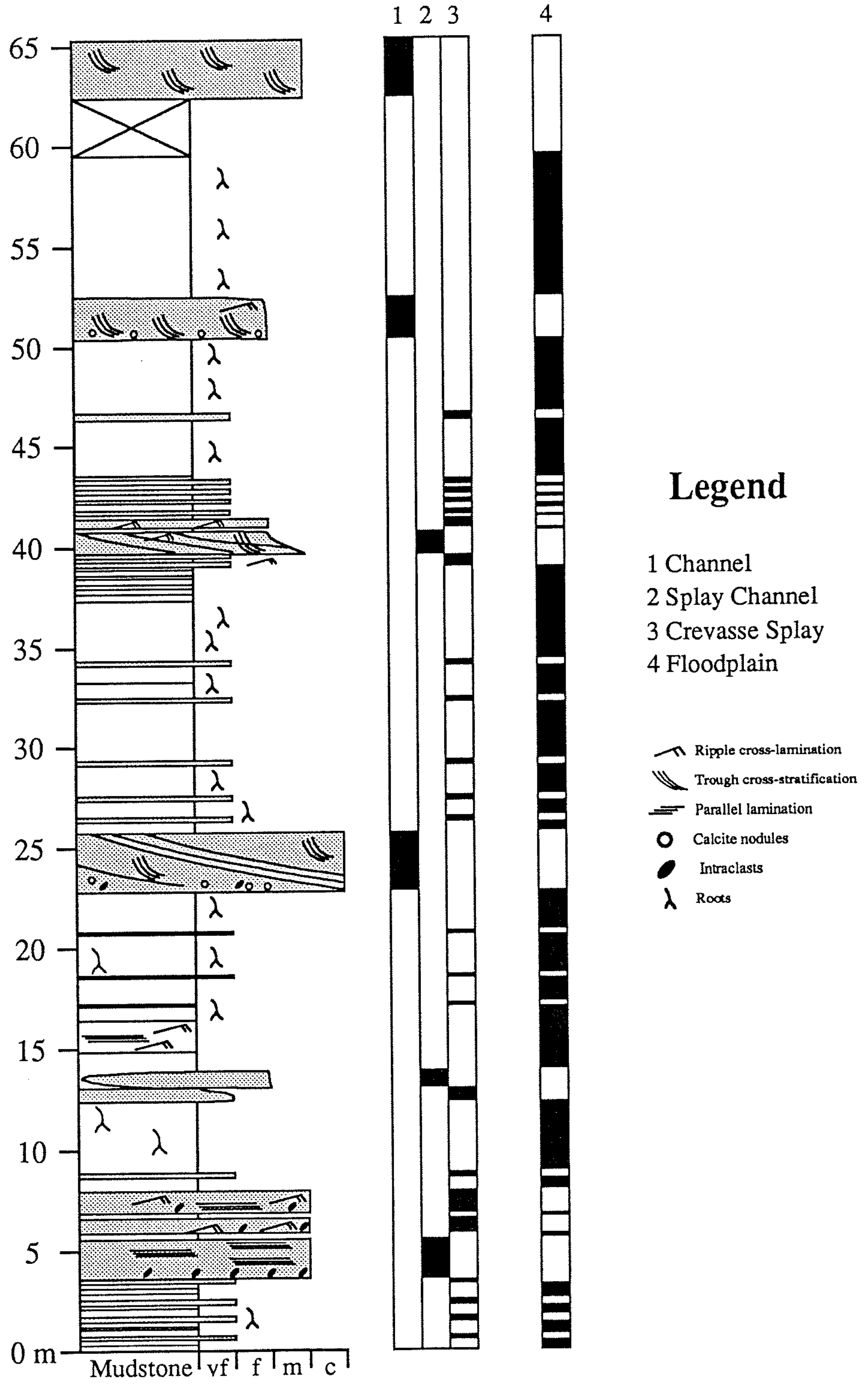


Figure 1.1.1. Measured section of meandering fluvial deposits of the Campanian Connelly Creek Formation (Belly River Group) at Black Diamond.

Stop 1.2:

Location: Rio Alto Ranch, Highwood River, west of Longview (Note: permission is required before accessing land)

Formation: Blairmore Group, Mill Creek Formation

Age: Albian

Fluvial Style: braided river, incised valley

Climate: warm, temperate with seasonal precipitation

Important Points: Incised braided channel deposits; far-traveled igneous clasts to cobble and small boulder size; paleocurrent perpendicular to mountains, into basin.

Description:

This outcrop of igneous clast conglomerate in the Blairmore group occurs within one of ten channels (Highwood Channel) that flowed east into the foreland basin (Fig. 1.2.1). Highwood Channel is 22 km wide and has been delineated by six outcrops occurring on four thrust sheets and subsurface data to the east. Outcrop at Forgetmenot Mountain may represent a tributary feeding into Highwood Channel. Overall, Highwood Channel is finer grained than that in the Crowsnest Channel area.

At Rio Alto Ranch, igneous clast conglomerate has been brought to the surface on two thrust ridges 0.75 km apart. The conglomerate bodies are 37.5 m (western) and 21 m (eastern) thick and are ~0.8 km wide (Fig. 1.2.2). The eastern conglomerate exposure consists of parallel-bedded gravels, 30-40 cm thick alternating with discontinuous parallel-laminated, pebbly sandstone layers which are about 10-15 cm thick. The lower half is massively bedded. There is an overall upward fining to the conglomerate. Clasts average 1.5 to 3 cm diameter with a maximum size of 25 cm. Shale clasts up to 1 m x 20 cm occur at the base. Carbonized tree casts are locally abundant. The two outcrops define a channel trending towards 100° which is consistent with the paleocurrent data (Fig. 1.2.1) and more regional channel trend. The conglomerate pinches out laterally over a short distance to the north and south. In Highwood River across the road, there is no conglomerate.

The conglomerate is overlain by 21 to 34 m of medium-grained, trough-crossbedded and parallel-laminated sandstone which contains shale clasts but no pebbles. This sandstone is present at all locales where the conglomerate has been found. The sandstone and conglomerate couplets probably define the depth valley incision. When cross the St. Mary River in two days, look at the river as a partial analog for this river type. The igneous clasts and associated detrital gold are derived from igneous and volcanic source terrains in the Omineca Belt where were about 350 to 400 km away.

Key References: Leckie and Krystinik (1995); Leckie and Craw (1995); Craw and Leckie (1996)

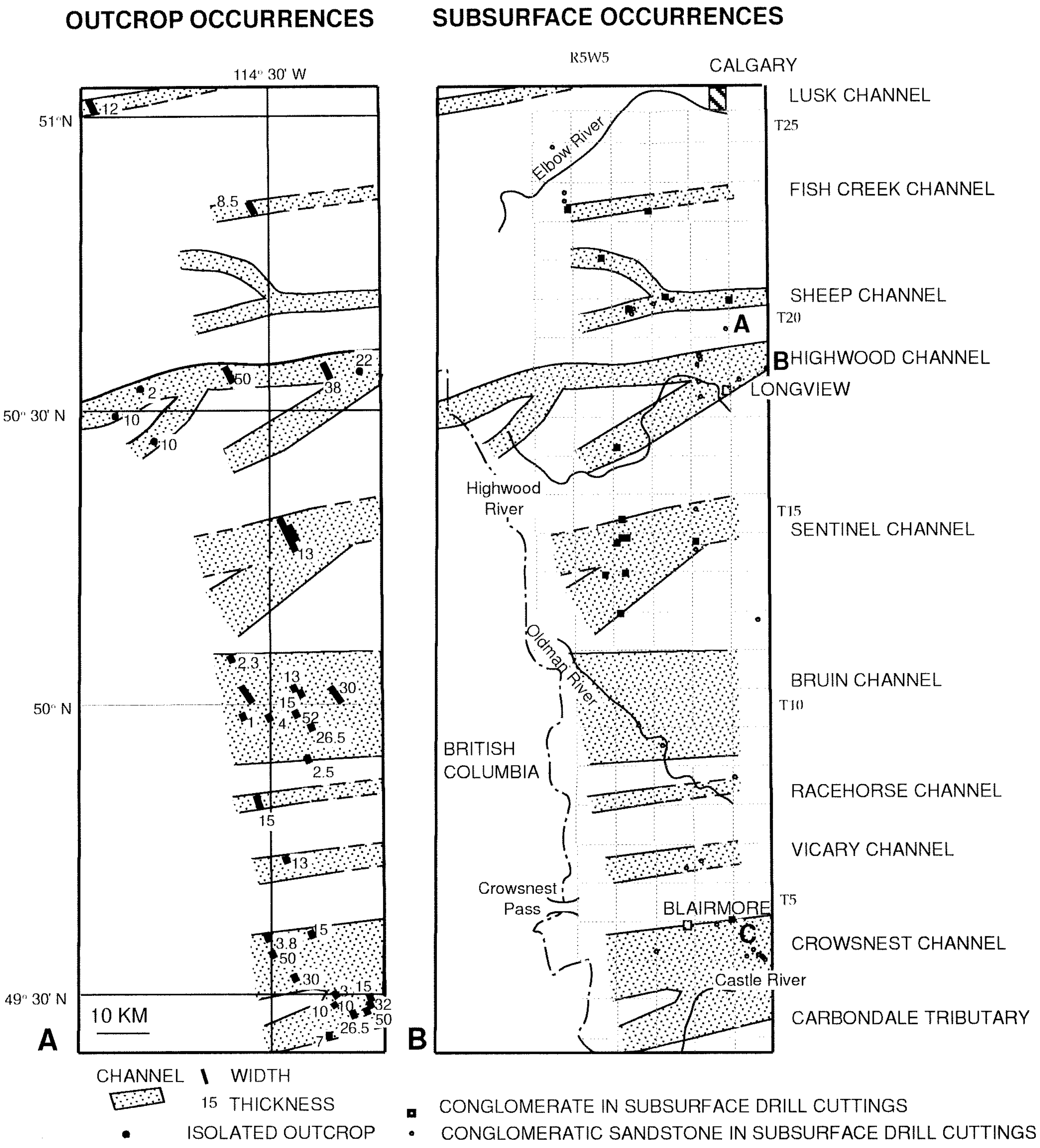


Figure 1.2.1. Distribution of channels of igneous-clast conglomerate based on outcrop (A) and subsurface data (B).

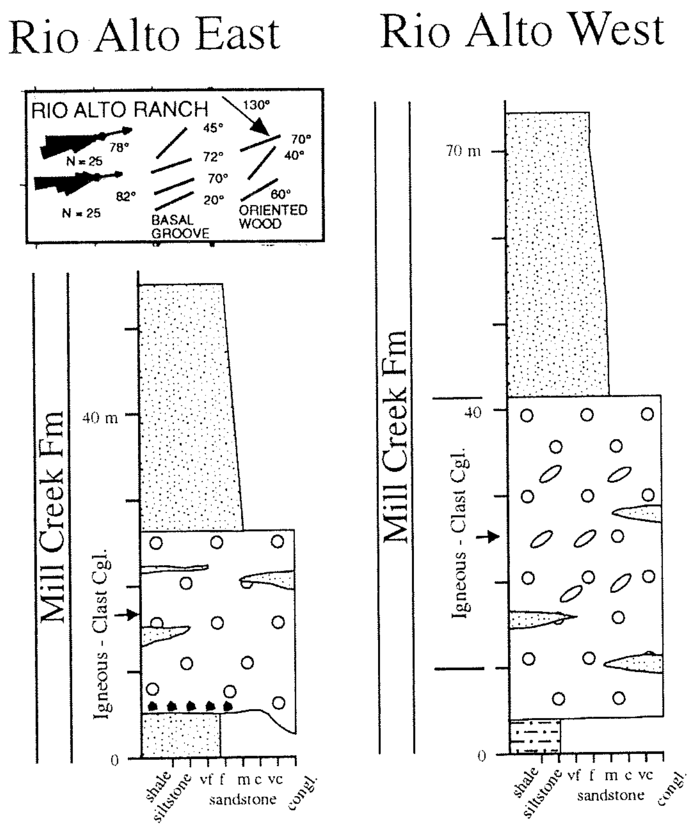


Figure 1.2.2. Measured section of incised braided river deposits of the igneous-clast conglomerate within the Blairmore Group.

Stop 1.3:

Location: Fir Creek, Kananaskis Country

Formation: Jurassic Kootenay, Cadomin Formation, Dalhousie Formation, Cretaceous Gladstone-Beaver Mines Contact

Age: Jurassic to Lower Cretaceous

Point of Interest:,

Fluvial Style: braided sandstone and conglomerate sheet; meandering river floodplain

Climate:

- Cadomin Formation: warm and dry climate with seasonal wet periods

Important Points: organic-rich nonmarine sandstones of Mist Mountain Formation below Cretaceous unconformity; basal Cretaceous Unconformity, braided conglomerate sheet, braided sandstone sheet; profound basin-wide unconformity at base of Cadomin Formation; weathering surface on Cadomin Formation.

Description:

Jurassic Kootenay Group

The lower part of the section (Figure 1.3.1) consists of the Jurassic Mist Mountain Formation of the Kootenay Group. A detailed analyses and interpretation of fluvial sedimentology of the Mist Mountain Formation has not been carried out. Features to note include the large amount of sandstone; coals, and transported carbonaceous debris. The water table was relatively high, preventing oxidation of organic matter.

Lower Cretaceous Cadomin Formation

The top of the Mist Mountain has been truncated by the regional unconformity associated with the Cadomin Formation. There is 5 m of conglomerate overlain by sandstone of the Dalhousie Formation.

Lower Cretaceous Dalhousie Formation

The Dalhousie Formation consists of 10 m of medium to fine-grained sandstone, capped by a weathering surface (paleosol).

Key References: Leckie and Cheel (1996); Ricketts and Sweet (1986)

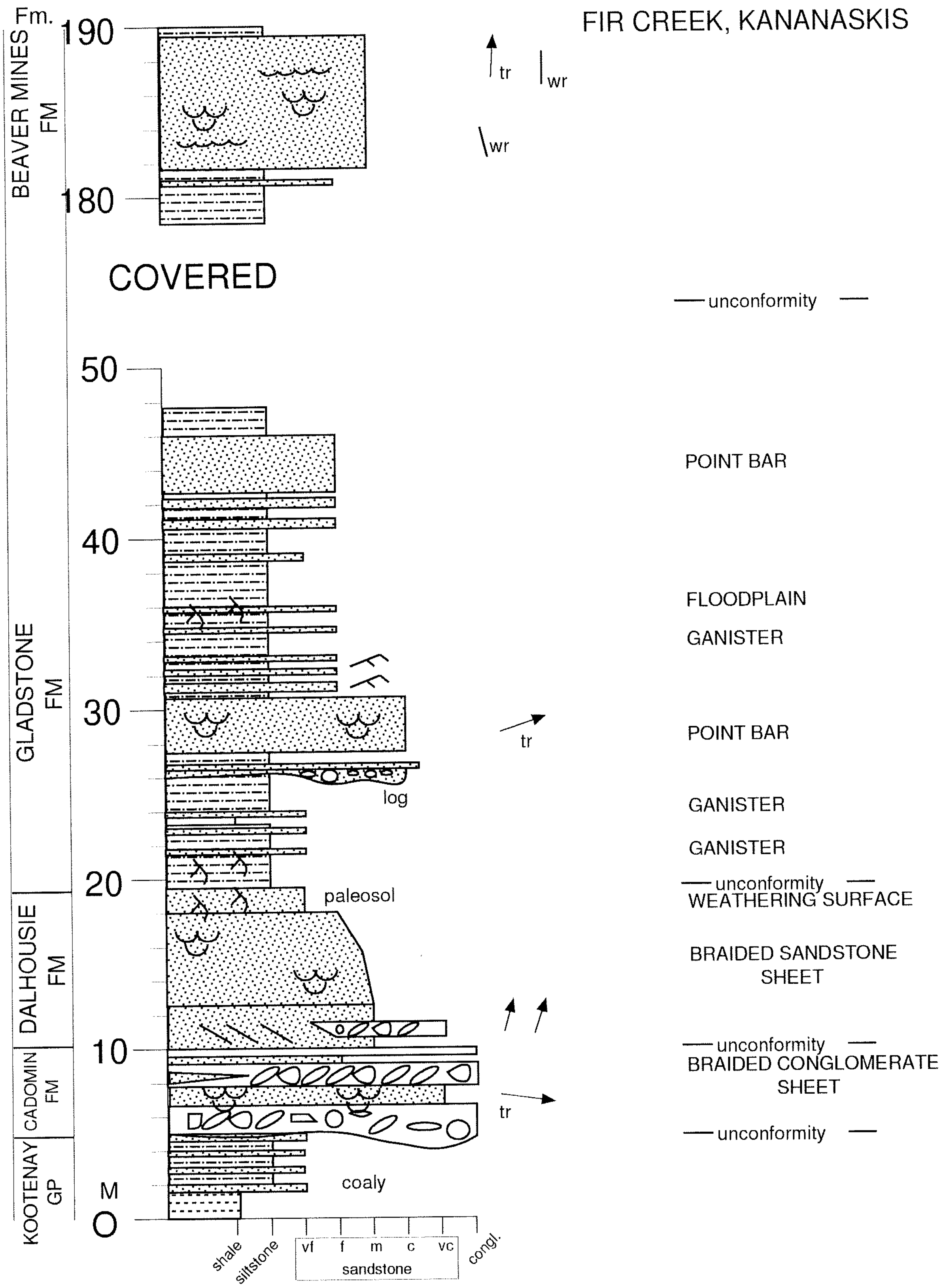


Figure 1.3.1. Measured section of Cadomin, Dalhousie and lower Gladstone formations at Fir Creek, Kananaskis Country.

Stop 1.4:

Location: Highwood Junction

Note: Pedogenic aspects of this stop carried out by P. McCarthy (cited below)

Formation: Jurassic Kootenay Group, Cretaceous Cadomin Formation, Gladstone-Beaver Mines Contact, Mill Creek Formation

Age: Jurassic to Lower Cretaceous

Fluvial Style: varying from braided fluvial sheet, to meandering river floodplain

Climate:

- Cadomin Formation: warm and dry climate with seasonal wet periods
- Mill Creek: mean annual temperature of 5-20°C; mean annual precipitation of 500-1500 mm (based on paleosol investigations of P. McCarthy, cited below)

Important Points: organic-rich nonmarine sandstones of Mist Mountain Formation; basin-wide unconformity at base of Cadomin Formation; weathering surface on Cadomin Formation; basinwide petrological change between Gladstone and Beaver Mines formation; paleosols in Mill Creek Formation.

Description:

Jurassic Kootenay Group

The lower part of the section consists of the Jurassic Mist Mountain Formation of the Kootenay Group. A detailed analyses and interpretation of fluvial sedimentology of the Mist Mountain Formation has not been carried out. Features to note include the large amount of sandstone; coals, and transported carbonaceous debris.

Lower Cretaceous Cadomin Formation

The top of the Mist Mountain has been truncated by the regional unconformity associated with the Cadomin Formation (Fig. 1.4.1). Some have suggested that this unit is actually is Pocaterra Creek Member, however, our call at this time, is that this the Cadomin.

Contact Between the Gladstone and Beaver Mines formations

The contact between the Gladstone and Beaver Mines formations (Upper to Lower Mannville Contact) is marked by a basinwide petrographic change. The contact occurs near the top of the marine to brackish Ostracode Member in the middle of the section. The Gladstone is characterized by dominantly quartzose (with lesser cherts) sandstone. The Beaver Mines Formation is characterized by an abrupt increase in feldspar content, volcanic rock fragments, slate and phyllite.

The reason for the abrupt and basinwide petrological change has not been properly accounted for yet.

Mill Creek Formation

Paleosols within the Mill Creek Formation typically do not preserve a conventional A-B-C horizon profile (McCarthy references cited below). Rather, they contain stacked cumulative, multiple soil events which are metres thick and are the result of near-balance between sedimentation and subsidence rates. Mud-dominated floodplain deposits contain stacked alternations of red, green and variegated mudstone. Macroscopic pedogenic indicators include:

- roots
- blocky structure
- color mottling
- ferruginous nodules
- illuvial clay coatings
- pedogenic slickensides.

The lack of coals and carbonaceous shale suggests at least seasonal oxidizing conditions on the floodplain or high depositional rates.

The variegated coloration may in part be due to the mineralogy of volcanic-derived material (from the Crowsnest Formation).

Key References: McCarthy et al. (in press, a, b, c, d,)

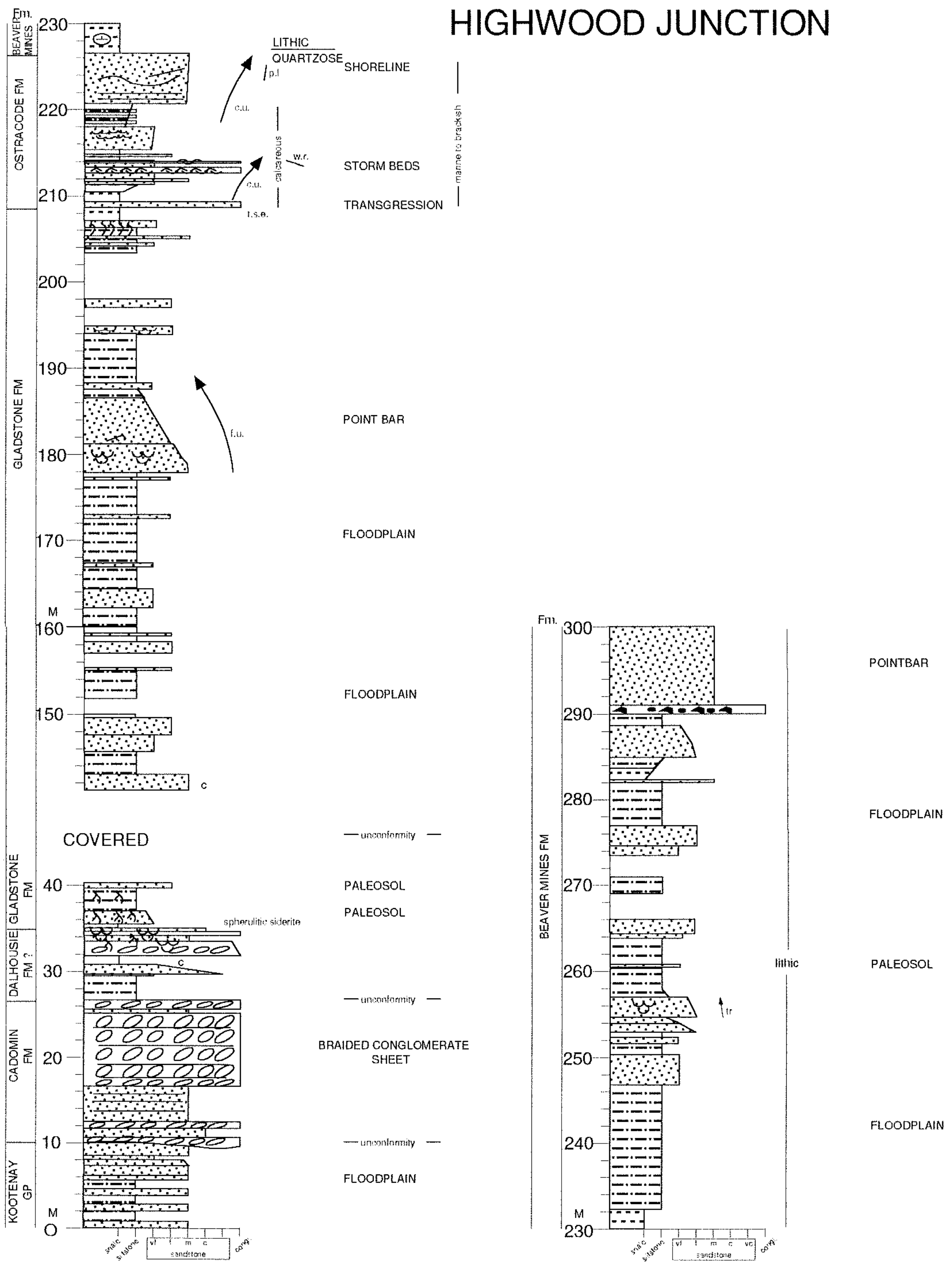
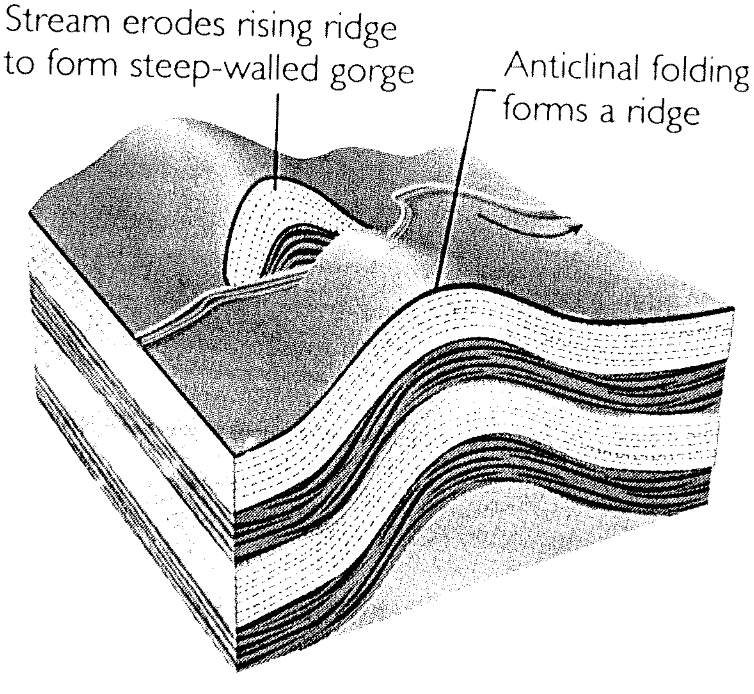


Figure 1.4.1. Measured section of Blairmore Group at Highwood Junction. The Gladstone/ Beaver Mines contact a basinwide petrographic change. The Gladstone is dominantly quartzose (with lesser cherts). The Beaver Mines is characterized by an abrupt increase in feldspar content, volcanic rock fragments, slate and phyllite.

Stop 1.5:
Location: Oldman Gap at junction of Oldman River and Highway 940
Age: Modern
Important Points: Antecedent topography
Description:
The field trip south along the Forestry Trunk Road (Hwy. 940) follows Livingstone Creek as it flows through strata of the Blairmore Group. Livingstone Creek joins the Oldman River as it turns south (approx. section 30 Twp 11 Rng 3W5) along a series of shallow synclines within the Blairmore strata. The Oldman River gradually passes through Kootenay and Fernie strata and then abruptly cuts east across the thrust sheets of Triassic and Mississippian carbonates that form the Rocky Mountain Front Ranges (Fig. 1.5.1). Douglas (1950) documented folded thrusts in the valley walls of the Gap. The Oldman River continues more or less eastward through the folded and thrusted sediments of the Jurassic and Cretaceous strata of the Foothills.
Key References: Douglas (1950)



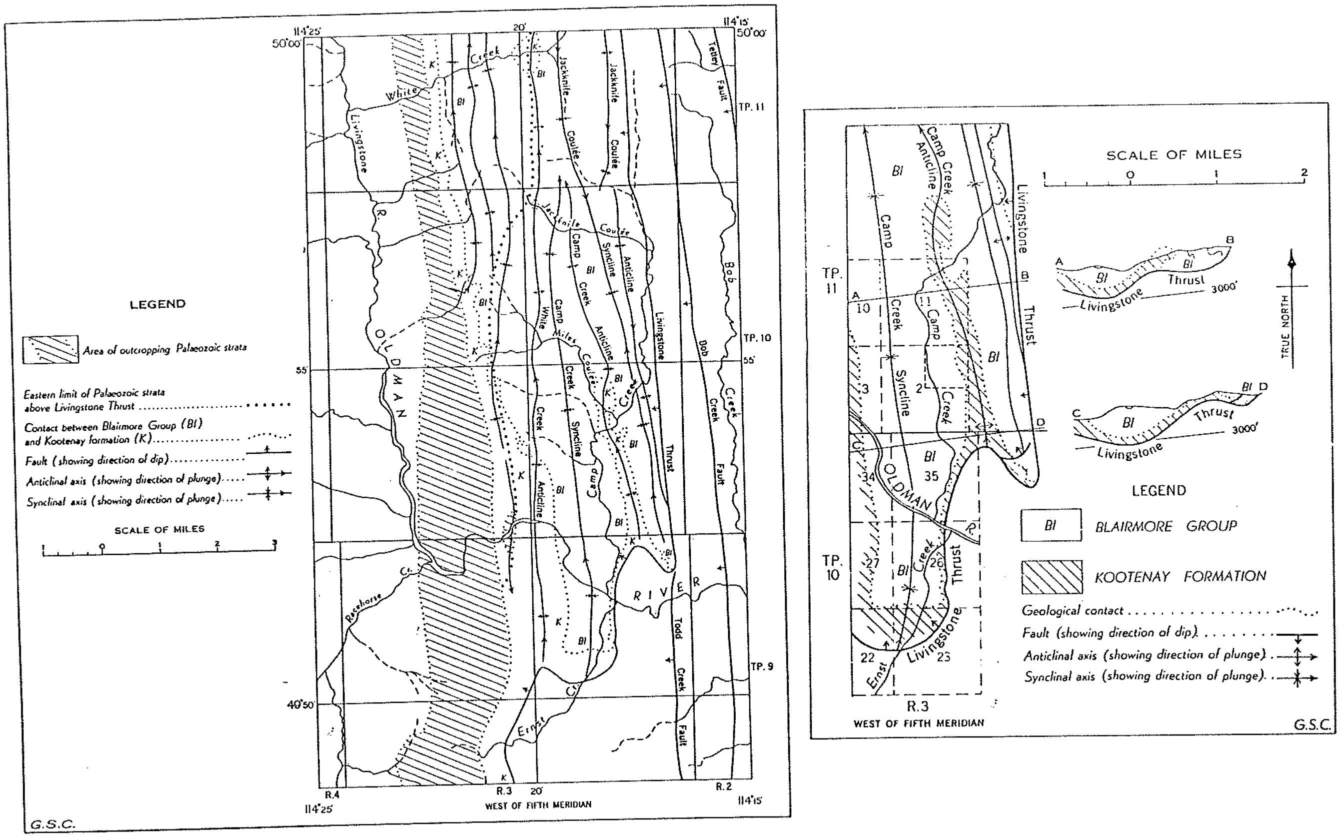


Figure 1.5.1. An example of antecedent topography where the Oldman River crosses the Rocky Mountain Foothills (Douglas, 1950).

Stop 1.6
Location: Oldman River at Maycroft
Formation: St. Mary River
Age: Campanian-Maestrichtian
Fluvial Style: Anastomosed
Climate: Seasonal, savanna-like
Important Points: Rare lenticular channels, abundant sheet sandstones, immature paleosols, dinosaur tracks.
Description:

This exposure of the St. Mary River Formation exhibits a near complete section (~900 m) from the underlying Campanian Bearpaw Formation to the Maastrichtian Willow Creek Formation (Fig. 1.6.1). Although there are numerous faults cutting the section there is very little repeated section (Stockmal, pers. comm., 1995). Thick sandstones are rare (Fig. 1.6.2; Currie *et al.*, 1991). Paleocurrents within the thickest sandstones show flow toward the northeast. The margins of several of the channel sandstones are present within the section.

The floodplain sediments, which predominate, contain thin, rippled to massive sheet sandstones with irregular bases that are commonly rooted and interbedded with mudstones. The mudstones vary from nearly black to light grey and from well laminated to thin blocky. Clayskins are common. Thin coals and carbonate beds are thin and rare.

The thick sandstones represent the main channel sandstones within the St. Mary River Formation. The presence of multiple channel margins along only 10 m of strike section is indicative of highly lenticular sandstone bodies, i.e., these channels did not meander across the floodplain. Thinner, sheet sandstones represent crevasse splay and overbank deposition during high water events. Disruption at the base of the sandstones represents the infill of dinosaur tracks (Nadon, 1993).

The mudstones represent environments varying from lacustrine (carbonate and laminated, black mudstone) to marsh (rooted, massive to blocky grey to green mudstones). The clayskins and peds are indicative of paleosols. The low intensity of the paleosols suggests that the section was rapidly aggrading.

Key References: Douglas (1950); Currie *et al.* (1991); Nadon (1994)

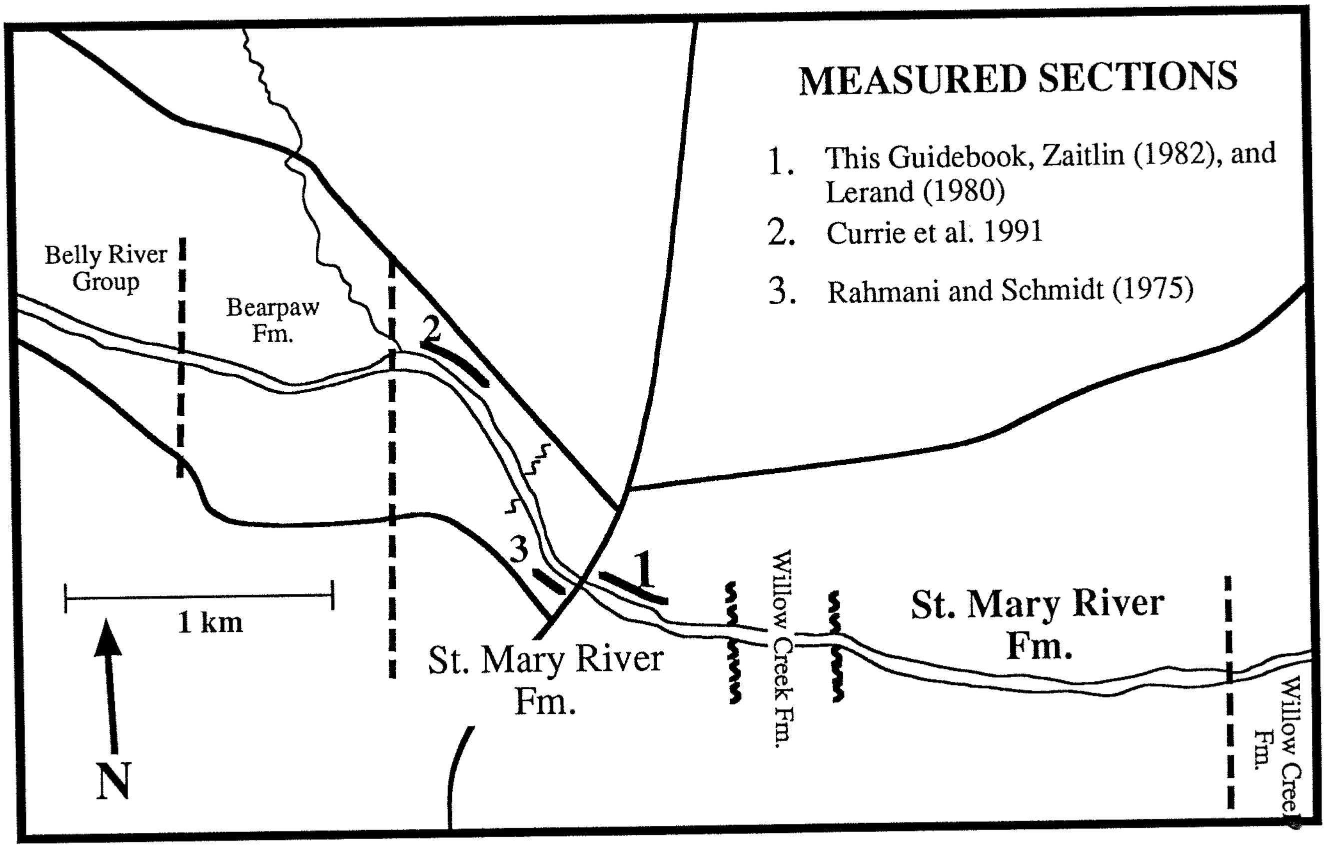


Figure 1.6.1. Simplified geological map in the Maycroft area showing location of measured sections.

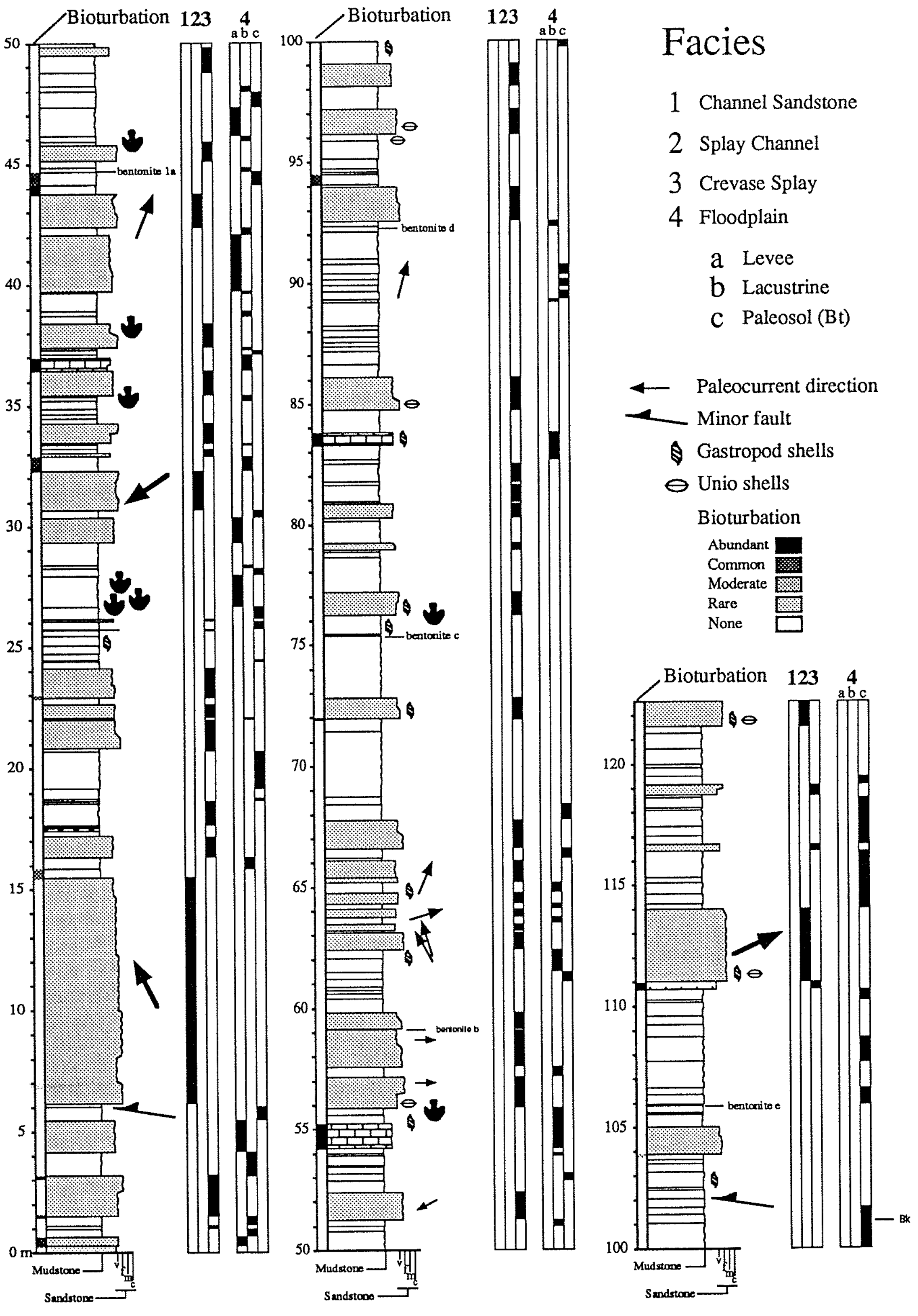


Figure 1.6.2. Measured section of St. Mary River Formation at Maycroft.

Day 2
Stop 2.1:
Location: Crowsnest Pass
Age: Modern
Climate:
Important Points: Modern drainage divide
Description:

The Crowsnest Pass (Fig. 2.1.1) is one of two separate, continental drainage divides we will visit during the field trip. The Columbian Orogeny which originated the Rocky Mountains commenced during the Early to Middle Jurassic. Over time, deformation front moved progressively eastwards. Drainage divides shifted eastwards and westwards throughout development of the Rocky Mountains. Uplift and faulting in the Foothills has continued at least into the Paleocene (McMechan and Thompson, 1993). The drainage divide remained within the Rocky Mountains, near the present divide position, probably since the end of the Paleocene, when modern drainage systems became established (Stalker 1968a). There has been over 100 m of downcutting by some outboard rivers over the past million years (e.g., Bow River; Stalker, 1968b; Osborn et al. 1991). Uplift has been sufficiently slow that the rivers can erode and keep pace with it, so stream capture and divide shifting was limited. However, the position of the present divide is tenuous, such that if major compression had continued, some parts of the divide may have undergone another eastward shift. Only about 250 m of net uplift in the Front Ranges is now required to allow westward capture of all the drainage of the Main Ranges through Yellowhead, Howse, Kicking Horse, and Crowsnest Passes. This capture could cause the drainage divide to step to the Front Ranges for the whole length of southwestern Alberta.

Consider also, that the Crowsnest Pass at the present drainage divide may represent the position of the Crowsnest River at a period when the drainage divide lay west of its present position.

Key References: Craw and Leckie (1996)

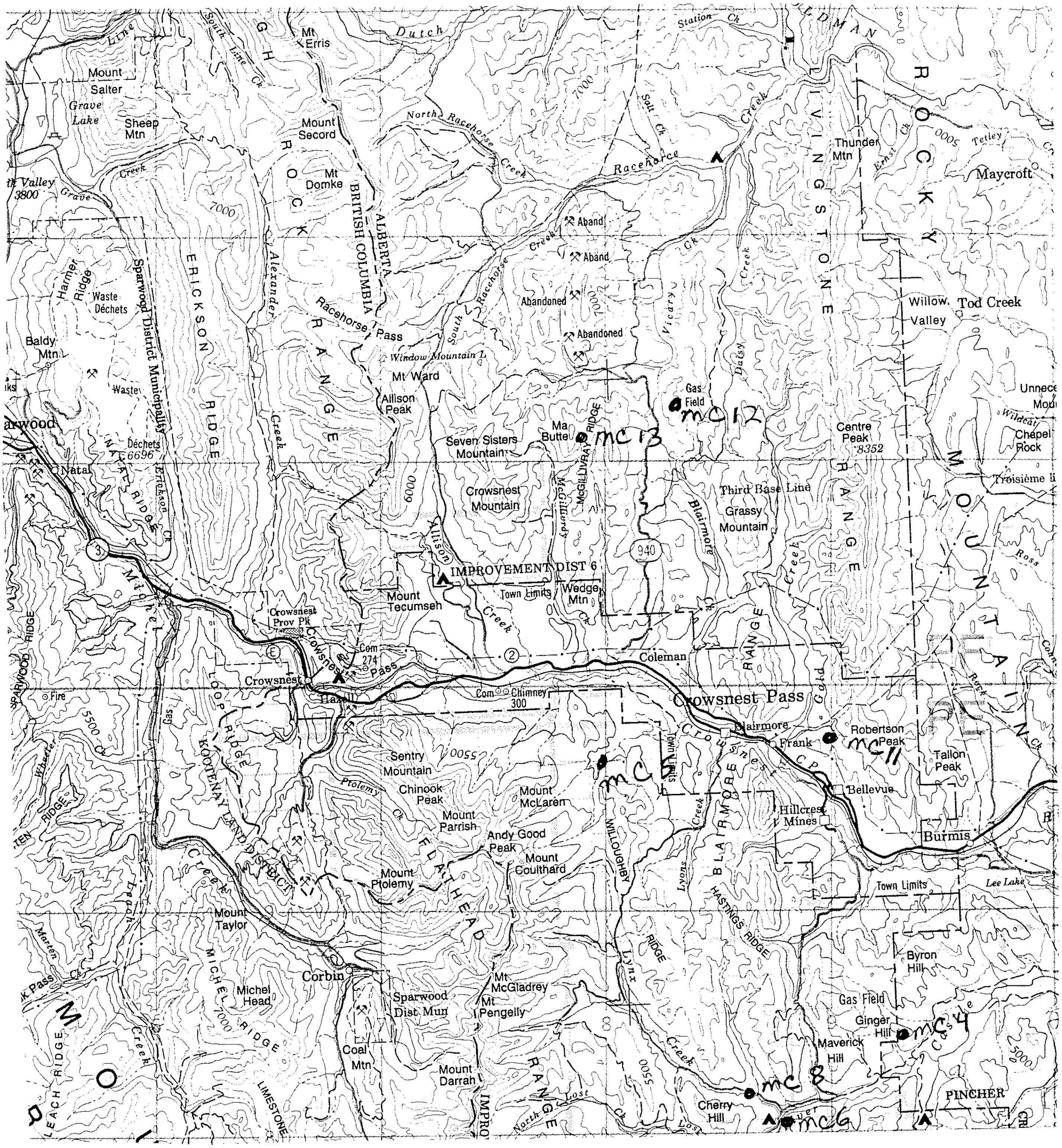


Figure 2.1.1 Crowsnest Pass.

Stop 2.2:
Location: Crowsnest Pass, Coleman, Highway 3
Formation: Cadomin and Dalhousie formations
Age: Valanginian to Berremian
Fluvial Style: Braided fluvial deposits, sand and gravel sheet; underlying basin wide unconformity; braidplain
Climate:
Important Points: Basin axial flow.
Description: At Coleman 3 measured sections within 500m of each other (Fig. 2.2.1), illustrate the lateral variation in the sedimentology of the Cadomin and Dalhousie formations. The general succession is similar at each section but the details differ.

Cadomin Formation

In section #4 (Fig. 2.2.1), the basal contact is obscured but a small outcrop 10 m below the base of the described sections exposes coal of the Kootenay Formation. The Cadomin consists of 3 m of clast-supported, massive, chert and quartz pebble conglomerate (maximum diameter 9 cm). Average clast imbrication is eastwards. The remainder of the section is characterized by interbedded medium- to coarse-grained sandstone, fining upward, overall, with interbedded conglomerate largely limited to thin (<0.5m) lenses (Fig. 2.2.1a). The proportion of conglomerate decreases up section although a 1 m thick conglomerate bed occurs at ~12 m. The sandstones display horizontal lamination and trough and planar tabular cross-stratification. Paleoflow indicators in the sandstone indicate flow towards the NW. A concentration of NW-SE oriented coalified logs and wood debris occurs at approximately 10 m above the base of the section (Fig. 2.2.1a). In Section #6 (Fig. 2.2.1b, 5 to 7 m), the thick middle conglomerate is channeled and the two conglomerate channel fills are nested. Symmetrical wave ripples occur in Section #5 (Fig. 2.2.1c) at 3.8 and 6.8 metres. The lowermost wave-ripples occur in carbonaceous fine sandstones that are associated with coarse-grained sandstone and conglomerate. The orientation of the ripple crests range from north-south to northeast-southeast and are unrelated to local unidirectional current indicators. The rippled sands were deposited in shallow lakes or ponds with standing waters.

Dalhousie Formation

The Dalhousie Formation consists of 23.8 m of medium sandstone with thin conglomeratic lenses (Figs. 2.2.1a,b,c). The predominant structures are horizontal to low-angle parallel lamination, trough cross-stratification and rare type A climbing-ripple drift.

In Section #5 (Fig. 2.2.1c), planar tabular cross-stratified coarse sandstones, indicating paleoflow towards the NW, are interbedded with fine-grained, massive sandstones across the middle portion of the section. A 1.5 m thick sandstone with sigmoidal bedding reflects lateral accretion surfaces that fine up-dip from shale intraclast conglomerate to fine-grained sandstone; along the basal portion of the cross-beds shale clasts become smaller downdip, from 20 cm to 75 cm. Section 5 ends with interbedded lenses of coarse and fine sandstone rather than the cross-bedded medium sandstones recorded elsewhere.

Key References: Leckie and Cheel (1997)

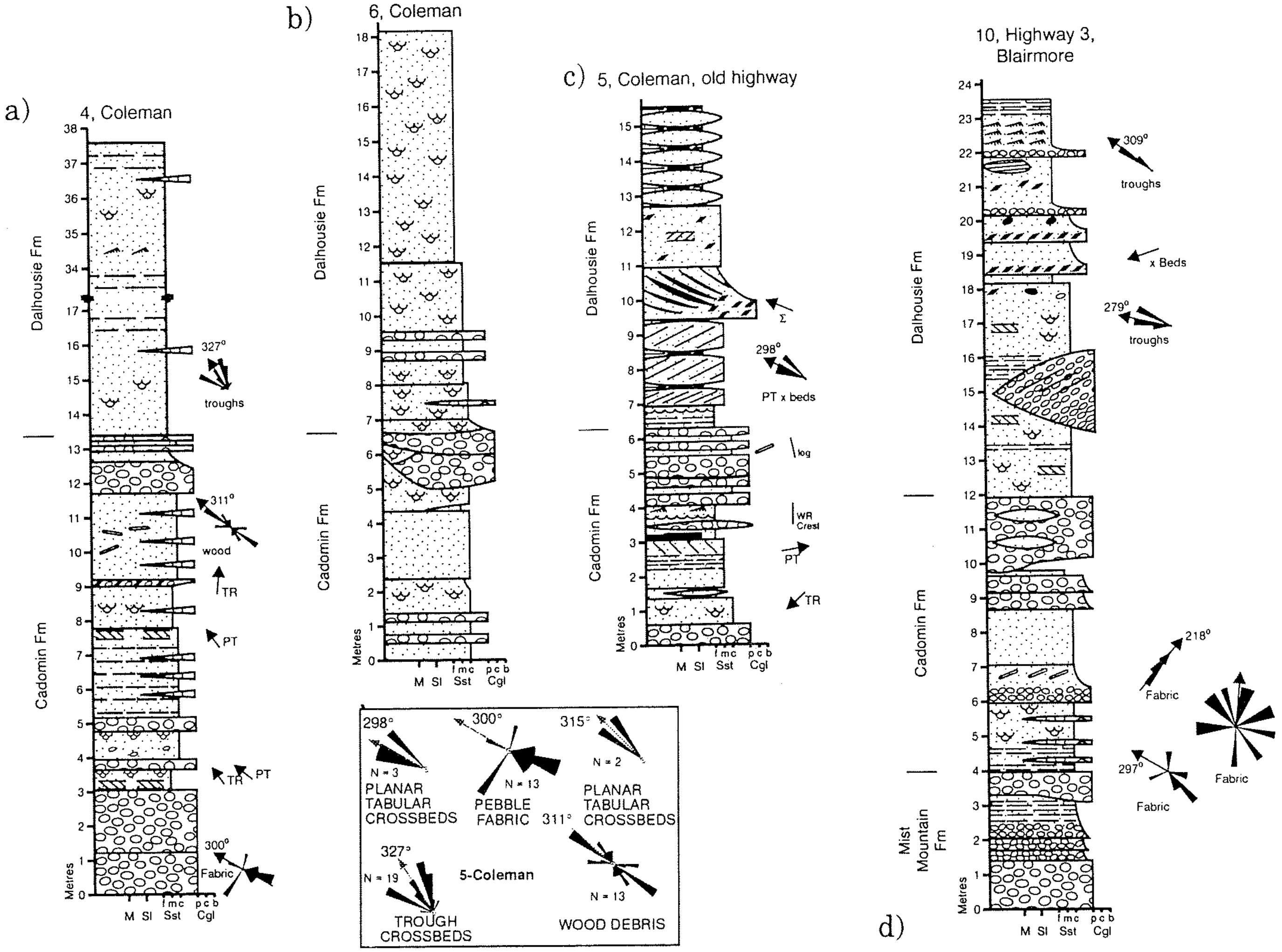


Figure 2.2.1. Measured section of Cadomin and Dalhousie Formations at Coleman and at Blairmore in Crowsnest Pass.

Stop 2.3:

Location: Crowsnest Pass, Coleman, Highway 3

Formation: Blairmore, including Dalhousie Formation,

Age: Albian

Fluvial Style: Meandering fluvial deposits

Important Points: subsidence and sedimentation are roughly in balance; meandering river/floodplain/lacustrine deposits.

Description:

Cadomin Formation

The Cadomin Formation is not present at this outcrop which is an important point. The Cadomin Formation is present in the next thrust sheet to west.

Dalhousie Formation

The basal Cretaceous unconformity at this locality is overlain by the sandstone of Dalhousie Formation which is approximately 42 m thick (Fig. 2.3.1). It predominantly medium to coarse sandstone containing silcrete clasts and at 30 m on the section is ~1 m of pebble to cobbles representing a flood event. The Dalhousie Formation is interpreted to be a braided sheet sandstone which had basin-axial drainage.

Beaver Mines Formation

This outcrop shows typical meandering river and associated floodplain deposits of the Beaver Mines Formation of the Blairmore Group. Evidence of paleosols occurs throughout the section, but individual paleosols are difficult to recognize. The implication is that the sediments accumulated under conditions of sedimentation and subsidence rates being roughly similar. Macroscopic pedogenic indicators include:

- roots
- blocky structure
- color mottling
- ferruginous nodules
- illuvial clay coatings
- pedogenic slickensides.

The lack of coals and carbonaceous shale suggests at least seasonal oxidizing conditions on the floodplain or high depositional rates.

Note the sideritized vertical tree trunks at the top of point bar/levee deposits.

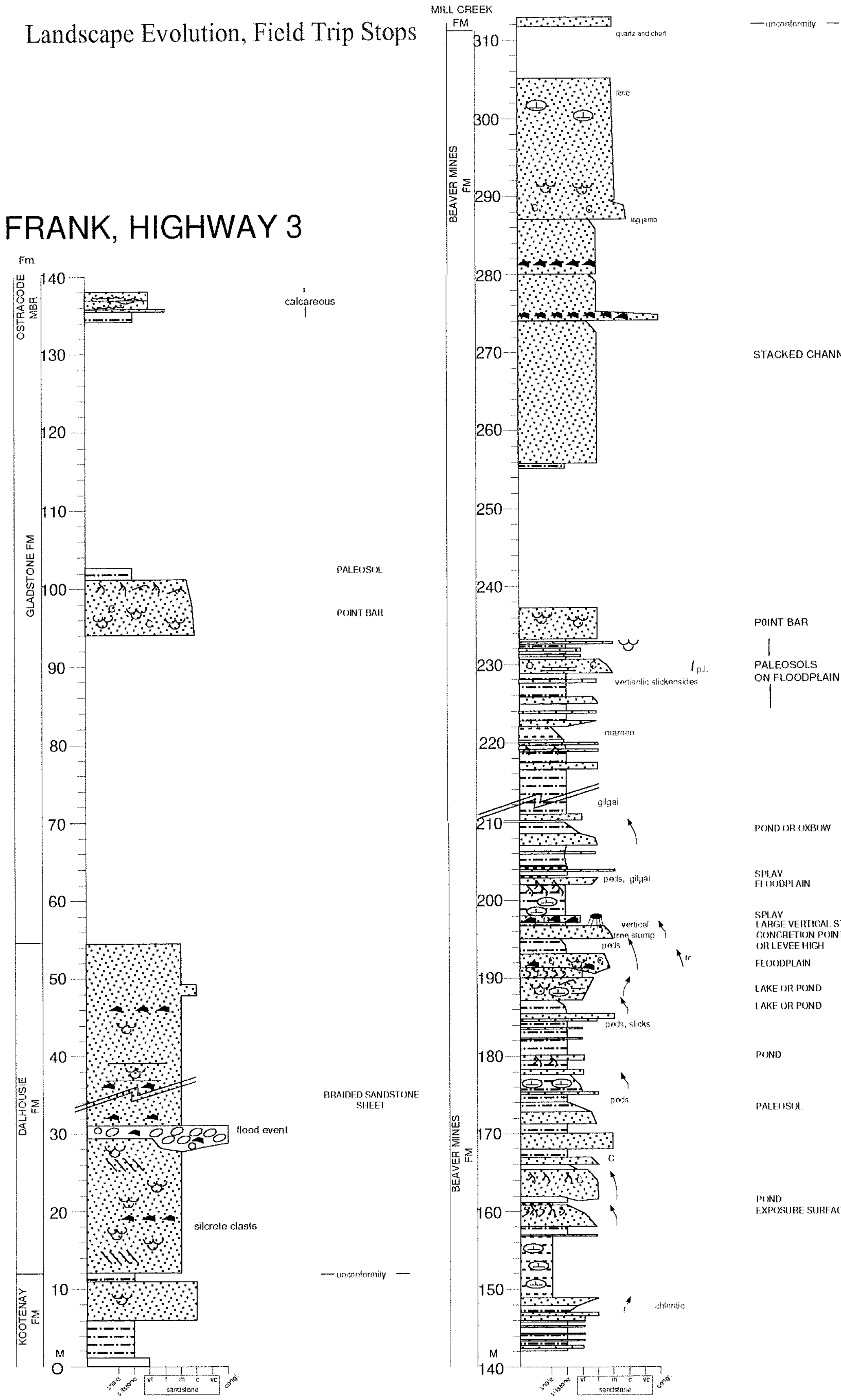


Figure 2.3.1. Measured section of Dalhousie Formation overlain by Gladstone and Beaver Mines formations.

Stop 2.4:
Location: Crowsnest Pass, Blairmore, Frank Slide Interpretive Centre
Formation: igneous-clast conglomerate, Blairmore Group
Age: Albian
Fluvial Style: Incised braided fluvial deposits
Climate:
Important Points: braided river, incised valley
Description:

This igneous clast conglomerate at this outcrop (Fig. 2.4.1) is one of the several outcrops used to define Crowsnest Channel (Fig. 1.2.1). The section shows that gravel was introduced into the basin as a pulse, with no indication of comparably-sized material in older, finer grained sediments. Average clast size is 3-4 cm with cobbles to 20 cm. Clasts are well imbricated, indicating east-southeasterly flow (Fig. 2.4.1). Poorly-defined bedding is decimetres-thick and parallel, with a low dip angle (<10°). The conglomerate becomes sandier upwards and is overlain by ~12 m of medium-grained, chloritic sandstone.

The conglomerate is predominantly clast-supported, with a medium to coarse-grained sandstone matrix. Individual strata vary from poorly to well sorted; some beds contain clasts decimetres in size which are abruptly overlain by beds containing centimetre-sized clasts. All pebbles are rounded to well rounded and are typically well imbricated, with clasts aligned transverse to paleoflow. Erosively-based horizons of cobble-sized material, 1 to 3 clasts thick, that can be traced for several tens of metres, occur throughout the conglomerate. Tree casts are locally common. Stratification consists of crude to well-stratified, parallel bedding with bed sets up to 40 cm. Planar-tabular crossbedded conglomerate, with sets up to 50 cm thick, are defined by clasts lying on foresets. Medium-grained, chloritic sandstone occurs as eroded pebbly, lenses up to 1.5 m thick, pinching out over a few metres to 20 m, and as the matrix for most of the conglomerate deposits. The sandstone is trough crossbedded and parallel laminated.

Key References: Leckie and Krystinik (1995); Leckie and Craw (1995); Craw and Leckie (1996)

Frank Slide Interpretive Centre

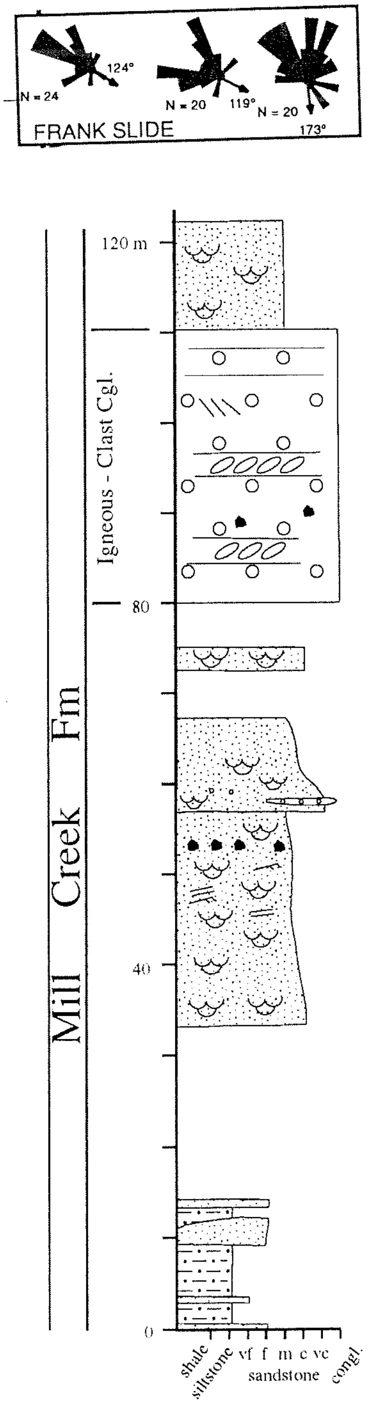


Figure 2.4.1. Measured section of incised braided fluvial conglomerate in top of the Beaver Mines or lower Mill Creek Formation at Frank Slide Interpretive Centre.

Stop 2.5:

Location:Adanac Mine site, Hastings Ridge, 13 km south of Blairmore on the Blairmore Range; 420 m long continuously-exposed, open-pit mine face

Formation: Cadomin and Dalhousie formations

Age: Barremian to Valanginian

Fluvial Style: Sandy and gravel braided rivers, sheet deposit

Important Points: braided river deposits; overlying major angular unconformity

Description:

A measured section of Fernie, Kootenay, Cadomin and Dalhousie formations is shown in Figure 2.5.1. A detailed panorama of the Cadomin and Dalhousie formations is shown in Figure 2.5.2.

The section consists of 5 m of Cadomin conglomerate overlain by 9 m of Dalhousie sandstone. The base of the Cadomin conglomerate is irregularly scoured with up to 1.5 m of relief into underlying coal and carbonaceous shale of the Mist Mountain Formation (Fig. 2.5.2). The base contains small, sinuous and fluted, north-trending gutters and northwest to north-trending prod and brush marks. The lower 2 m of the Cadomin Formation contains intraformational detritus including coal clasts ranging to 160 by 76 by 15 cm; rounded siderite clasts to 22 cm diameter; coalified wood debris as logs and branches; silicified wood debris several metres long; and angular clasts of grey/white silicified sandstone (silcrete?) up to 40 x 15 cm. The silicified log is 27 cm in diameter, 5 m long and oriented towards 340°; it has not been compacted indicating early silicification before significant burial took place.

The conglomerate consists of clast-supported, sub- to well-rounded pebbles to cobbles; the matrix is poorly-sorted, fine to medium-grained sandstone. Bedding, up to 40 cm thick, occurs as poorly-defined parallel to sub-parallel stratification and some northwest-directed, planar tabular crossbedding. Small channel forms with up to 1 m of relief are evident across the cliff face. Pebbles are imbricate, long-axis transverse, indicating flow to the north and northwest (Fig. 2.5.2). Discontinuous, medium and coarse-grained, trough and planar sandstones up to 40 cm thick occur throughout the conglomerate. Coalified wood debris occurs throughout the conglomerate. At the south end of the pit, at the basal contact of the Cadomin, diagonal sand-filled burrows up to 8 mm diameter occur, associated with wood debris. The burrows are locally dense, subparallel to one another and do not cross.

The overlying Dalhousie sandstone is pebbly, medium to coarse grained, dominantly quartz and chert. Stratification occurs as 10 to 45 cm sets of trough and planar tabular crossbeds with paleoflow variably to the west and northeast. At the north end of the exposure, low-angle bounding surfaces extend 9 m up towards the top of the sandstone, downlapping onto the Cadomin conglomerate at angles of 10 to 25°. There is no fining upwards in grain size or decrease in bed thickness along the bounding surfaces. The bounding surfaces trend NNW and dip to the east. There are isolated rippled intervals. These surfaces may have formed by the lateral accretion of side bars and sand shoals, which are common on the modern sandy braided deposits of the Kosi megafan (Singh et al., 1993). The 7 to 9 m height of the lateral accretion surfaces provide an estimate of channel depth.

At the north end of the exposure, a 2.3 m thick olive-grey siltstone drapes the underlying sandstone, extends laterally for approximately 110 m, and pinches out to the north and south. The siltstone is blocky, weakly fissile and contains sideritic layers and nodules; no sedimentary structures are evident. Two shale samples yielded a sparse assemblage of gymnosperm pollen but no angiosperm pollen (J. White, pers. comm., 1995).

Key References: Leckie and Cheel (1997)

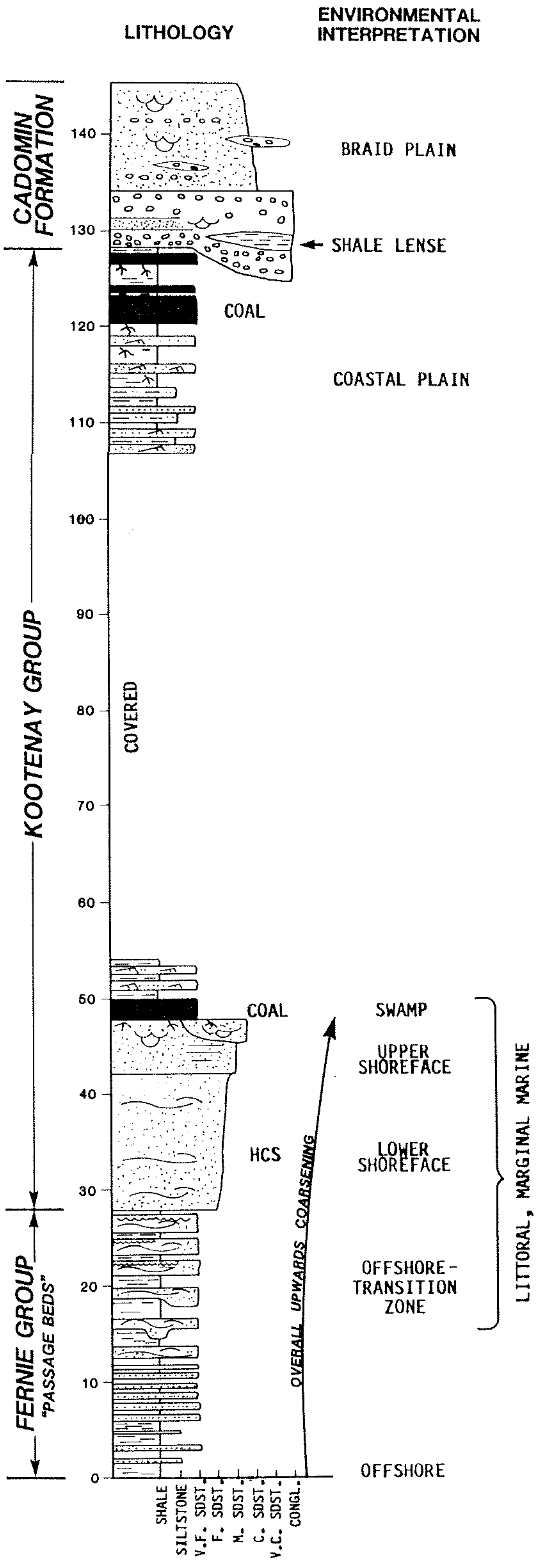


Figure 2.5.1. Measured section of Fernie, Kootenay, Cadomin and Dalhousie formations at Adanac Mine.

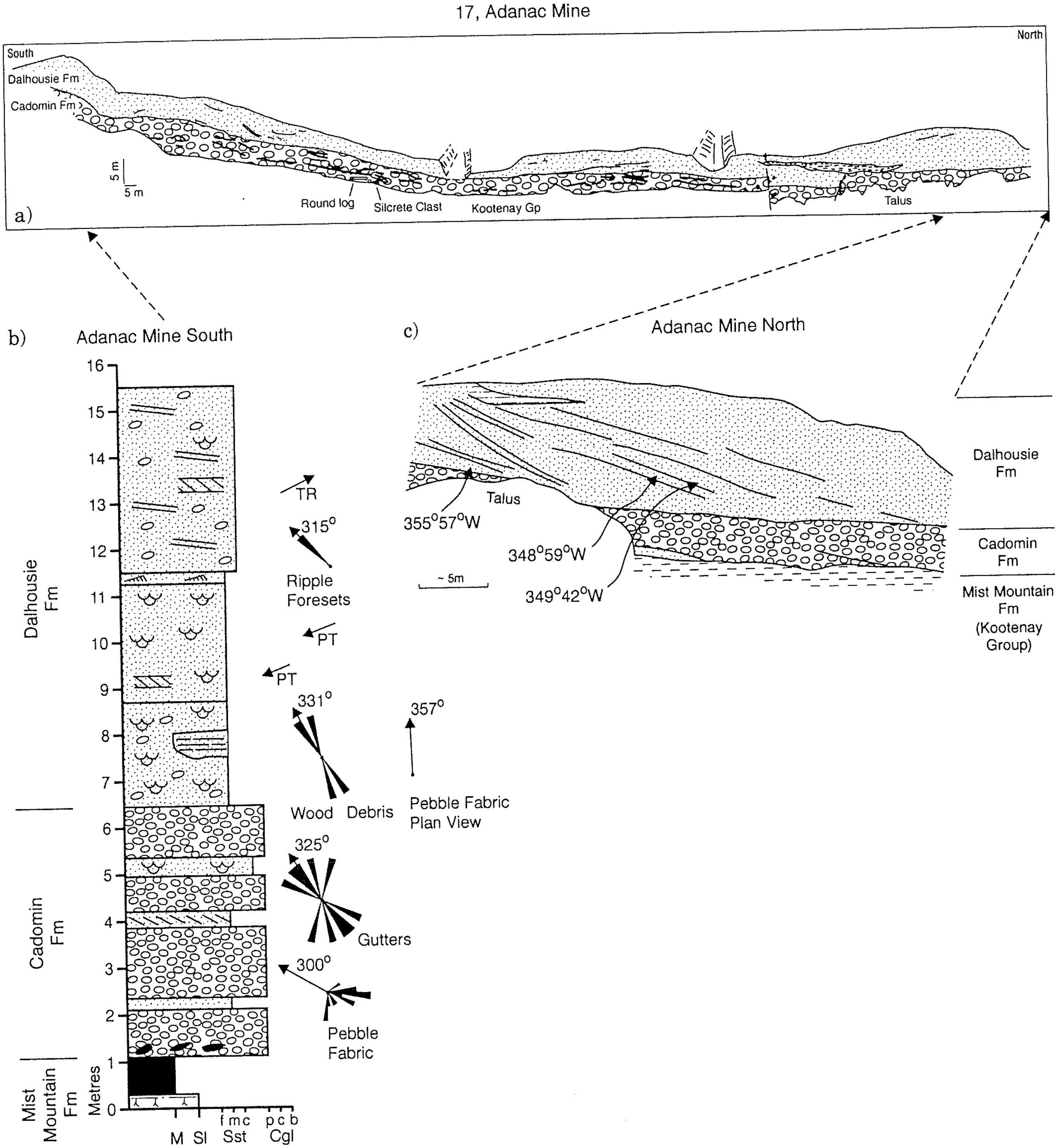


Figure 2.5.2. Detailed panorama of the braided fluvial sheet deposits of the Cadomin and Dalhousie formations at Adanac Mine.

Stop 2.6:
Location: Crowsnest Pass
Formation: Crowsnest
Age: Albian
Fluvial Style: volcanic upland on floodplain (?)
Description:

Volcanic rocks in the Coleman area of southwest Alberta form the Crowsnest formation of the Blairmore Group. The volcanics consist of trachytic, analcite-bearing agglomerates, tuffs, rare flows and lahars (Fig. 2.6.1). Potassium-argon dates of 96 Ma have been obtained from sanidine crystals. The Lower contact is gradational and the upper contact is a disconformity. A maximum thickness of 425 m occurs on the Coleman fault plate with rapid thinning east and west. The volcanic rocks covered 1800 m^2 with an area of 290 km^3. Three main volcanic centres have been recognized. Lithologies present in the volcanic rocks include red trachyte, sanidine-rich trachyte, garnet trachyte, analcite phonolite and blairmorite. Palinspastic reconstruction places the greatest thickness having been emplaced in what is now the Cranbrook area.

Adair and Burwash (1996) argue that the bulk of the deposits are of pyroclastic flows, density stratified surges, fallout of pyroclastic material from vertical eruption columns and mud flows that occurred during explosive subaerial eruptions. Elevated temperatures likely prevailed during deposition of pyroclastic flow and surge deposits. The eruptions were initially dominated by explosive volcanism changing to effusive volcanism in later stages.

Key References: Norris (1964), Pearce (1970) Rickets (1982), Adair and Burwash (1996)

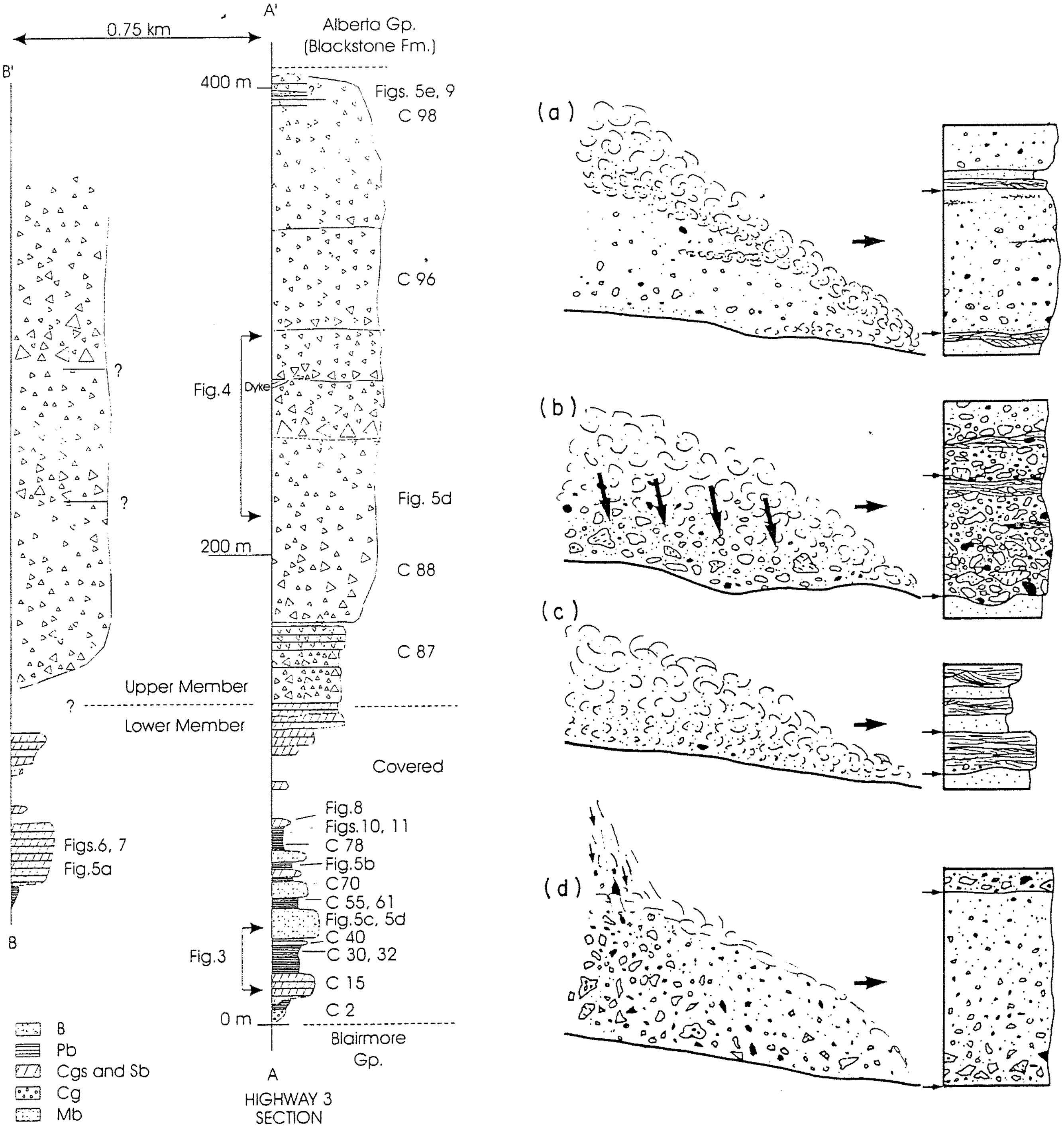


Figure 2.6.1. A) Stratigraphic measured section of Crowsnest Formation on Highway 3 (B=breccia deposits; Pb=parallel-bedded deposits; Cgs=coarse-grained deposits with stratified tops; Mb=massive deposits; Cg=matrix-supported, coarse-grained deposits with no stratification. B)Flow types and resulting deposits; a-Mb resulting from nonturbulent pyroclastic flows; b-Cgs resulting from density-stratified surges; c- stratified tops emplaced by surges; B-emplaced by vent proximal pyroclastic flows. From Adair and Burwash, 1996.

Day 3
Stop 3.1
Location: Pincher Creek
Important Points: Alberta Syncline
Description:

The Alberta syncline is a structural element that exists between the eastern end of the triangle zone of the Foothills and the Plains. The beds of the Porcupine Hills Formation show both limbs of the syncline north of the Oldman River from this location.

Key References: Douglas (1950)

Stop 3.2:
Location: Waterton River Bridge on Hwy. 810.
Formation: Willow Creek
Age: Paleocene
Fluvial Style: Anastomosed
Climate: Seasonally wet, savanna-like
Important Points: Lenticular thick sandstones, abundant mudstone with caliche
Description:

The red beds of the Willow Creek Formation along Willow Creek is a maximum of 1219 m (4,000 ft.) thick (Douglas, 1951). The section north of Glenwood is only 2 km east of the axis of the Alberta Syncline. The interval along the north bank of the river on either side of the bridge is within 200 m of the top of the formation in the upper member of Jerzykiewicz (1997).

The thick, lenticular sandstones are similar in size, facies, and W/T ratio to those in the underlying St. Mary River Formation (Nadon, 1994). The sandstone lenses are surrounded by red, purple, and grey bentonitic mudstones and thin bentonites. The mudstones vary from laminated to massive with clayskins. Beds of discontinuous to amalgamated carbonate nodules up to 30 cm thick are scattered throughout the section.

The lenticular sandstones are the fluvial channels formed in an anastomosed fluvial system. Clayskins in the mudstones are indicative of low-intensity paleosols indicative of rapid aggradation of the floodplain. The nodular carbonates are primarily rhizoliths forming caliche beds of varying intensity. These caliche beds imply periods of stasis in the floodplain that lasted long enough for the plants to form the carbonates. However, the length of time involved is far from obvious. The 50,000 - 100,000+ years suggested by Jerzykiewicz and Sweet (1988) and Jerzykiewicz (1997) for these intervals is derived from comparison to caliches formed in the American southwest (Gile *et al.*, 1981). It is not clear how to extrapolate the formation and duration of arid-zone caliche beds to those formed by rhizoliths in a semi-arid climate. Therefore, while these beds still indicate period of low sediment input to the floodplain, they may represent substantially smaller temporal gaps than commonly assumed.

Key References: Douglas (1950); Nadon (1994)

Stop 3.3:
Location: St. Mary River
Formation: St. Mary River
Age: Maestrichtian
Fluvial Style: Anastomosed
Climate: Seasonally wet, savanna-like
Important Points: Thick, lenticular sandstone bodies at the same
Description:

This section of the St. Mary River Formation (Fig. 3.3.1) is important for the exposures of intra- and interchannel geometry. This location provides evidence to demonstrate the contemporaneous nature of some of the fluvial channel sandstones and illustrates many of the problems inherent in interpreting similar deposits from smaller exposures or well logs and core.

The detailed section (Fig. 3.3.1) was measured in the gully just upstream of the southern channel sandstone (CH-1). The section is composed mainly of Facies Association 4 mudstones with minor amounts of crevasse splay sheet sandstones (Association 3), and crevasse splay channel sandstones (Association 2). The mudstones show evidence of weakly developed paleosols and disruption by dinosaur tracks. Two lens-shaped, orange-coloured massive limestones indicative of lacustrine sedimentation are also present high in the cliff. Roots are common in all facies. Freshwater gastropods vary from absent to abundant.

The two channel sandstone lenses at the base of the section along the eastern bank of the river are at the same stratigraphic level and are joined by interbedded sandstones and siltstones off-lapping the flanks. The southern lens is composed of medium-grained, trough cross-bedded sandstone at the base, with paleoflow toward 034°. Long, thin roots and stems are present from the top to the base in both channels. The right-hand margin of the channel is stepped, finer grained, has a higher density of roots and shows paleoflow trends roughly 90° to that of the lens.

The base of the northern channel is relatively flat with grooves cut into the underlying siltstone/shale and a scour pit near the right hand margin. Flute and tool marks indicate paleoflow was toward 017°. The basal sandstones directly above the scour pit are medium-grained trough crossbedded sandstone whereas to the right they are medium-grained parallel laminated sandstone. Paleoflow shown by the parting step lineation and the heavy mineral shadows agree with those of the flutes and tool marks. The right margin of the sandstone has two prominent steps. However, this margin, although it represents a sharp contrast with the adjacent siltstones and shales, is the product of scour not of channel incision and infill. A close examination of the strata in the upper step shows that bedding planes dip into and merge with the adjacent shales and siltstones (Fig. 8 of Nadon, 1994). These strata dip at the same angle as the overlying offlapping strata in the wing above. Both represent the growth of levees. Note the similarity of the levee sedimentation to amalgamated splay deposits.

The lack of scour features except in the centre of the lens, the presence of off-lapping strata along the lens margins, and the presence of *in situ* tree trunks elsewhere all indicate that the lenses are complex assemblages of both levee and channel sandstones. The abrupt contact at this exposure is due in part to the effects of differential cementation and in part to scour produced by the limited lateral migration of the thalweg.

The levees of Cretaceous fluvial systems were not anchored by the extensive roots systems present in Tertiary and modern plants, therefore the lateral migration of the thalweg was limited only by the overall low slope of the system and the presence of the floodplain fines.

Key References: Nadon (1993; 1994)

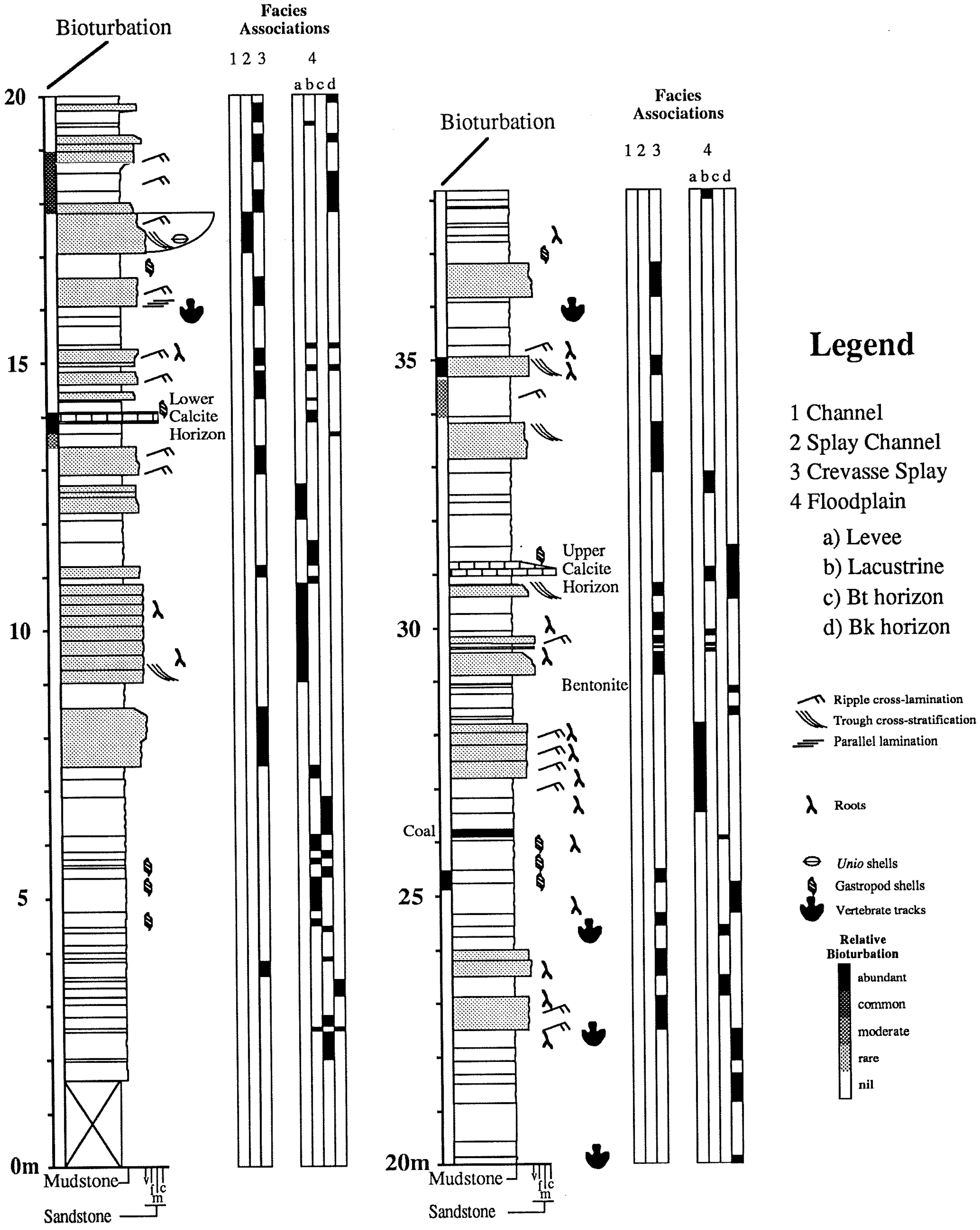


Figure 3.3.1. Measured section of St. Mary River Formation on the St. Mary River.

Stop 3.4

Location: Del Bonita gravel pit. Pit is located south of Shanks River andnorth of Del Bonita. Map co-ordinates: 49° 02.38', 112° 47.31'.

Note: This is an initial summary of ongoing investigations with Jan Bednarski.

Age: Pliocene to Quaternary ?

Comment: As we drive south form Cardston, observe the flat-topped hills to the south and southeast. These are erosional remnants of an older Tertiary landscape. Our next stop will examine gravels deposited on this depositional surface. Notice the notches which appear to dissect the southern horizon. These may be old channels.

Crossing the St Mary River, observe the braided gravel fill. This may be a comparable analog tot he incised braided conglomerate channels in the Blairmore Group.

Fluvial Style: braided river

Climate: periglacial; mean annual temperature of -6 to -8° C; land surface cooling to -15 to -20°C

Important Points: Frost-patterned ground, permafrost, aggrading braided river deposits

Description:

The Del Bonita uplands are situated on the drainage divide between the Mississippi drainage and the Hudson's Bay drainage. The uplands separate the St. Mary River from the North Milk River. Del Bonita gravels consist of sandstone, quartzite, argillite and conglomerate.

The gravel pit at Del Bonita is situated on an upland surface which has never been glaciated. Glacial ice from the Canadian Shield and Rocky Mountain cordillera has occupied local valleys around the uplands. The pit contains 5 to 6 m of mixed sands and gravels which are capped by 1 m of silt (Fig. 3.4.1).

The lower 2-3 m of gravel consists of crudely bedded, 10-30 cm thick beds of pebble to cobble-size gravel. The gravel is clast supported with fine to medium sand matrix. Much of the gravel is well imbricated. Poorly-defined planar tabular cross bed sets are locally present. Clasts are subangular to subrounded. Discontinuous sandstone beds up to 20 cm thick and 2 m long are common. The sands are parallel laminated, rippled and trough and planar cross stratified. Scours within the unit commonly have a cobble layer armoring the bottom. The upper surface to this unit is scoured with small channel forms having decimetre-scale relief, and a basal layer of coarser cobbles which armored the channel bottom.

Hung from the top of this unit are several vertical V-shaped wedges, which are up to 1.5 m long and up to 40 cm wide at the top. Within these wedges, original bedding has been disrupted. The dip-angle of clasts within the wedge are steep, becoming near vertical at the axis of the feature.

A discontinuous silt layer up to 30 cm thick overlies this basal gravel. The silt is locally eroded by channeling from the overlying unit or the cryoturbation features described below.

The upper 2 m of gravel are highly disturbed. Structures include modified ball and pillow-type features, vertical downward-tapering wedges. The wedges are up to 1 m deep and have a near vertical pebble fabric. Several wedges have pronounced rims bordering them. Several of the wedges cross cut lower wedges, indicating multiple periods of wedge formation. One face of the outcrop contains an upward tapering wedge of gravel surrounded by finer grained silts and sands. The clasts within the gravel fine laterally away from the core. Clasts are manganese and calcium carbonate coated. Clast lithologies are dominated by red and green sandstone and siltstone, as well as well-indurated red and white sandstone of Belt/Purcell affinity. The top 30 cm to 1 m is siltstone, containing roots and a B-soil horizon.

Interpretation

The facies exposed in this pit suggest two episode of braided fluvial aggradation. For the lowermost gravel, there is no evidence of periglacial activity. The lower 2 to 3 m have not been as disrupted as the upper 2 m. Vonhof (1969) suggests a Pliocene age for this event, although it is poorly constrained. For the upper gravel, there were alternating periods of aggradation and periglacial activity.

A period of intense cold resulted in the formation of ice-wedge casts and cryoturbation on this surface. Thermal contraction cracks (ice-wedge and sand-wedge cracks) require temperatures of -15 to -20° C at the top of the permafrost layer, which in the modern environment, requires a mean annual temperature of -6 to 8 °C (French, 1976). The result is disruption of the silts which cap the basal unit and the top of the gravel. The upper 2 m are interpreted to have been disturbed by cryoturbation processes which produced ice-wedge casts and sorted circles. The interpenetrating and cross-cutting ice-wedge casts indicate alternating episodes of aggradation and multiple cryoturbation surfaces. Cryoturbation appears to become more intense upwards.

The final siltstone cap infilled the ice wedges of the underlying gravel. The silt is interpreted to be aeolian loess, deposited during a dry period, as is the silt overlying the basal gravel. The lack of evidence of till, absence of striated clasts, and no Canada Shield-derived clasts indicate that this upland was not glaciated.

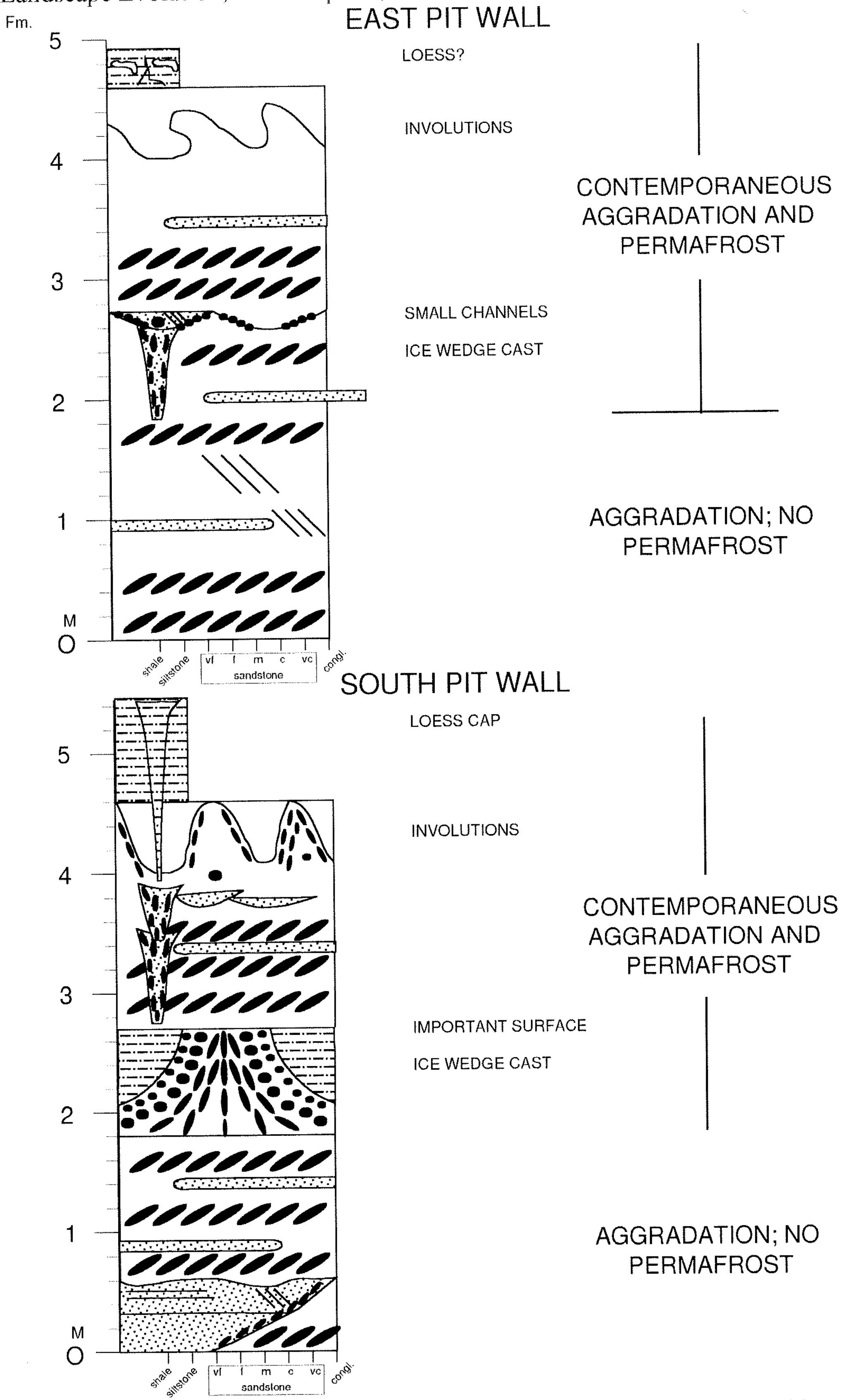


Figure 3.4.1. Measured section of braided river gravels containing evidence of periglacial patterned ground.

Day 4

Stop 4.1:

Location: Writing on Stone Provincial Park

Age: modern

Fluvial Style: incised meandering river

Important Points: modern incised valley in glacial meltwater channel; view point straddles Sweetgrass Arch; misfit stream; glacial meltwater channel; Sweetgrass Hills to the south.

Sweetgrass Hills

The three Sweetgrass Hills in northern Montana rise ~1000 m above the surrounding plains. They are the result of igneous intrusion at 49.8 -53.6 Ma (Marvin et al., 1980). The high peaks have outcrops of igneous rocks in radiating and interconnecting dykes with small isolated stocks or laccoliths adjacent to the central masses. Some dykes occupy faults. the igneous rocks range from syenite to diorite fine-grained porphyries. The intrusions have only slightly and locally modified the structure of southern Alberta.

The Sweetgrass Hills are important for our landscape evolution interpretation because the associated uplift is interpreted to have been responsible for the recycling the conglomerates of the Oligocene Cypress Hills Formation.

Stop 4.2:

Location: Cypress Hills

Formation: Cypress Hills

Age: Oligocene

Fluvial Style: braided river sheet deposits overlying major unconformity

Climate: Arid to semi-arid with season rainfall.

Important Points: Debris flow and braided fluvialdeposits; silcrete; profound unconformity.

Description: There will be severalstops along the axes of the Cypress Hills to examine the make of these Oligocene gravels. There is an east to west fining of gravel and increase in sand matrix and interbeds. This lateral variation appears to occur along strike and not down the paleoslope.

At the Elkwater firetower (Fig. 4.2.1), 12 to 13 m of gravel can be traced for more than 2 km. The basal contact is scoured and erosional. Outcrop consists of well rounded cobbles and boulders and isolated lenses of pebble gravel. The largest clast is of 42 cm diameter. Stratification is poorly defined, horizontal bedding with beds 0.3-1.5 m thick. The gravels are poorly sorted and clast supported with a medium to coarse sand matrix. Paleoflow was towards the northeast.

Examine the upper gravels for evidence of two episodes of periglacial activity (Westgate et al., 1972):

- initially cold moist soil conditions: steep to vertical pebbles, involutions
- followed by dry very cold conditions: frost wedges, with delicate bottoms; undeformed silt indicative of aeolian activity

At Conglomerate Cliffs (Fig. 4.2.1), sandstone interbeds are more common than at the firetower.

At Ravenscrag Butte, the contact between the Ravenscrag Formation and the Cypress Hills Formation is well exposed. The contact is scoured with smooth erosional margins displaying up to 3.5 m of relief and trending 50-230°. Isolated scours ("potholes"), 20 to 30 cm wide and approximately 20 cm deep, cut into the Ravenscrag and are infilled with poorly sorted gravel. The basal gravel above the contact is slightly coarser than the overlying material and contains sandstone clasts derived from the Ravenscrag and angular marl clasts. This outcrop yielded clasts of monzonite porphyries and syenite porphyries which likely originated from the Sweetgrass Hills to the southwest.

The most extensive single outcrop occurs on a roadcut north of Eastend (Fig. 4.2.1). This outcrop is near the Calf Creek paleontological site, one of the more important Tertiary vertebrate fossil sites in North America. Note that the outcrop has a reverse fault on the north end. Imbricate and cross-stratified, well-rounded pebble to cobble gravels occur throughout the section, but constitute less than 50% of the outcrop. Crossbed sets are up to 1 m thick. Gravel is cobble to boulder size (to 20 cm diameter). Crossbeds and imbrication indicate paleoflow to the northeast. These gravels are interpreted as braided fluvial. The basal contact of the Cypress Hills Formation with underlying Ravenscrag Formation is well exposed.

A second type of conglomerate at this outcrop forms resistant, decimetre- to metre-thick horizontal beds and lenses of a well-cemented, ungraded, very poorly-sorted, matrix-rich material. Clasts consist of marlstone, angular sandstone fragments, well rounded pebble to cobble-size quartzite clasts (to 27 cm diameter) in a matrix of clay to sand-sized sediment. Bones and quartzite clasts protrude out of the tops of the beds, where they are draped by rippled, fine to medium sandstone. Bones and teeth are commonly unabraded. The fabric is disorganized with clasts ranging from horizontal to vertical. These deposits are interpreted as debris flows.

Sands in the outcrop are rippled, parallel laminated and wave-rippled. The sands on one horizon contain white to buff silcrete nodules, which are eroded laterally by a cross bedded sandstone. The nodules are up to 7.3 cm diameter, disc-shaped and are not laterally connected. The external morphology varies from simple to highly irregular. The nodules are silcretes similar in form and chemistry to those found in the modern shallow pans along channel margins of the Nata River in the Kalahari desert.

An interpretation of the Cypress Hills Formation is shown in Figure 4.2.2.

Key References: Leckie and Cheel (1989, 1990)

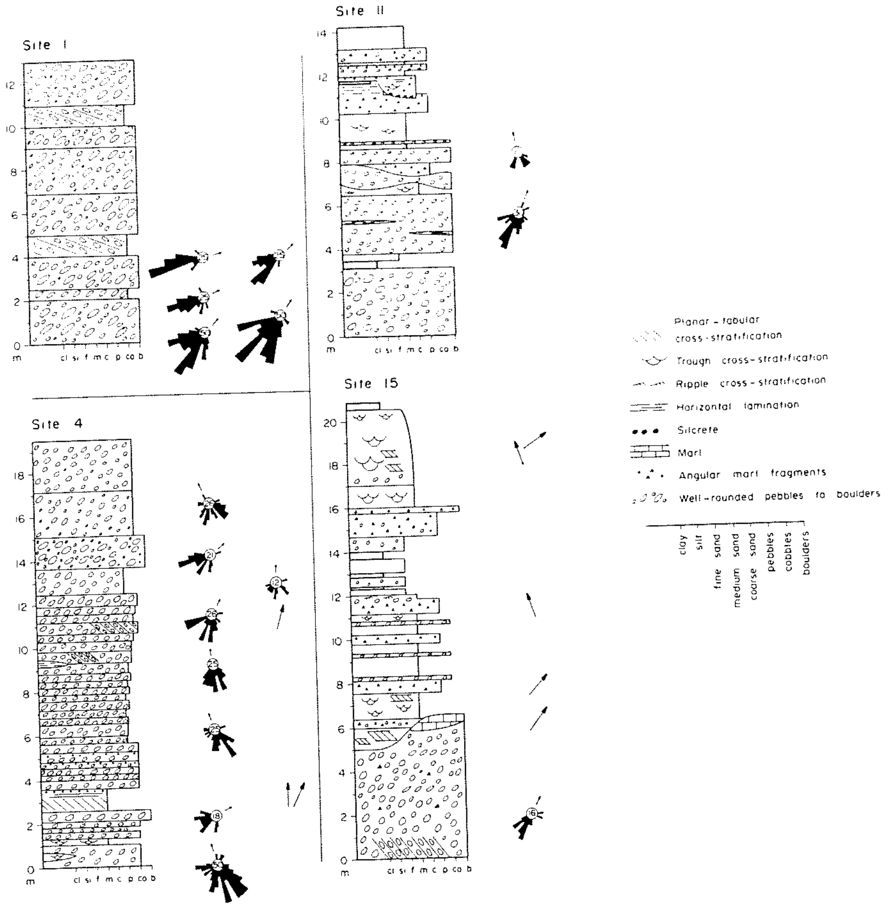


Figure 4.2.1. Measured sections of braided fluvial conglomerate sheet deposits of the Tertiary Cypress Hills Formation.

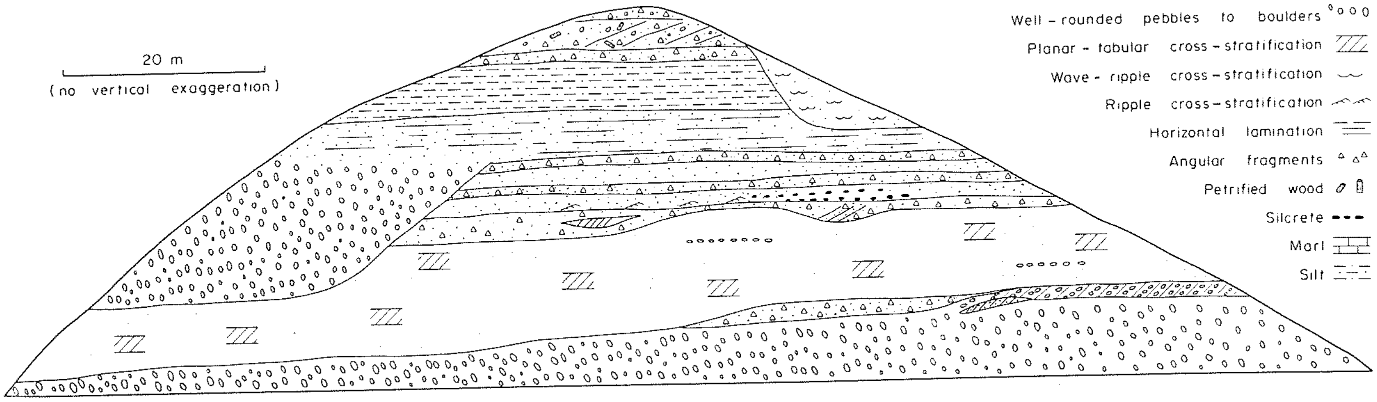


Figure 4.2.1. Outcrop north of Eastend

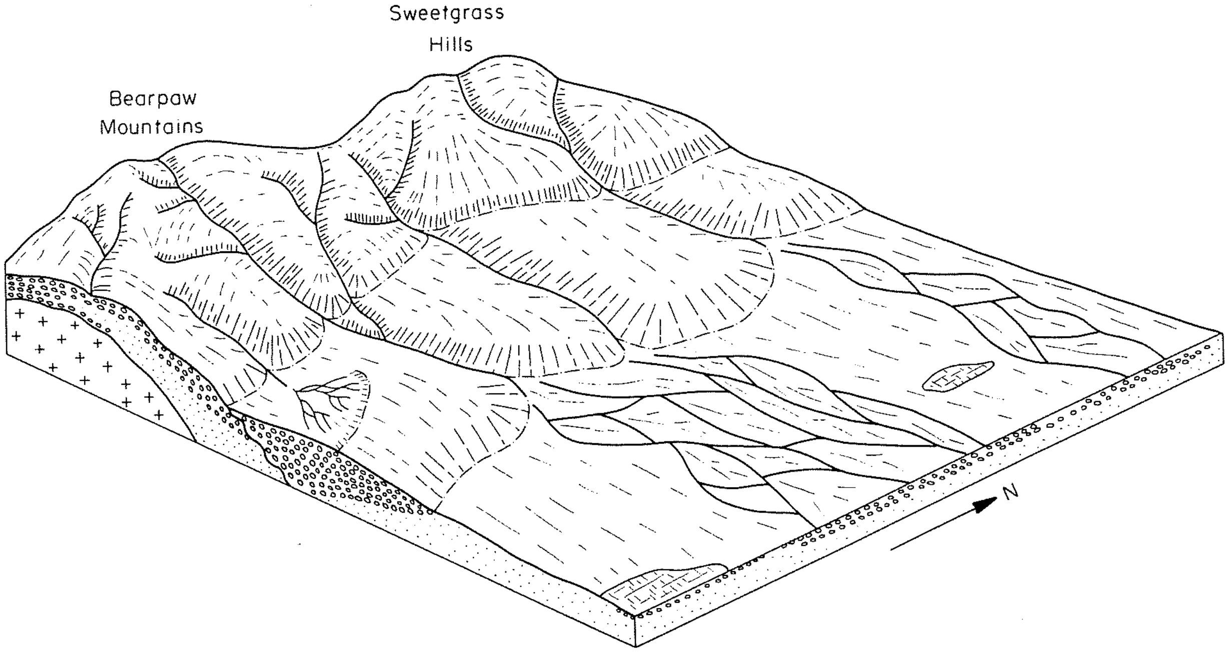


Figure 4.2.2. Interpretation of deposition of the Cypress Hills Formation.

Stop 4.3:
Point of Interest:
Location: Cypress Hills
Age: modern
Important Points: Drainage Divide
Description:The Cypress Hills is an erosional remnant occurring at a major continental drainage divide. These uplands are situated approximately feet above the regional level of the Interior Plains. The highest point of the Cypress Hills is 1466 m asl in the west, which is the height of land between the Rocky Mountains and Labrador.. Rivers to the south flow to Mississippi River and into the Gulf of Mexico. Rivers to the north flow into the Hudson's Bay.

Stop 4.4:
Point of Interest: Evolution of the Cypress Hills Landscape
Location: Belanger Canal, Cypress Hills, Saskatchewan, off Highway 21
Age: Miocene to modern
Important Points: landscape evolution of the Cypress Hills;most importantly, much of the present landscape was created by Late Miocene.
Description: Within the Belanger Canal section, a 1 km long sectionis exposed, which reveals a composite, lateral stratigraphy. The composite measured section in Figure 4.4.1 was constructed from descriptions in the following key references. The gully contains calcite-cemented Paleocene Ravenscrag fluvial sands and gravels, overlain by Late Miocene gravels on the Moirvale downcutting surface, Davis Creek Silt (9.3-8.2 Ma), Late Wisconsin diamicton and glaciolacustrine sediments, Holocene colluvium and loess, and Mazama ash (6.8 ka BP). The Moirvale Surface has been downcut at least 150 m below the height of land associated with Cypress Hills Formation.

The different surfaces downcutting the Cypress Hills are shown in Figure 4.4.2.

Key References: Vreeken et al. (1989), Vreeken and Westgate (1992), Vreeken (1996)

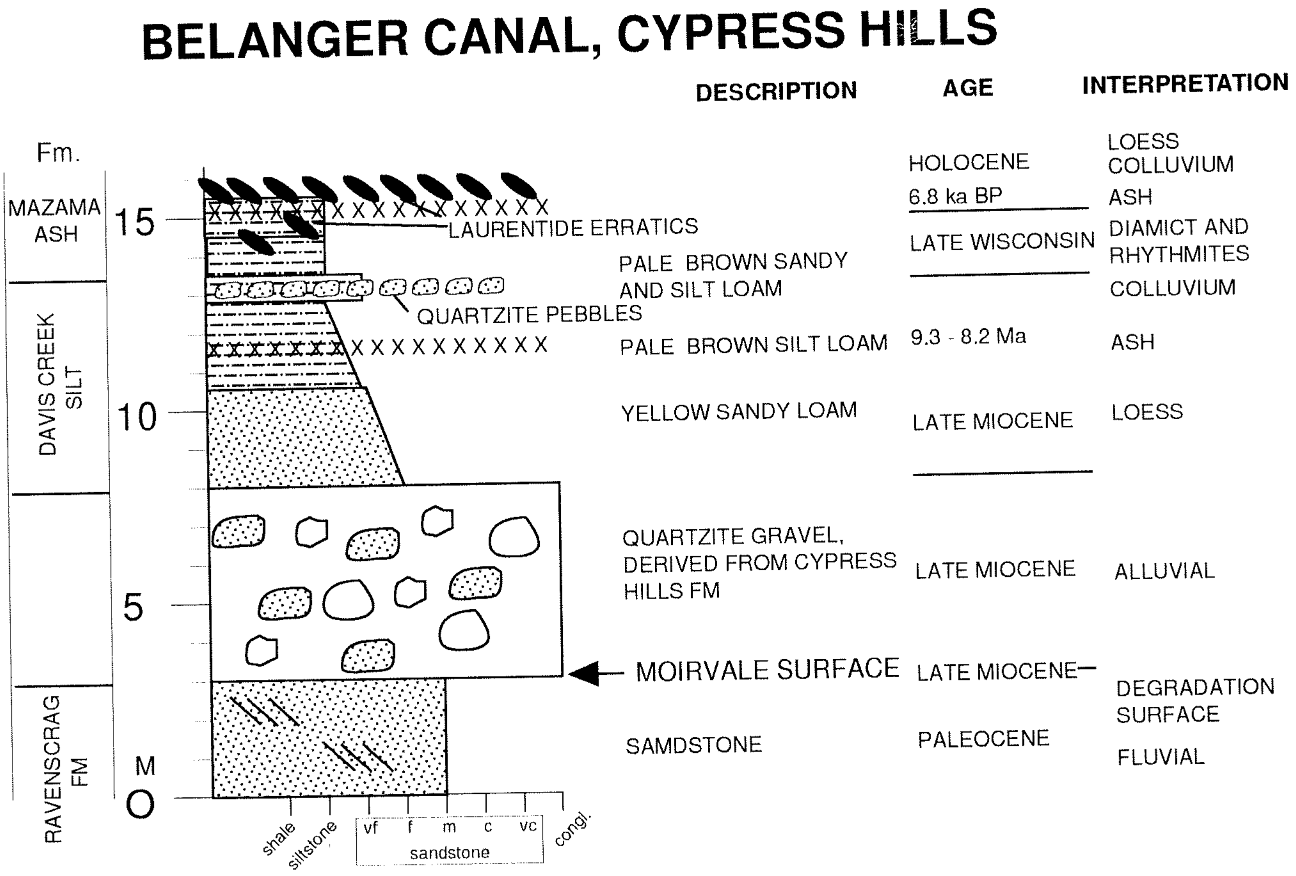


Figure 4.4.1. Composite measured section of stratigraphy in Belanger Canal. Constructed from data in Vreeken et al. (1989), Vreeken and Westgate (1992), and Vreeken (1996)

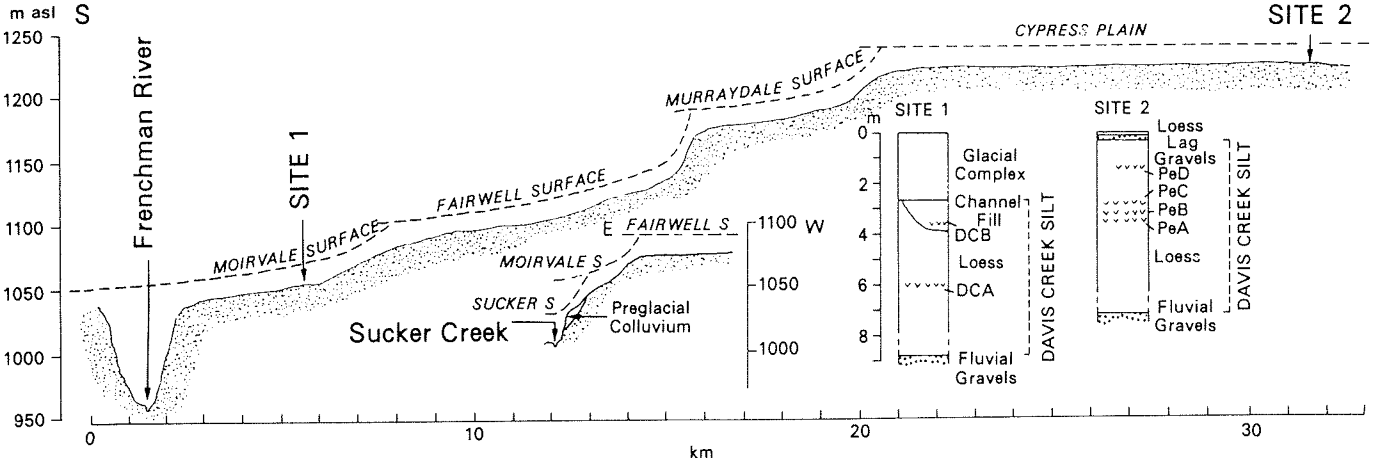


Figure 4.4.2. Inferred erosional surfaces on the south side of Cypress Hills, Saskatchewan. Vreeken and Westgate (1992).

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