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**A GUIDEBOOK ON LOWER CRETACEOUS
SEDIMENTOLOGY AND STRATIGRAPHY OF
SOUTHERN ALBERTA - TECTONIC AND EUSTATIC
IMPLICATIONS AND ECONOMIC SIGNIFICANCE**

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INTRODUCTION	1
ACKNOWLEDGMENTS	1
REGIONAL GEOLOGICAL SETTING	2
DEPOSITIONAL CYCLES AND PALEOGEOGRAPHY	4
CYCLES, BOUNDING SURFACES AND HIATAL-GAPS	4
CYCLE 1: BASE OF FERNIE SHALES TO TOP OF NIKANASSIN FORMATION/KOOTENAY GROUP (OXFORDIAN TO LATE VALANGINIAN)	5
CYCLE 2: CADOMIN FORMATION TO TOP OF MANNVILLE GROUP (HAUTERIVIAN TO ALBIAN)	5
CYCLE 3: BASE OF JOLI FOU FORMATION/PADDY MEMBER TO TOP OF WAPIABI FORMATION/COLORADO GROUP (ALBIAN TO CAMPANIAN)	7
CYCLE 4: SAUNDERS GROUP/(BASE BELLY RIVER TO TOP OF PORCUPINE HILLS) (CAMPANIAN TO EARLY EOCENE)	8
CYCLE 5: TERTIARY CONGLOMERATES (EOCENE TO PLIOCENE)	10
STOP 1: THE CHUNGO SANDSTONE AT LUNDBRECK, ALBERTA	11
THE DEPOSITIONAL FACIES IN THE LUNDBRECK OUTCROP	11
LOG RESPONSE OF THE CHUNGO-NOMAD IN SUBSURFACE	12
STOP 2: THE TRIANGLE ZONE	12
ECONOMIC SIGNIFICANCE	13
STOP 3: CHUNGO OUTCROP AT COLEMAN	13
STOP 4: BLAIRMORE GROUP STRATA ALONG HIGHWAY 3 NEAR BLAIRMORE AND COLEMAN	14
INTERPRETATION	15
STOP 5: THE FERNIE GROUP, KOOTENAY GROUP AND CADOMIN FORMATION AT ADANAC MINES	15
STOP 6: CADOMIN FORMATION	16
STOP 7: CROWSNEST FORMATION	16
INTERPRETATION	17
LAHARIC BRECCIA	18
LATERAL VARIATIONS	18
STOP 8: CARDIUM FORMATION ON HIGHWAY 3	19
STOP 9: UPPERMOST MILL CREEK FORMATION AND SHALES OF THE BLACKSTONE FORMATION AT MILL CREEK BRIDGE (INCLUDES SECOND WHITE SPECKS FORMATION)	19
STOP 10: THE CALCAREOUS MEMBER, GLADSTONE FORMATION (OSTRACODE EQUIVALENT) AT GLADSTONE CREEK	20
STOP 11 MILL CREEK SECTION	20
MILL CREEK FORMATION	20
LYNX CREEK MEMBER (NEW NAME — INFORMAL)	21
INTERPRETATION OF THE LYNX CREEK MEMBER	22
BRUIN CREEK MEMBER (NEW - INFORMAL NAME)	22
DESCRIPTION	24
STOP 12: CARBONDALE RIVER SECTION	25
STOP 13: VICARY RIDGE	26
STOP 14: FRANK SLIDE INTERPRETIVE CENTRE, BLAIRMORE	27
STOP 15: MCDOUGALL-SEGUR CONGLOMERATE	28
STOP 16: MILL CREEK FORMATION AND SECOND WHITE SPECKED SHALE OF THE BLACKSTONE FORMATION AT BRUIN CREEK AND LIVINGSTON RIVER	29
STOP 17: SECOND WHITE SPECKLED SHALE: HIGHWOOD RIVER	29
STOP 18: MILL CREEK FORMATION AND BARONS SANDSTONE EQUIVALENT AT THE HIGHWOOD RIVER	29
STOP 19: MCDOUGAL SEGUR CONGLOMERATE: RIO ALTO RANCH	29
HYDROCARBON PROSPECTS IN SOUTHERN ALBERTA	30
SHALLOW GAS PRODUCTION IN SOUTHERN ALBERTA	30
FOOTHILLS GAS IN SOUTHERN ALBERTA	30
LOWER CRETACEOUS OIL AND GAS IN SOUTHERN ALBERTA	31
REFERENCES	31
APPENDIX : GOLD ASSAYS	35

INTRODUCTION

The Albian Blairmore Group in southwestern Alberta has long been a source of geological fascination (Figs. 1,2,3). The Crowsnest Formation of the Blairmore Group (G.M. Dawson, 1886), is the only extrusive volcanic deposit within Mesozoic strata of the Foothills and Rocky Mountains of Western Canada east of the Rocky Mountain Trench. The Mill Creek and Beaver Mines formations of the Blairmore Group have long been differentiated due to distinctly different floral successions (J.W. Dawson, 1886; Bell, 1956; Mellon, 1967). The Beaver Mines Formation is characterized by abundant ferns, cycadophytes and conifers with only rare angiosperms, whereas the Mill Creek Formation contains abundant angiosperms.

The Crowsnest Pass/Oldman River area (Fig. 1) is also reputed to have been the source for the legendary lost Lemon Gold Mine (Riley et al., 1968). The source of the alleged gold deposits has been attributed to gravels in modern streams in this area, paleo-placer deposits and, more recently, from the volcanic rocks of the Crowsnest Formation.

The Blairmore Group is outcrop equivalent to reservoirs found in the subsurface Mannville Group in the Western Interior Plains. The Mannville Group contains $33,333 \times 10^9$ cu ft. initial established marketable reserves and $1,545 \times 10^6$ BBLS of conventional initial established crude oil reserves. The Viking and Bow Island Formations are subsurface equivalents of the Mill Creek Formation containing in excess of $10,213 \times 10^9$ cubic feet of natural gas and 502×10^6 barrels of oil (Porter, 1992). As such, the outcrop expression of sandstone and conglomerate in the Mill Creek Formation may provide an indication of hydrocarbon reservoirs in the subsurface.

The purpose of this field guide is to present arguments for major controls on sedimentation within the basin and to informally present a new and refined stratigraphy of the upper Beaver Mines and Mill Creek formations. The new stratigraphy will be formally presented elsewhere by D.A. Leckie and E. Burden. A new and revised stratigraphy (Fig. 2B) has been formally proposed by Bloch et al (in press). Unconformities that formed within the Beaver Mines and Mill Creek Formations were deposited during a period of time when significant unconformities developed elsewhere in Western North America. However, the interregional relationships of these unconformities are not well understood. In this field guide, the first documentation of a middle Albian marine incursion into the Foothills of southwestern Alberta is made (**STOPS 11,12,13**). Finally, because of the historic interest in gold from the Crowsnest Pass area assay results from the Blairmore Group are presented to provide background information for potential mineral prospecting in the sediments.

ACKNOWLEDGMENTS

This guidebook has been pirated from several other publications in which I have been involved.

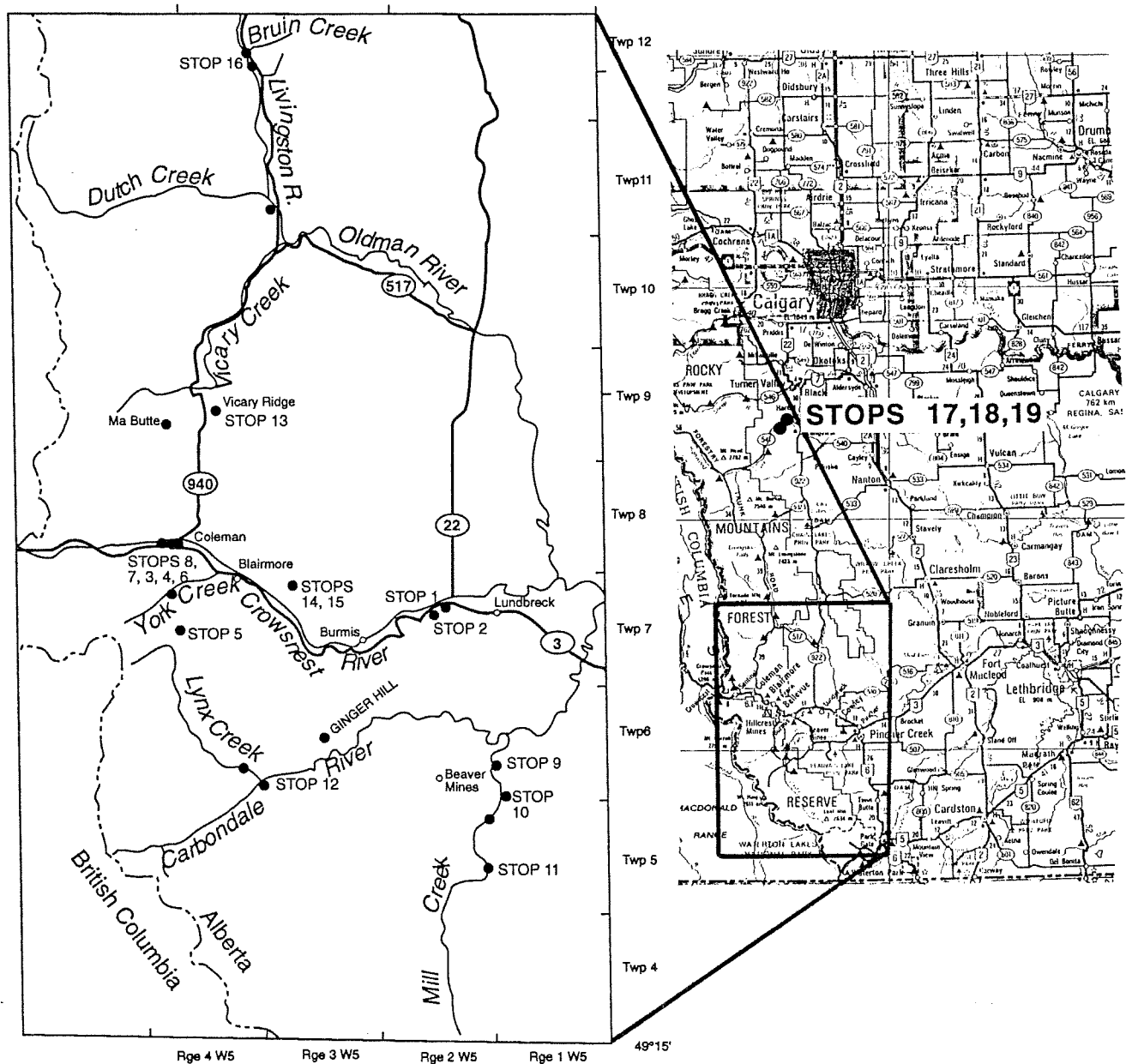
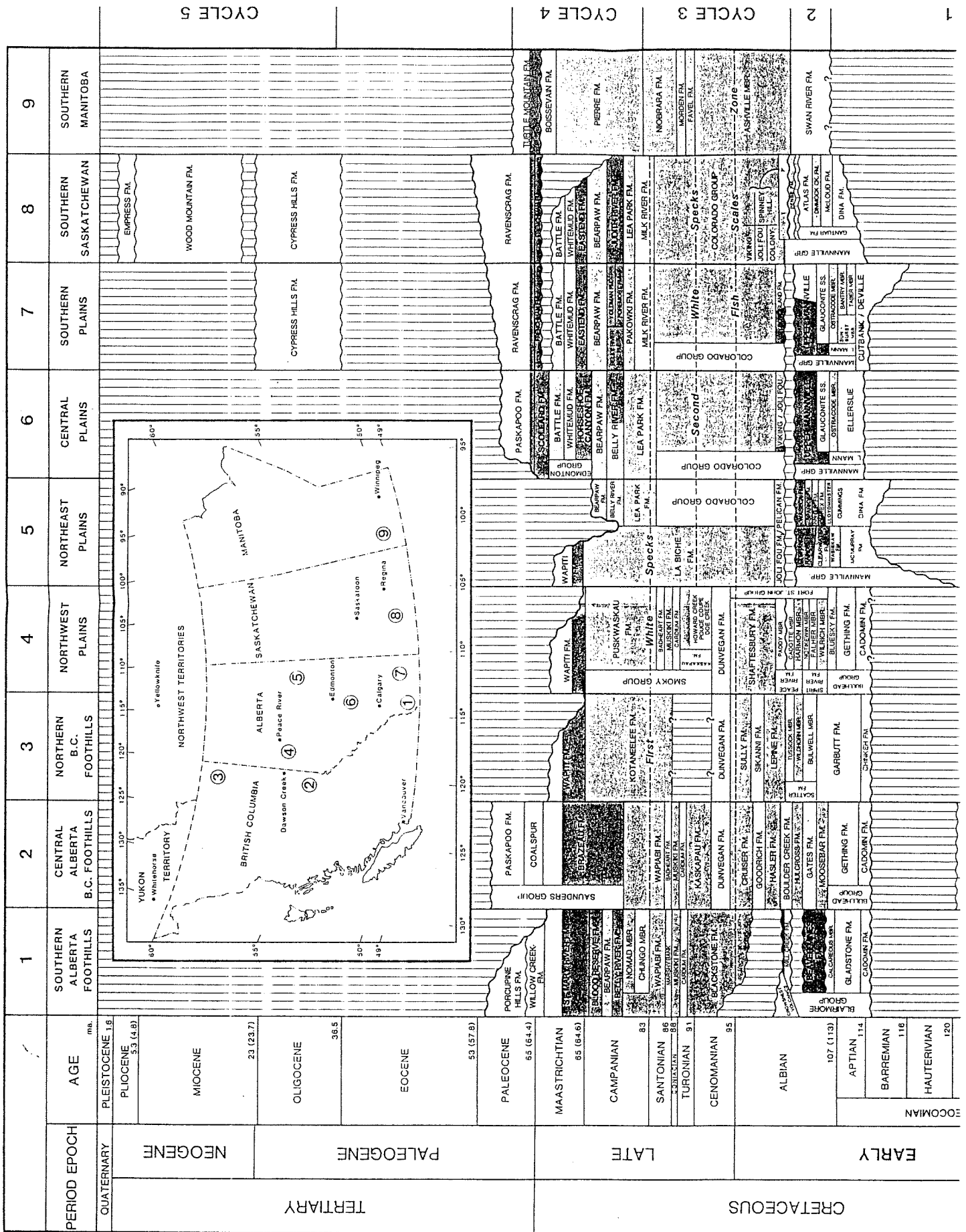


Figure 1. Field trip stops.

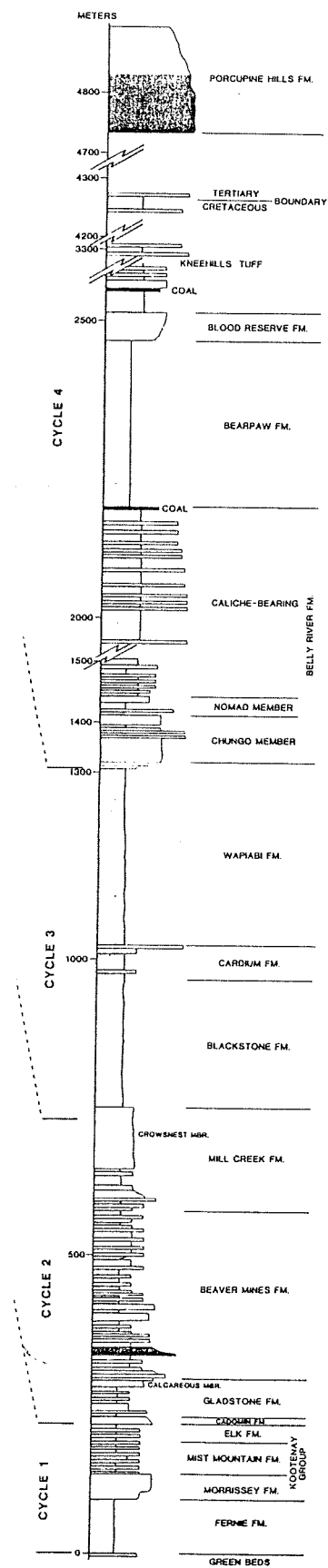
Figure 2A () Cretaceous stratigraphy of Western Canada.



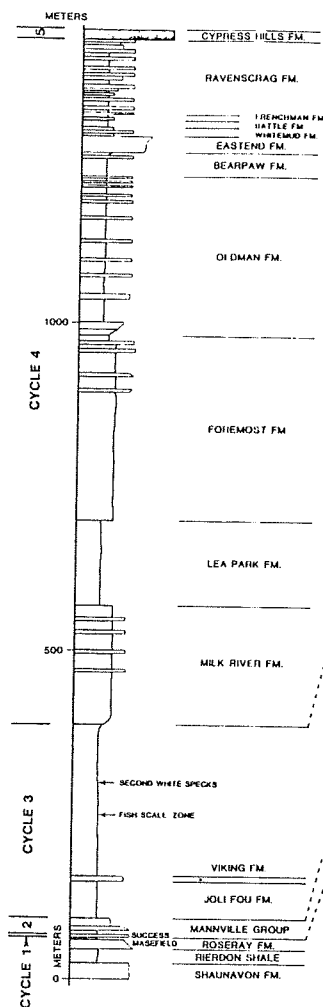
PERIOD	EPOCH	STAGE AGE (Ma)	1	2	3	4	5	6	7	
CRETACEOUS	LATE	CAMPANIAN	BELLY RIVER FM.	BRAZEAU FM.	PUSKASCAU FM.	BELLY RIVER FM.	BELLY RIVER FM.	BELLY RIVER FM.	PIERRE FM.	not studied
		84	WAPIABI FM.	WAPIABI FM.	BADHEART FM.	LEA PARK FM.	MILK RIVER FM.	LEA PARK FM.		
		SANTONIAN			MUSKIKI FM.	MEDICINE HAT	MEDICINE HAT	MEDICINE HAT	NIOBARARA FM.	
		87								
		CONIACIAN								
	EARLY	89								
		TURONIAN	CARDIUM FM.	CARDIUM FM.	CARDIUM FM.	CARDIUM FM.			MORDEN FM.	not studied
		93	OPABIN FM.							
			HAVEN FM.				JUMPING POUND		FAVEL FM.	
			VIMY FM.							
	LATE	CENOMANIAN	BLACKSTONE FM.	KASKAPAU FM.	KASKAPAU FM.					not studied
		97-99	SUNKAY FM.		HOWARD CRK.		PHILLIPS			
					POUCE COUPE					
					DOE CRK.					
	EARLY	ALBIAN	BLAIRMORE GROUP	DUNVEGAN FM.	DUNVEGAN FM.					not studied
	LATE									not studied
	EARLY									not studied

Figure 2B) Revised stratigraphy of the Colorado Group in Western Canada. From Bloch et al. (in press).

③ SOUTHERN ALBERTA FOOTHILLS



④ CYPRESS HILLS, SASKATCHEWAN



⑤ CENTRAL ALBERTA

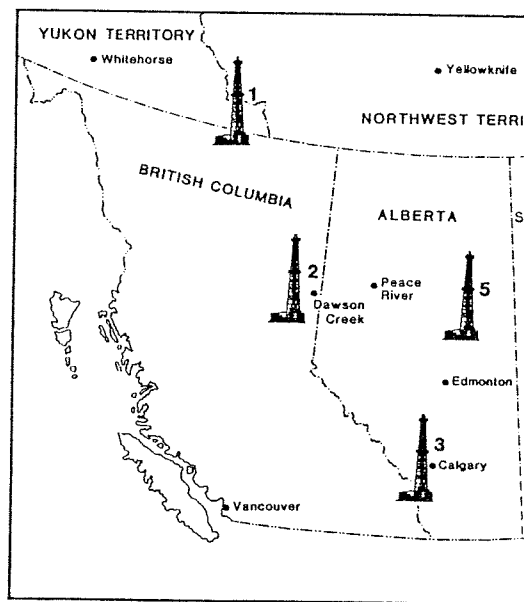
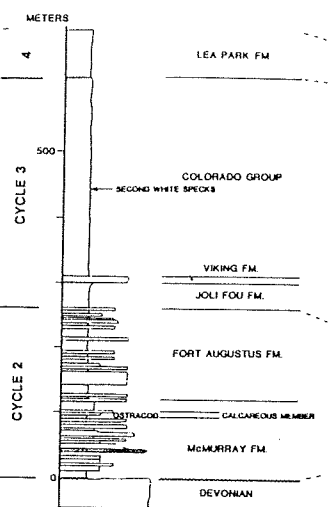


Figure 3. Representative lithological logs from Western Canada.

The guidebook is not yet complete but will evolve over the years as more data becomes available and I get it boiled down. I want to thank several people with whom I have looked at these rocks and argued about their origins over the years: Indranil Banerjee, John Bloch, Ross Campbell, Richard Cheel, David Gibson, David James, Lee Krystinik, Angus Leech, Paul McCarthy, Greg Nadon, Lorne Rosenthal, Mike Staniland, Chaitanya Singh, David Smith, John Wall; Roger Walker.

REGIONAL GEOLOGICAL SETTING

The western North American foreland basin was an elongate trough that developed between the eastern flanks of the ancestral Rocky Mountains and the stable interior platform of the Canadian Shield (Fig. 4). At its maximum extent, the foreland basin was more than 6000 km long, stretching from the Arctic Ocean to the Gulf of Mexico and up to 1600 km wide, extending from westernmost Ontario to central British Columbia. The Western Interior Seaway repeatedly occupied this foreland basin which developed as a direct result of crustal loading along the elongate fold and thrust belt (Price, 1973; Beaumont, 1981). The major controlling factors on basin subsidence and sedimentation were the combination of plutonism, volcanism and lithospheric loading (Fig. 4B) in the thrust belt caused by subduction that extended from Alaska to Mexico; sediment loading within the foreland played a secondary role. Major fluctuations in sea level, some of which were eustatically controlled, also affected basin sedimentation (Jervy, 1992).

The tectonic history of the Western Canada Sedimentary Basin can be divided into three stages (Porter et al., 1982; Fermor and Moffat, 1992).

Stage 1 represents a generally passive, continental margin terrace wedge which existed throughout the Paleozoic and ended in Early to Middle Jurassic time. This passive continental margin comprised, from west to east, eugeoclinal, miogeoclinal and platformal sediments which may have been up to 20 km thick in the west (Price, 1981).

Stage 2 records the oblique collision of "foreign" terranes, which now generally correspond to the Intermontane Belt (Fig. 4), with the westward-moving North American craton (Monger et al., 1982). The Intermontane Belt today consists of amalgamated terranes composed of oceanic volcanic arc assemblages on a basement of Triassic and Upper Paleozoic rocks. The collision, associated with the Early Jurassic Columbian Orogeny, resulted in the compression of the western part of the passive-margin wedge between the Intermontane Belt and the North American craton. The suture of the Intermontane Belt with the craton is represented by high-grade metamorphic and granitic rocks of the Omineca Belt (Fig. 4). Metamorphic minerals within the Omineca Belt indicate burial depths of 20 to 27 km, probably as a result of westward-dipping subduction (Ghent et al., 1977).

Supracrustal platform rocks deposited during Stage 1 were scraped off the westward-subducting

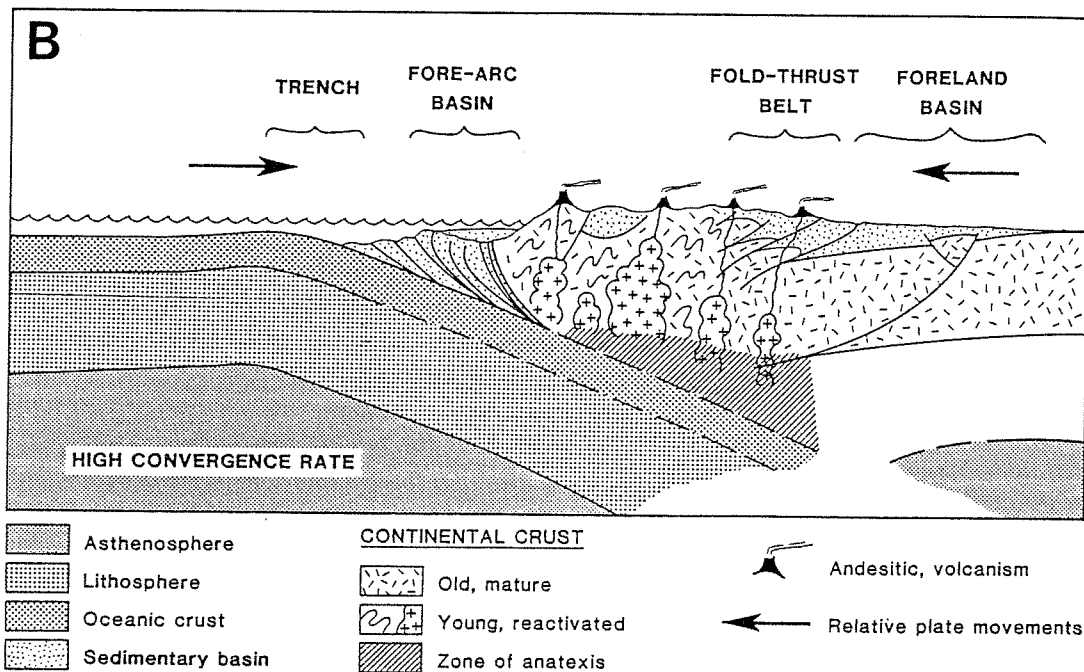
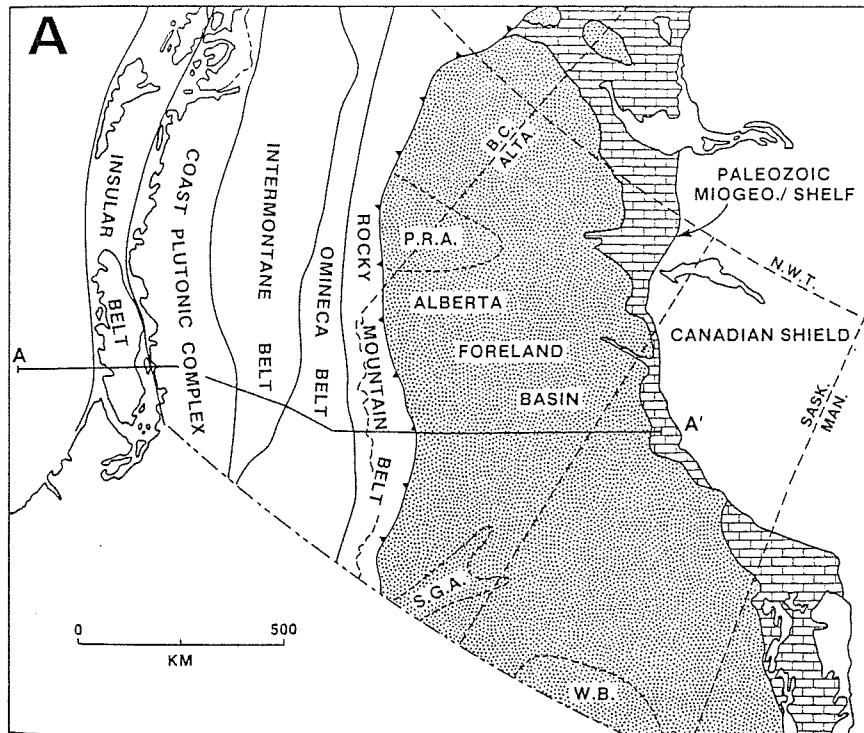


Figure 4A) Tectonic subdivisions and features of the Western Canada foreland basin and Canadian Cordillera. From Stockmal et al. (1992). 4B) Subduction along an Andean-type continental margin magmatic arc. This model is most commonly used to explain the formation of the Western Canada Foreland Basin.

now present in the Rocky Mountain Fold and Thrust Belt. Uplift took place where metamorphic rocks of the Omineca Belt were wedged under the platform sediments, resulting in a prolific sediment source and the progradation of two early sedimentary cycles into the foreland basin. The tectonic thickening and eastward overthrusting of the continental terrace deposits caused loading and downward isostatic flexure of the underlying lithosphere, resulting in the formation of the foreland basin (Price, 1973). Much of the tectonic thickening may have initially taken place below sea level, thereby limiting the development of an early, extensive, high relief source area.

By mid-Jurassic time, most of the foreign terranes had been welded to North America, but considerably farther south than their present location. Composite right-lateral strike-slip movement from at least mid-Cretaceous through to Oligocene time translocated the accreted terranes northwards by up to 900 km (Gabrielse, 1985).

During latest Jurassic to late Neocomian time there was generally very little magmatism within the Canadian Cordillera. From post-Neocomian to Late Cretaceous time, volcanism and associated sedimentation from an Andean-type continent-margin magmatic arc prevailed (Armstrong, 1988), resulting in the deposition of a thick coarse-clastic continental succession. During mid-Cretaceous time, convergence of the Intermontane Belt with the craton appears to have waned, resulting in a period of tectonic quiescence (Stott, 1984), although changes in plate motion and internal stress regimes may have resulted in large-scale downflexing of the craton (Lambeck et al., 1987). This period also coincided with mid-Cretaceous global sea level rise on the order of 200 to 300 m (Haq et al. 1987). In any event, maximum subsidence and a low coarse-clastic sediment supply during this period combined to produce a thick marine shale succession in the foreland basin, as discussed below.

Stage 3 marks resumption of Late Cretaceous to Paleocene oblique convergence. A second major, foreign exotic terrane, generally corresponding to the Insular Belt (Fig. 4), collided with the North American craton and the previously accreted Intermontane Belt, causing the Laramide Orogeny. The Coast Plutonic Complex (Fig. 3) represents the suture along which the Insular Belt accreted to North America. Renewed thrusting and stacking resulted in eastward expansion of the foreland basin and the deposition of a thick sequence of mostly terrigenous sediments. In the southern Canadian Rocky Mountains, cratonic strata and overlying foreland basin strata were shortened by up to 200 km between Early Campanian and latest Eocene time as a result of this late stage compression (Price, 1981).

A major lull in magmatism in the Cordillera from mid Maastrichtian to Late Paleocene (about 70 to 60 m.y. B.P.) (Armstrong, 1988) resulted in a massive isostatic uplift of the orogen and foreland basin, and a significant erosion surface developed. Foreland basin-style sedimentation and compressive deformation ceased during the Eocene, with the deposition and subsequent folding of the sediments in the eastern fold and thrust belt (Price, 1981). Within the western Cordillera, the magmatic lull was followed by intense magmatism from Paleocene to Middle Miocene (64-40 Ma). Right-lateral strike-slip movement

along the Tintina-Northern Rocky Mountain Trench fault zone continued during this time (McMechan and Thompson, 1989).

Foreland basins are asymmetric, being deepest on the fold-thrust belt side due to the combined effects of thrust-plate loading in the orogenic belt and subsidiary sediment loading in the basin itself (Fig. 5; Price, 1973;). In the western Canadian foreland basin, the amount and rate of subsidence was greatest adjacent to the advancing thrust sheets and it was here that the greatest amount of sediment accumulated, resulting in stacked, westward thickening clastic wedges. The asymmetric subsidence of the basin also affected drainage patterns, creating a prevailing drainage system which was largely parallel to basin axis (e.g., Cadomin Formation, **STOPS 5,6**) . Modeling of foreland basins indicates that basin-axial drainage patterns are characteristic of underfilled basins caused by rapid thrusting (Flemings and Jordan, 1989). By contrast, overfilled foreland basins have a drainage pattern which is orthogonal to the mountain belt. As the fold-thrust belt continued to migrate eastward, pre-foreland basin platformal and miogeoclinal as well as foreland basin strata were progressively incorporated into the deformed belt. The deformed belt was compressively shortened, penecontemporaneous with, and after, basin sedimentation by up to 50 km in the north (Thompson, 1981) and 200 km in the south (Bally et al., 1966).

DEPOSITIONAL CYCLES AND PALEOGEOGRAPHY

CYCLES, BOUNDING SURFACES AND HIATAL-GAPS

A regional correlation chart of strata deposited within the Canadian foreland basin is shown in Figure 2. For descriptive purposes the depositional history of the foreland basin has been divided into five cycles of differing ages, each representing strata bounded by major unconformities or lithologic changes (Fig. 3). These are, in ascending order:

Cycle 1: Oxfordian to late Valanginian: base of Fernie shales to top Nikanassin Formation/Kootenay Group

Cycle 2: Hauterivian to Albian: Cadomin Formation/Dina Member to top of the Mannville Group

Cycle 3: Albian to Campanian: base of Joli Fou Formation/Paddy Member to top of Wapiabi Formation/Colorado Group

Cycle 4: Campanian to Early Eocene: Saunders Group (base Belly River to top of Porcupine Hills Formation/Paskapoo Formation)

Cycle 5: Eocene to Pliocene: Cypress Hills, Wood Mountain and Empress formations

Generally, each succeeding cycle records a major reorganization of the paleogeography within the basin and accordingly, a different regime of petroleum exploration plays. Although several sequences within the various cycles may approximately coincide with global sea level lowstands or highstands, each

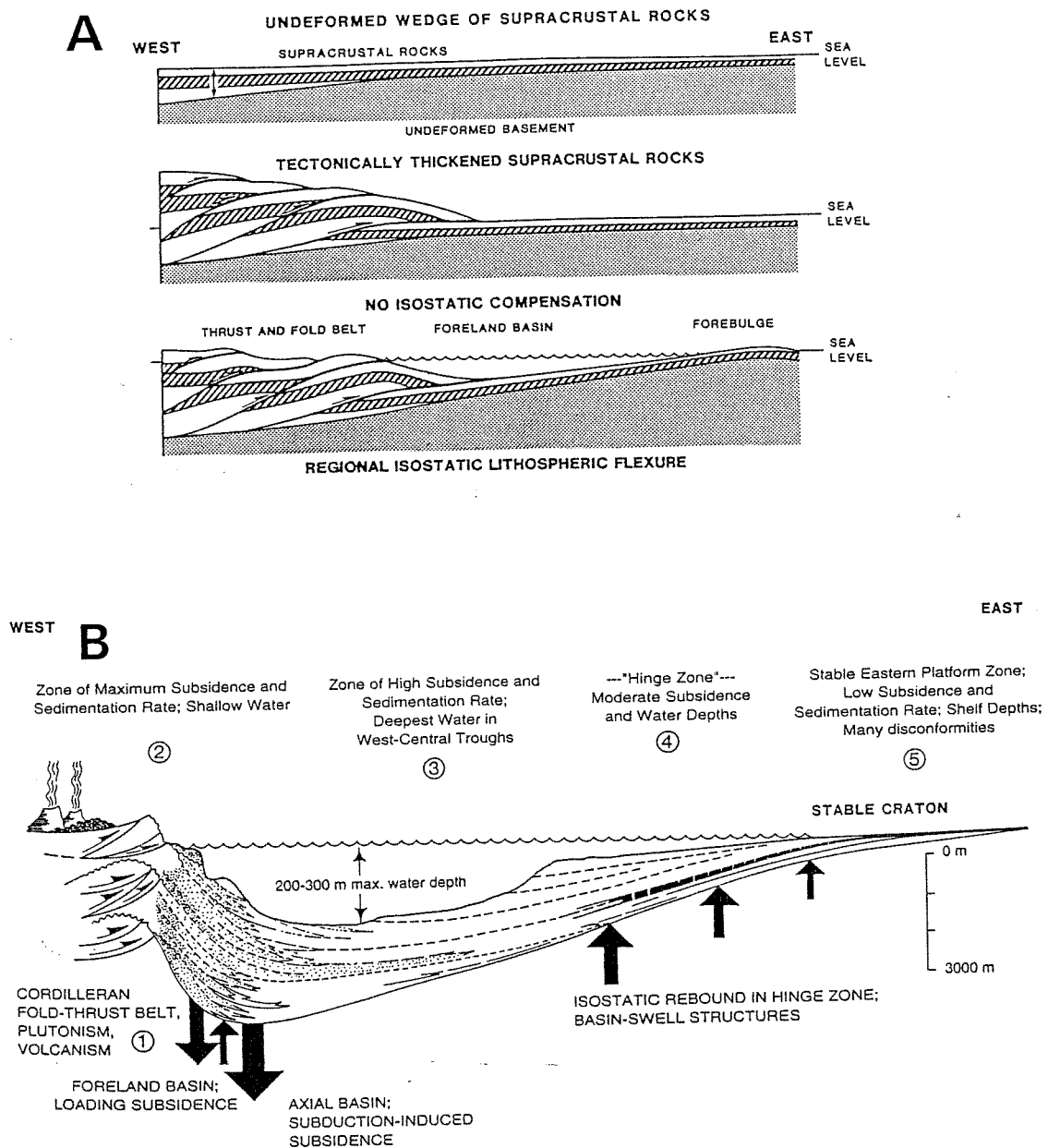


Figure 5A) Model describing formation of the Western Canada Foreland Basin. Supracrustal rocks are overthrust as a result of plate accretion and compression. This results in isostatic flexure of the lithosphere and deformation of the foreland basin into which synorogenic detritus is deposited (From Price, 1973). B) The synorogenic foreland basin into which sediment is deposited. Modified from Kauffman, 1984.

cycle as a whole corresponds to specific tectonic events in the Cordillera to the west.

A series of paleogeographic maps showing the illustration of the basin are shown in Figure 6.

CYCLE 1: BASE OF FERNIE SHALES TO TOP OF NIKANASSIN FORMATION/ KOOTENAY GROUP (OXFORDIAN TO LATE VALANGINIAN)

The lowermost cycle of the foreland basin succession contains Oxfordian to late Valanginian-aged sediment (**STOP 1**) deposited as a result of the collisional tectonics associated with the Columbian Orogeny. (i.e., the collision of the Intermontane Belt with western North America). The foreland basin was narrow and elongate, subsiding most rapidly in northeastern British Columbia (Stott, 1984). The end of Cycle 1 is represented by a major basin-wide unconformity at the base of the Cadomin Formation (**STOPS 5, 6**).

Westerly-derived sediment from the uplifted Omineca Belt and the newly-formed Rocky Mountains of the Columbian Orogen first occurs in the upper parts of the Oxfordian Fernie Formation (Figs. 2, 3). The upper Fernie unconformity (base of Cycle 1) truncates progressively older strata east- and northeastwards. The overlying Green Beds of the Fernie Formation, which consist of glauconitic mudstone and quartzose, craton-derived sandstones, represent the initial flooding of the foreland basin (Poulton, 1984). A major Oxfordian transgression persisted for approximately 10 million years and resulted in deposition of several hundred metres of black shales (upper Fernie Formation) in an offshore marine environment (Figs. 3,6). The younger Passage Beds and Kootenay Group record basin-filling in a northerly direction along the axis of the basin. The Passage beds (siltstone and shale) represent marine deposition during the initial stages of basin fill. Sandstones of the Morrissey Formation, which is the basal formation of the Kootenay Group, were deposited along a north to northwesterly prograding high-energy shoreline (**STOP 5**). The Morrissey Formation is overlain by the fluvio-deltaic quartz and chert-rich sandstones, siltstones and shales of the Mist Mountain Formation (Gibson, 1977). Extensive peat deposits at the base of the Mist Mountain Formation accumulated on strandplain sediments of the Morrissey Formation. The Kootenay Group grades northwards into the increasingly marine sediments of the Nikanassin Formation (central Foothills) and the Minnes Group (northern Foothills) (Stott, 1984).

CYCLE 2: CADOMIN FORMATION TO TOP OF MANNVILLE GROUP (HAUTERIVIAN TO ALBIAN)

The contact between Cycles 1 and 2 is represented by a major basin wide post-Valanginian unconformity ("pre-Cretaceous unconformity") at the base of the Cadomin Formation and its equivalents (**STOPS 5,6**). In the westernmost outcrops, little or no hiatus is apparent between the Cadomin and underlying strata (Rapson, 1965; Gibson, 1977; Stott, 1984a). Erosion beneath the unconformity resulted in very irregular regional topography, consisting of valleys and interfluvies which controlled sedimentation patterns during subsequent early Cretaceous deposition.

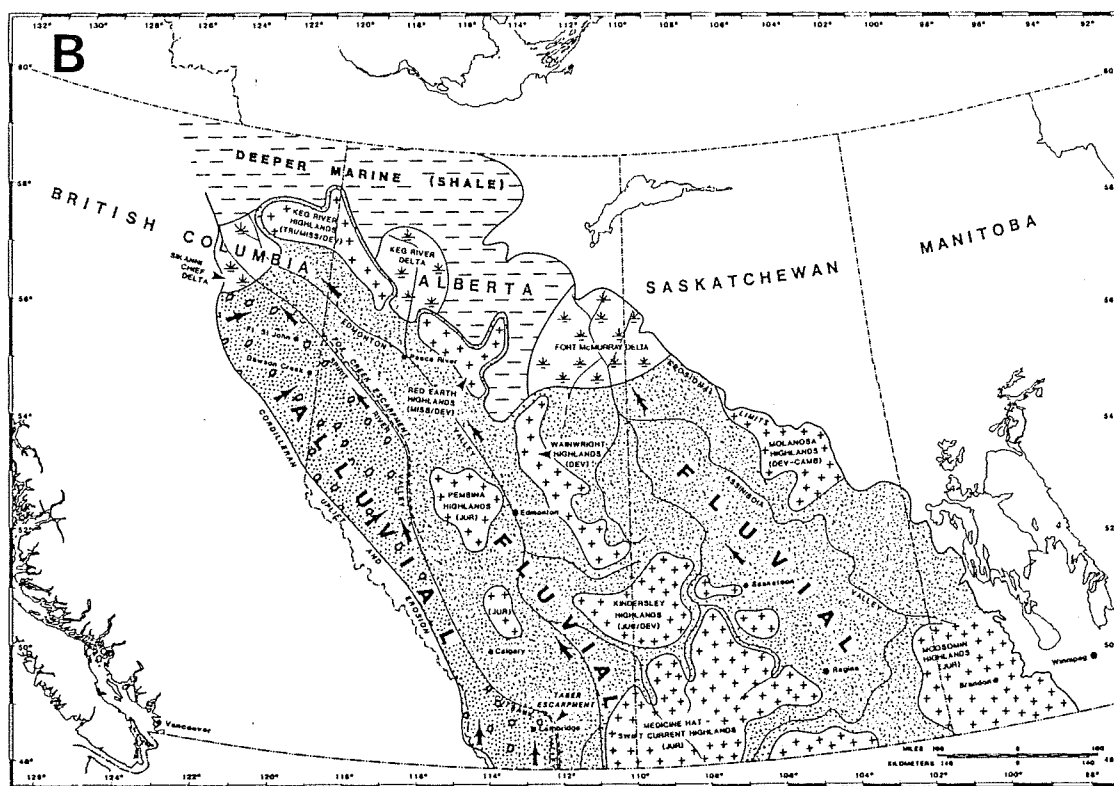
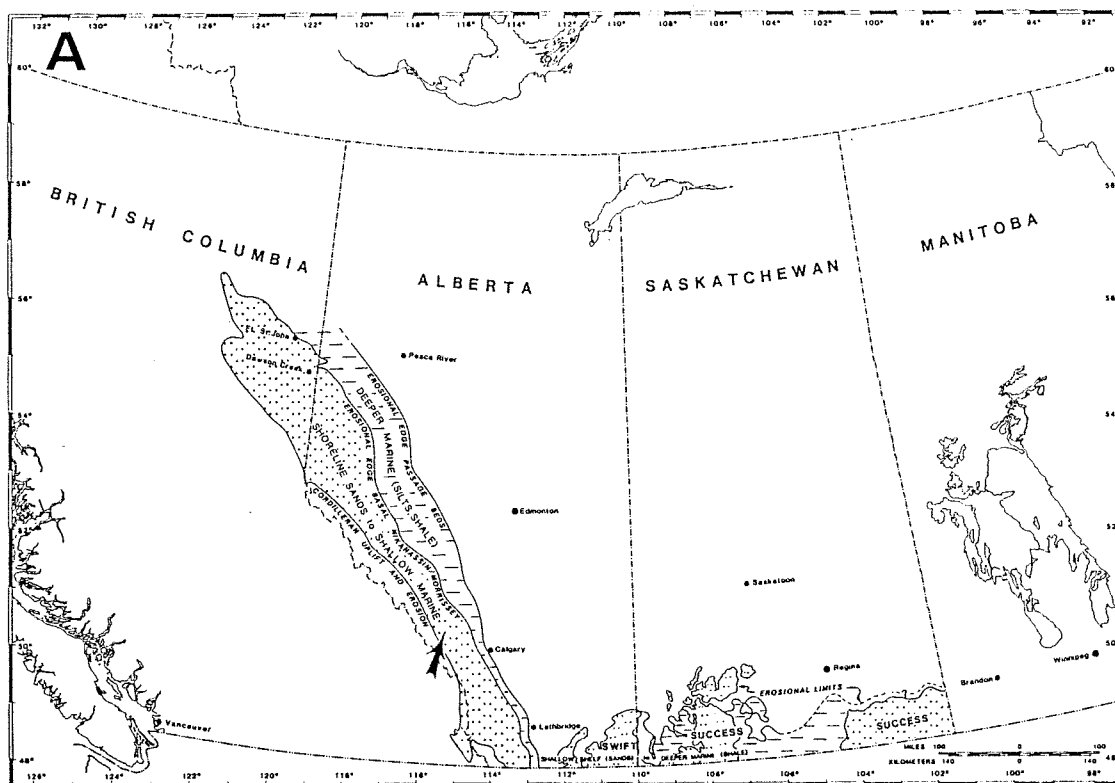


Figure 6. Paleogeographic reconstruction of the A) Morrissey, Swift and Success formations and the Passage Beds deposited in Cycle 1. B) Cadomin, Ellerslie, Gething and Dina formations deposited in Cycle 2. From Leckie and Smith (1992).

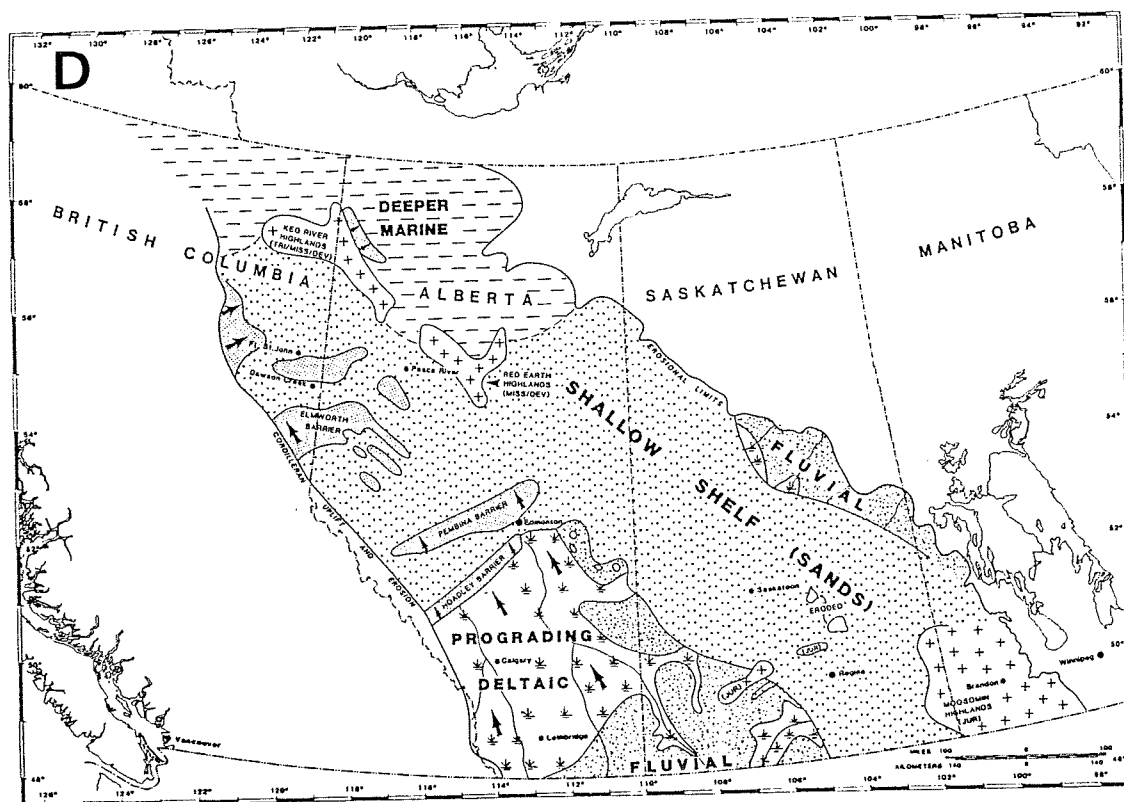
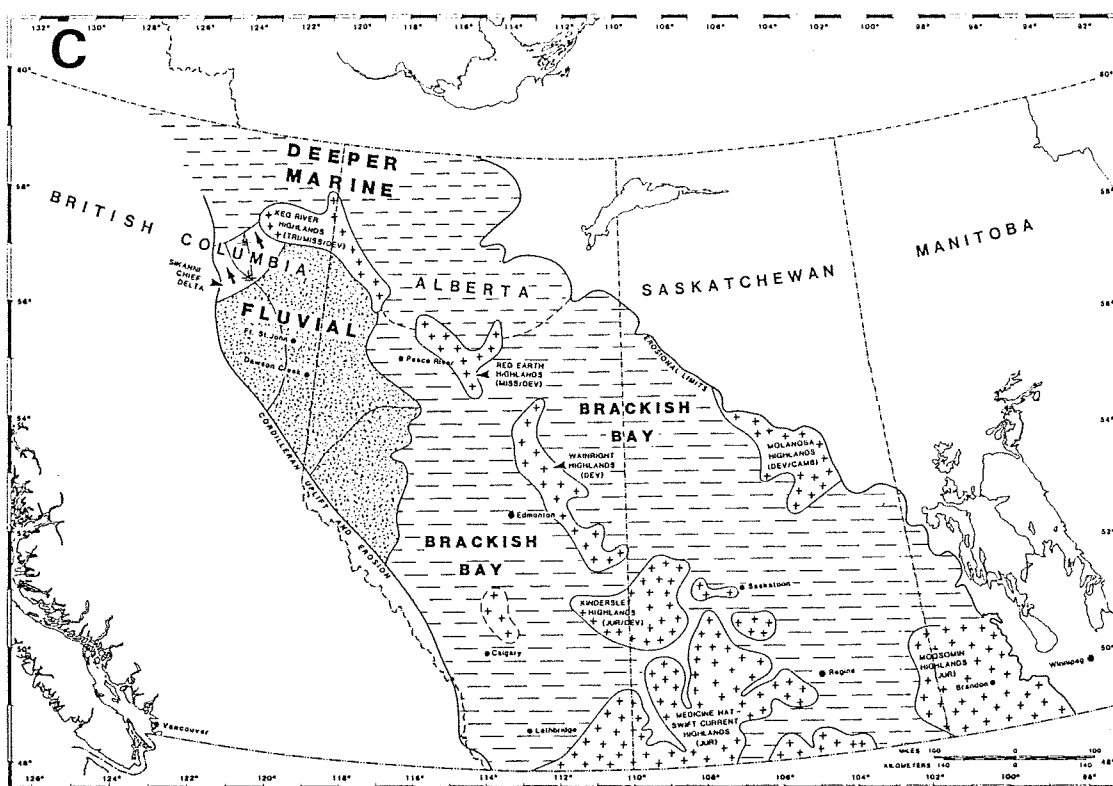


Figure 6. Paleogeographic reconstruction of the C) Calcareous, Ostracod and Cummings members during deposition of Cycle 2. D) Glauconite, Bluesky, Wabiskaw and Lloydminster units formations deposited in Cycle 2. From Leckie and Smith (1992).

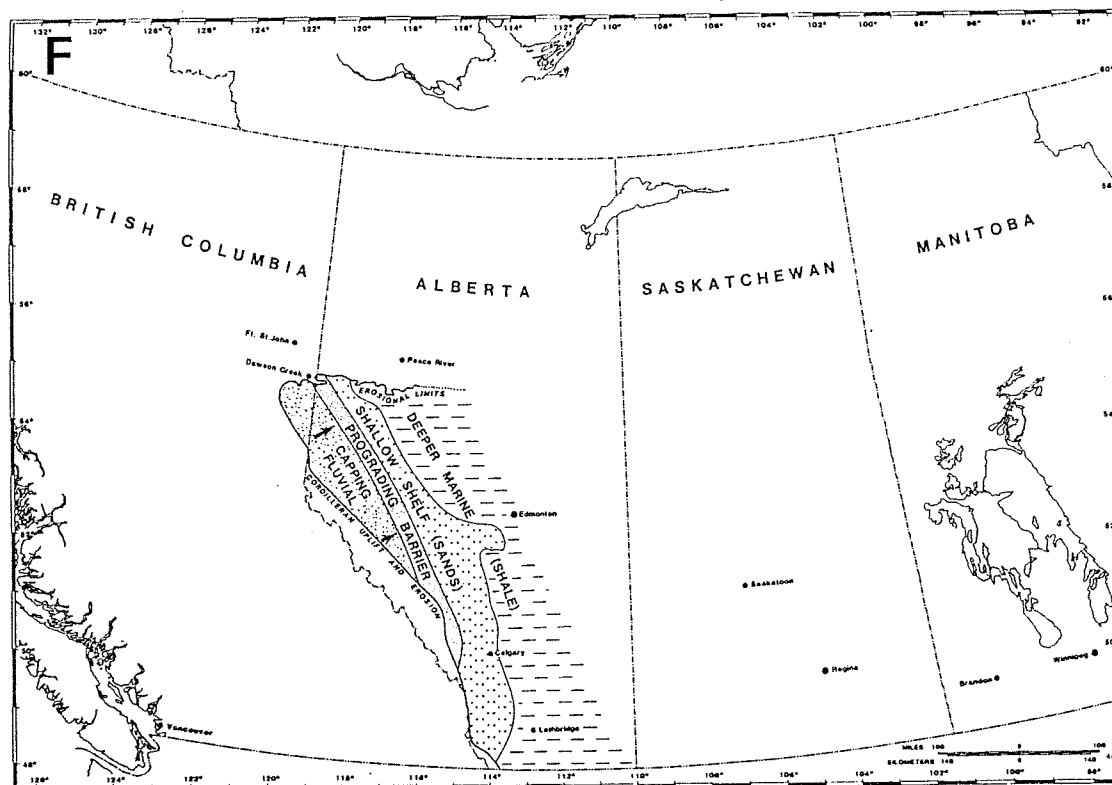
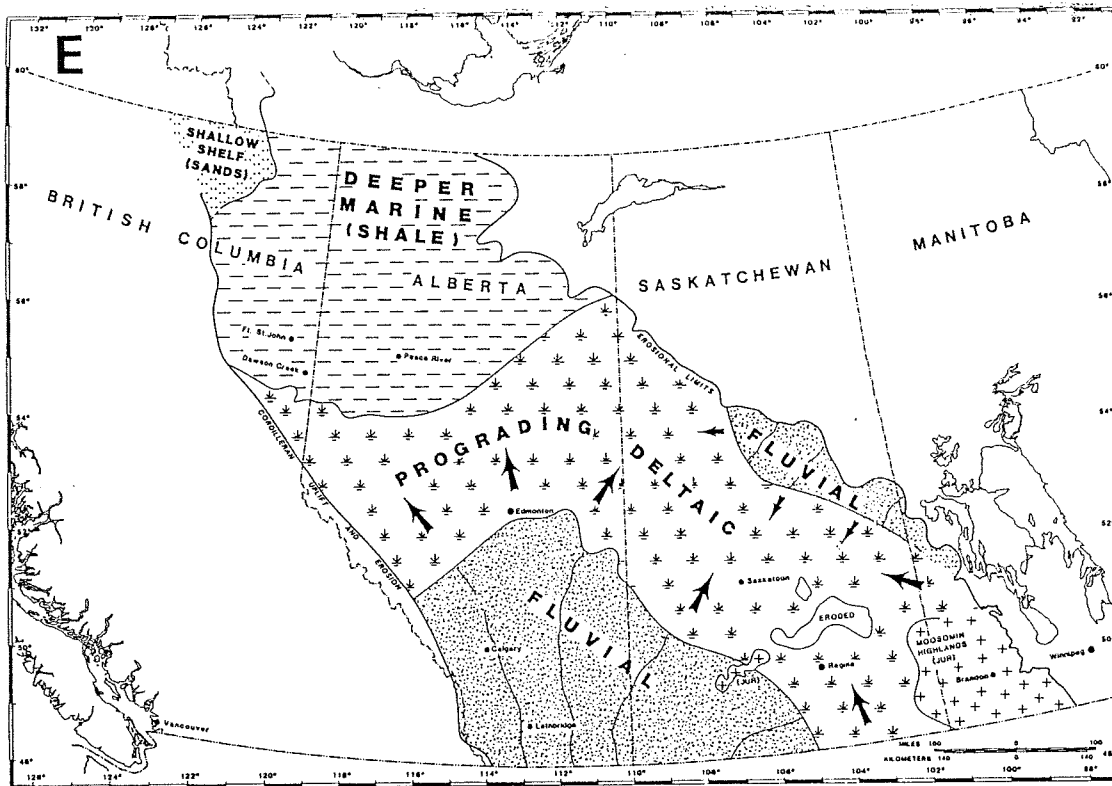


Figure 6. Paleogeographic reconstruction of the E) Upper Mannville, Rex, General Petroleum, Waseca, Gates and Clearwater formations deposited in Cycle 2. F) Cardium Formation deposited in Cycle 3. From Leckie and Smith (1992).

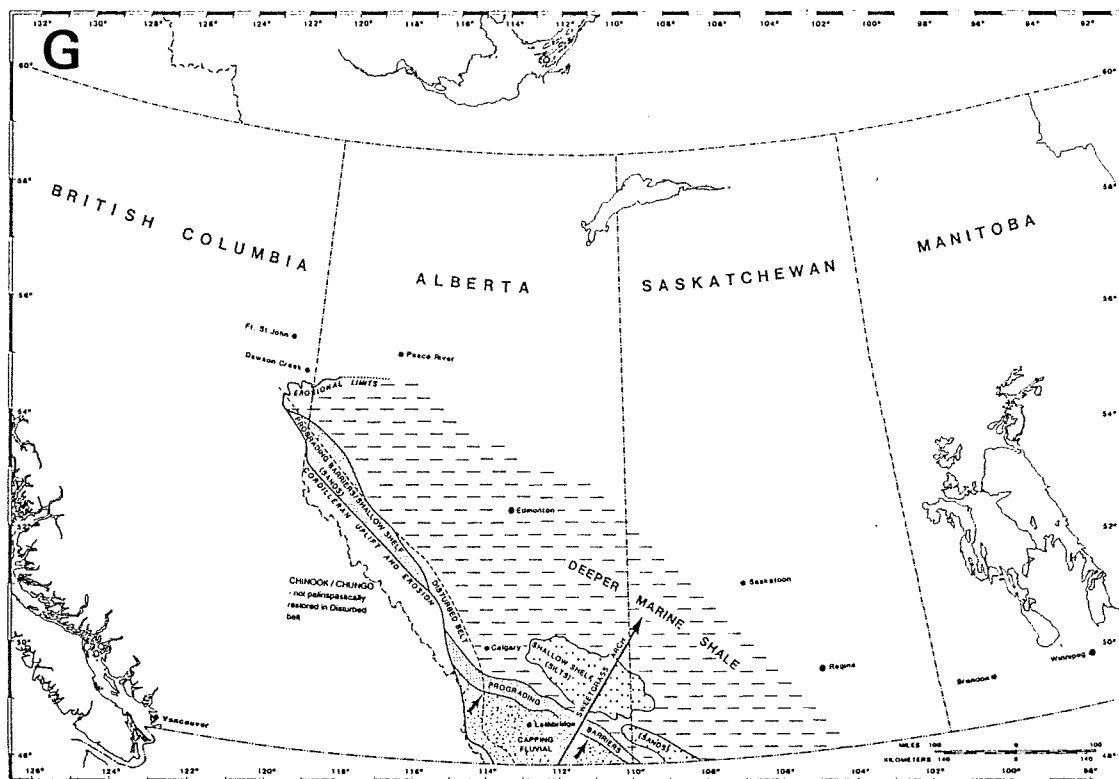


Figure 6. Paleogeographic reconstruction of the G) Milk River Formation and the Chungo and Chinook members deposited during Cycle 3. From Leckie and Smith (1992).

The Cadomin Formation is a chert and quartzite pebble conglomerate locally up to 200 m thick and possibly derived from several point-source alluvial fans along the rising Cordillera (Fig. 6; Stott, 1968; McLean, 1977; Schultheis and Mountjoy, 1978). Historically, the Cadomin gravels are interpreted to have been transported eastward as alluvial fans and braidplain (?) deposits into the axis of the basin where they entered the drainage system of the northwest-flowing Spirit River. However, data from southwestern Alberta and southeastern British Columbia indicate northwards flow. Deposition of the Cadomin Formation occurred during a renewed episode of subsidence which accompanied the emplacement of thrust sheets in the adjacent foldbelt. Erosion of the thrust sheets would have resulted in isostatic rebound and flexural uplift of the foreland basin and associated orogen, causing detritus to be shed out into the basin (Heller et al. 1988). With this model the Cadomin sediments appear to represent an interval of tectonic quiescence in the Cordillera when much of the Rocky Mountains and eastern Foreland Basin were being isostatically uplifted and sediments older than Hauterivian were regionally beveled. The major lull in magmatic activity in the western Cordillera during the Early Cretaceous (135-125 m.y.; Armstrong, 1988) relates to the cessation in tectonic activity.

Following deposition of the Cadomin Formation and correlative units, progressive but intermittent flooding of the foreland basin from the north occurred. In southern and central Alberta, the younger brackish-bay shales, fine-grained sandstones and argillaceous limestones of the Calcareous/Ostracode member (**STOP 10**; Fig. 6) marked the flooding event (Glaister, 1959).

The transgression of the Boreal Sea continued southward across Alberta, Saskatchewan and the northern United States along the pre-existing drainage network. Tidally-influenced sedimentation resulted in isolated sands of the Ostracode member within and near the mouths of estuaries. In southern and central Alberta, prior to inundation by the Moosebar Sea proper, black calcareous mud and minor sandstone of the Calcareous member (Ostracode limestone/Gladstone equivalent) were deposited in large lakes and swamps which were periodically linked to the sea (McLean and Wall, 1981). Renewal of volcanic activity in the Western Cordillera is indicated by the abundance of volcanic rock fragments and feldspars in the Calcareous member and the predominance of volcanically-derived, smectitic clays of the Bantry shales of the Ostracode member (Farshori, 1983).

As the transgression progressed, the discontinuous sandstones of the Glauconite, Bluesky, Wabiskaw and Lloydminster units were deposited as retrogradational shoreline, estuarine and shallow-shelf deposits. Fluctuations in relative sea level during this time resulted in incised valleys, estuarine-fill sequences and local progradational shorelines. Paleo-valleys infilled with estuarine and brackish-water sediments are found as far south as northern Montana (Burden, 1982). In west-central Alberta, three transgressive-regressive events are recognized in the retrogradational Glauconite and Bluesky formations within the overall larger scale advance of the Moosebar Sea (Rosenthal, 1988). Maximum transgression occurred below the Glauconite Formation. The Hoadley shoreline and offshore sands are dissected by fluvial channels, some of which had headwaters in southern Alberta.

Continued transgression resulted in deeper water sediments being deposited in the Moosebar Sea. At its maximum transgression, the Moosebar Sea inundated eastern British Columbia, Alberta and Saskatchewan leaving only isolated uplands in the Swift Current, Kindersley and Moosomin areas.

The climate during deposition of Cycle 2 was warm and humid. The Cadomin Formation was largely deposited in a warm, humid setting. However, in southern Alberta, much farther from the coastline, thick deposits of red beds in the Blairmore Group (**STOPS 4, 9**) and *in situ* caliche as well as transported caliche clasts in the Cadomin Formation indicate arid to semi-arid conditions.

In southwestern Alberta, the Middle to Late Albian Crowsnest Volcanics (**STOP 7**) of the Mill Creek Formation represent the only *in situ* extrusive volcanic rocks preserved within the foreland basin. A palinspastic reconstruction of the present position of the Crowsnest Volcanics places the site of intrusion about 200 km to the west, near Cranbrook, British Columbia (Norris, 1964).

CYCLE 3: BASE OF JOLI FOU FORMATION/PADDY MEMBER TO TOP OF WAPIABI FORMATION/COLORADO GROUP (ALBIAN TO CAMPANIAN)

The deposition of sediments of Cycle 3 corresponds to a long term period of global sea level rise from Cenomanian through Santonian time (Haq et al., 1987; Jervy, 1992) which was coincident with a regional downflexing of the North American craton (Lambeck et al., 1987). Cycle 3 includes three major marine inundations separated by two lowstand, regressive pulses represented by the Viking-Peace River and Cardium (**STOP 8**) formations. During the highstands, warm marine waters from the Gulf of Mexico mixed with the boreal waters extending south from the Arctic. This cycle consists primarily of marine shale and is in excess of 1100 m thick.

In southern Alberta, the oldest record of the transgression is the Cenomanian Blackstone Formation (**STOP 17**) where it onlaps the Blairmore Group. The lowermost Cenomanian Fish Scale Zone is a basin-wide marker containing abundant fish remains deposited with finely laminated, unbioturbated sandstones and siltstones. The Fish Scale Zone, which is characterized by high total organic carbon contents (up to 8%) and a low concentration of benthic foraminifera, likely was deposited under poorly-oxygenated bottom conditions. In Saskatchewan and Manitoba, the base of the Fish Scale Zone may represent a major hiatus with substages missing below it (Caldwell, 1984), whereas in western Alberta, strata above and below the Fish Scale Zone appear to be more conformable (Stelck and Armstrong, 1981). The Fish Scale Zone is generally considered to contain a condensed section deposited during a peak transgression which occurred during deposition of the Colorado Group.

The upper Turonian is marked by a regressive event in the west which is capped by an erosional disconformity that can be traced across the basin. In the west, this unconformity is overlain by the conglomerates of the Cardium Formation. The unconformity approximately coincides with the 90 my eustatic lowstand of Haq et al., 1987) although Plint and Walker (1987) attributed Cardium shoreline

progradation and unconformities within the formation to tectonic uplift at the western margin of the basin.

The Cardium Formation and its correlative units are disconformably(?) overlain by the Coniacian to Campanian marine shales of the upper Colorado Group, Wapiabi Formation and Niobrara Formation, which represent a second major marine inundation during Cycle 3. The peak of this marine transgression is represented by the planktonic foraminifera found in the First White Specks Zone. In the First and Second White Specks and perhaps the Fish Scale Zones, the presence of biogenic chalk and planktonic foraminifers indicate open marine conditions within the seaway during the peaks of the marine transgressions.

The final regressive event of Cycle 3 (Early Campanian) is represented by extensive shoreline sandstones of the Milk River Formation and the Chungo Member (Fig. 6) (**STOPS 1, 3**), which extend from southeastern Alberta and Montana to the central Alberta Foothills. The shoreline prograded as a wave-dominated sheet of sandstone that extended laterally for at least 350 km. The influence of tides in the foreland basin at this time is recorded in an extensive tidal-inlet sequence preserved in outcrop at Writing-On-Stone Park in southern Alberta (Cheel and Leckie, 1990). During Early to early Late Campanian time, sea level rose again and the marine shales of the Pakowki Member/Nomad Member were deposited (Clagget Cyclothem of Kauffman, 1977). Isopachs of the Pakowki/Nomad Member thin regularly in a westerly direction due to the advancing deltaic deposits of Cycle 4.

Planktonic faunas indicate a warm temperate climate in at least the eastern part of the basin during the latest Cenomanian, Turonian and Early Santonian (McNeil, 1984). During maximum marine transgressions, warm waters from the Gulf of Mexico may have extended as far north as 54° N latitude, warming water temperatures by up to 5° C to a temperature near 20° C (McNeil and Caldwell, 1984). The winds which dispersed volcanic ash (bentonites) within the Joli-Fou and Viking formations across southern Alberta blew towards the northeast (Amajor, 1985).

CYCLE 4: SAUNDERS GROUP/(BASE BELLY RIVER TO TOP OF PORCUPINE HILLS) (CAMPANIAN TO EARLY EOCENE)

Cycle 4 represents an interval of primarily nonmarine deposition of clastic detritus making up the Campanian to Maastrichtian Belly River, St. Mary River, Edmonton, Willow Creek, Brazeau and Wapiti formations and Paleocene Paskapoo Formation (Fig. 3) with one marine incursion represented by shale of the Bearpaw Formation. The top of Cycle 4 is represented by a basinwide erosion surface over which lie sediments of Cycle 5. Sediments of Cycle 4 were deposited during an episode of subsidence and thrusting, resulting from collision of the Intermontane Belt with North America.

Subsidence rates and sediment supply within the foreland basin were very high at this time (Stott, 1984; Stockmal and Beaumont, 1987). During Belly River/Judith River time, a wedge of nonmarine sediments up to 1370 m thick (Wall and Rosene, 1977) was shed eastwards. Belly River sediments are

primarily fluvial channel and associated floodplain, crevasse splay and lacustrine in origin. In east-central Alberta, the correlative Judith River Formation was deposited by east to southeasterly-flowing braided and low-sinuosity meandering streams flowing into an estuarine, channel-dominated shoreline. Sediments of the Brazeau Formation in the central Alberta Foothills were deposited by northeast-flowing meandering rivers (McLean and Jerzykiewicz, 1978); thick coals accumulated in meandering channel back swamps. The overall upward coarsening nature of the Brazeau Formation may reflect an easterly-migrating, and thus increasingly proximal, thrust zone. A west-to-east facies change from fluvial-deltaic in western Alberta to predominantly marine in eastern Saskatchewan was demonstrated by Stelck *et al.* (1972) for sediments of the St. Mary River and Belly River formations.

The marine shale of the Bearpaw Formation represents the last major marine inundation to have affected the foreland basin. The Bearpaw sea extended from the Gulf of Mexico through to the Arctic (Wall and Singh, 1975) with water depths on the order of 45 to 60 m (McLean, 1971). Several upward-coarsening marine sandstone units occur within the Bearpaw Formation (Link and Childerhose, 1931). The transition from the Bearpaw Formation to the overlying coal-bearing strata of the Horseshoe Canyon Formation in south-central Alberta is represented by an upward-coarsening, fluvial- or tide-dominated deltaic sequence scoured by lowstand fluvial activity and backfilled as estuaries (Rahmani, 1988). Significant peat accumulated in the associated coastal-plain during the transgression and regression of the Bearpaw Sea (Jerzykiewicz and Sweet, 1988). As the Bearpaw Sea receded, the coastal sediments of the Blood Reserve Formation (southern Alberta), Eastend Formation (Saskatchewan) and Boissevain Formation (Manitoba) were deposited followed by the nonmarine St. Mary River Formation and Willow Creek formations (Frenchman and lower Ravenscrag formations in Saskatchewan). The shorelines of the Blood Reserve Formation varied from low-energy to wave-dominated, with a significant tidal influence as inferred from the presence of tidal-channel deposits and oyster bioherms (Nadon, 1988).

Cycle 4 sediments were derived primarily from volcanic, low-grade metamorphic and sedimentary sources with minor input from granitic and gneissic sources (Mack and Jerzykiewicz, 1989). Volcanic rocks in the Elkhorn Mountains of southwestern Montana have been cited as a sediment source for the Belly River Formation and equivalent strata in the southern foreland basin (McLean, 1971) although this has been questioned by Mack and Jerzykiewicz (1989), who suggested a westerly source in the Omineca and Rocky Mountain belts. In southwestern Alberta, rivers depositing the St. Mary River Formation flowed north to northeastward out of Montana (Nadon, 1988), whereas in south-central Alberta, the rivers of the correlative Edmonton Formation flowed south to southeastwards (Rahmani, 1981).

Beyond the most northerly and westerly limits of the Bearpaw transgression, the term Brazeau Formation is used to represent sediments lying above the top of the Wapiabi Formation and below the Coalspur Formation (Jerzykiewicz and Sweet, 1988).

The climate during deposition of cycle 4 alternated from warm and humid to semi-arid. Major

caliche beds at the top of the Belly River Formation and in the Willow Creek and Porcupine Hills formations in southern Alberta may have required hundreds of thousands of years of semi-arid climate to form (Jerzykiewicz and Sweet, 1988). The climate became increasingly humid northwards (Jerzykiewicz and Sweet, 1988). In south-central Alberta, the Judith River Formation was deposited in a humid tropical to subtropical coastal plain setting having a mildly seasonal rainfall (Visser, 1986). Palynoflora and coal in sediments below and above the Bearpaw Formation indicate a warm temperate to subtropical, humid setting in environs proximal to the Bearpaw Sea. Mean annual rainfall may have been on the order of 120 cm or more (Béland and Russell, 1978). Water temperatures in the Bearpaw Sea were approximately 17 to 27° (Forester et al., 1977) and prevailing winds were westerly.

CYCLE 5: TERTIARY CONGLOMERATES (EOCENE TO PLIOCENE)

Late Eocene to Pliocene gravels form the uplands in at least ten isolated plateaus throughout southern Saskatchewan and Alberta, and constitute much of the sediment of Cycle 5. Cycle 5 deposition postdates the phase of foreland basin compressional deformation. The origin of the gravels is enigmatic, being very coarse-grained (clasts to > 40 cm long) and far from the Cordillera. At the time of deposition, overthrusting in the Cordillera had ceased and the deformed belt and foreland basin were being isostatically uplifted and eroded. Major tectonic uplift and erosion in the Omineca Belt are indicated by potassium-argon dates of ~ 50 Ma). The gravels overlie a major unconformity throughout most of the basin (Fig. 2). The unconformity directly follows and may be related to magmatic quiescence in the Cordillera during the Paleocene (70 to 60 m.y.; Armstrong, 1988). As much as 1.5 to 2.0 km of sediment may have been eroded from the western side of the basin during this period of erosion (Hacquebard, 1977). From latest Paleocene to Middle Eocene (55-45 m.y.), the Cordillera was again affected by extension related magmatism in all the terranes (Armstrong, 1988).

The western Canada basin was characterized by major geographic variations in climate during the Paleocene portion of Cycle 5 (Jerzykiewicz and Sweet, 1988). Silcretes and vertebrate faunal remains in the Oligocene Cypress Hills Formation of southwest Saskatchewan indicate that semi-arid conditions existed at least during early Cycle 5 time. However, northwards in west-central Alberta, the climate was characterized by much more humid conditions as indicated by better preserved coal deposits.

STOP 1: THE CHUNGO SANDSTONE AT LUNDBRECK, ALBERTA

The Chungo Member of the Wapiabi Formation is equivalent to the sandstone of the Milk River Formation at Writing-on-Stone Provincial Park and the Eagle Sandstone of the northern U.S. The Chungo-Milk River sandstone marks the termination of a long period of marine sedimentation (represented by Alberta-Colorado Group shales; Figure 3) in the Alberta Basin and the initiation of a long period dominated by non-marine sedimentation of the Belly River-Foremost-Oldman formations. In the plains, the Milk River is overlain by a thick (maximum 200 m) marine shale of the Pakowki or Claggett

Formation. This shale thins to the south and west; where recognized in the Foothills, it occurs as the Nomad Member, generally 10 to 30 metres thick.

The Chungo Member sandstone exposed along the Crowsnest River at Lundbreck was deposited by a shoreline-delta complex which was oriented WNW-ESE across southern Alberta and prograded northeastwards into the interior seaway (Fig. 6G). The divergence of the trend of the shoreline and disturbed belt observed in southern Alberta forms part of a broad lobe which extends several hundred kilometres east of the mountain front. This deposition lobe is approximately centred on the Elkhorn Volcanic Field of western Montana. More than 3 km of explosive calc-alkalic volcanics were deposited in this area during the Upper Cretaceous and this probably contributed vast quantities of detritus into the basin. Rice (1980) and Rosenthal (1984) interpreted that the high proportion of clear angular quartz and feldspar detritus in the Chungo Member suggested a volcanic derivation.

South of Longview, the Chungo Member is represented by a single coarsening upward marine sandstone unit overlain by ~60 metres of non-marine coastal-plain strata. These non-marine sediments are overlain by marine mudstone of the Nomad Member which, in turn, is overlain by several hundred metres of non-marine strata of the Belly River Formation.

Further north, in the Longview and Sheep River area, the non-marine interval above the Chungo shoreline thins and the Chungo is represented by three and four coarsening upward sandstone/mudstone marine cycles, some of which are terminated by a thin unit of pebbly mudstone or conglomerate. In the Ghost Dam-Cochran area, the Chungo interval is almost absent and is replaced by bioturbated sandy mudstones of the Hanson Member.

The Chungo sandstone records the northeasterly progradation of a storm-dominated shoreline-delta complex into the seaway. Near Longview and Sheep River, this progradation was halted due to either to a rise in sea level or a cutoff of the sediment supply, or both. The shoreline oscillated back and forth several times before being completely overwhelmed by the Nomad transgression. North of Longview, deposition of shallow-shelf, bioturbated sandy mudstone continued throughout Chungo and Nomad time.

THE DEPOSITIONAL FACIES IN THE LUNDBRECK OUTCROP

The Lundbreck outcrop (Fig. 7) exposes the coarsening upward sequence developed at the base of the Chungo. The upper non-marine part of the Chungo is exposed on the north side of the river. A few marine forams have been recovered from a shale located ~60 metres above the top of the "main" Chungo sandstone on the north side of the river. This interval probably represents the southwestward limit of the transgressing Nomad-Pakowki sea.

The gradational base of the Chungo Member overlies several hundred metres of Wapiabi shales.

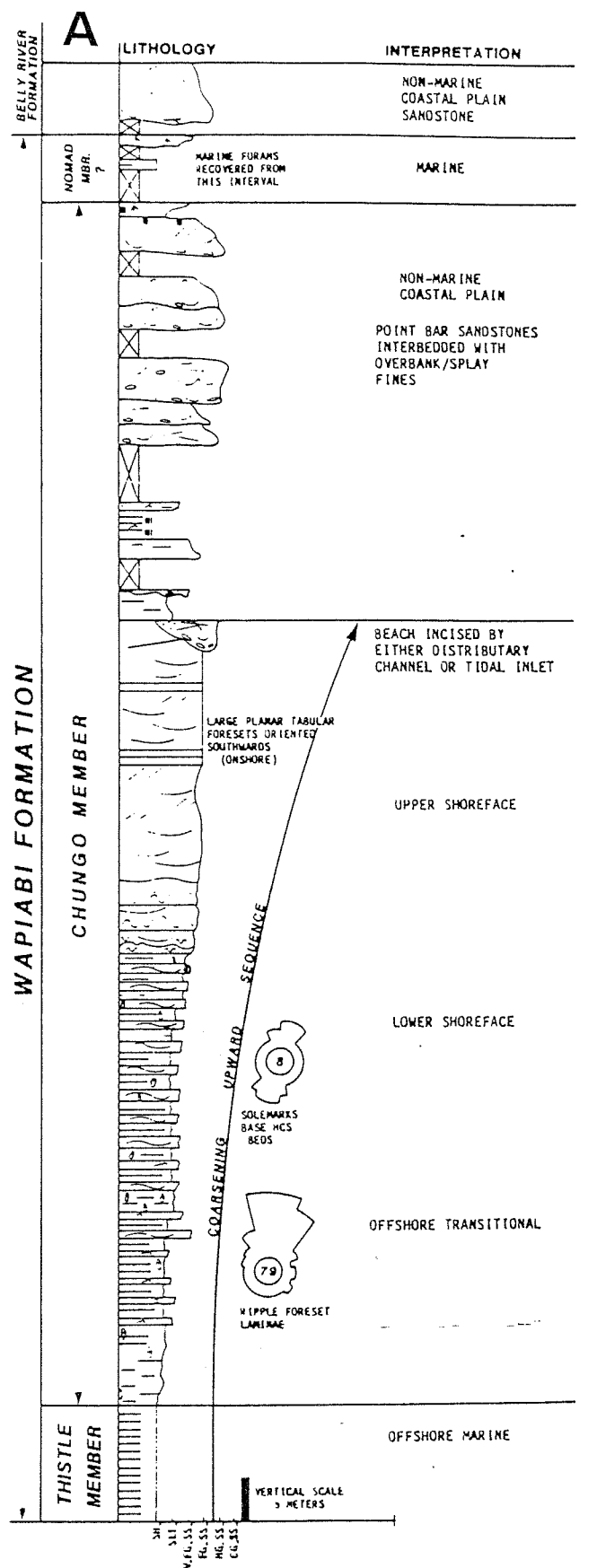
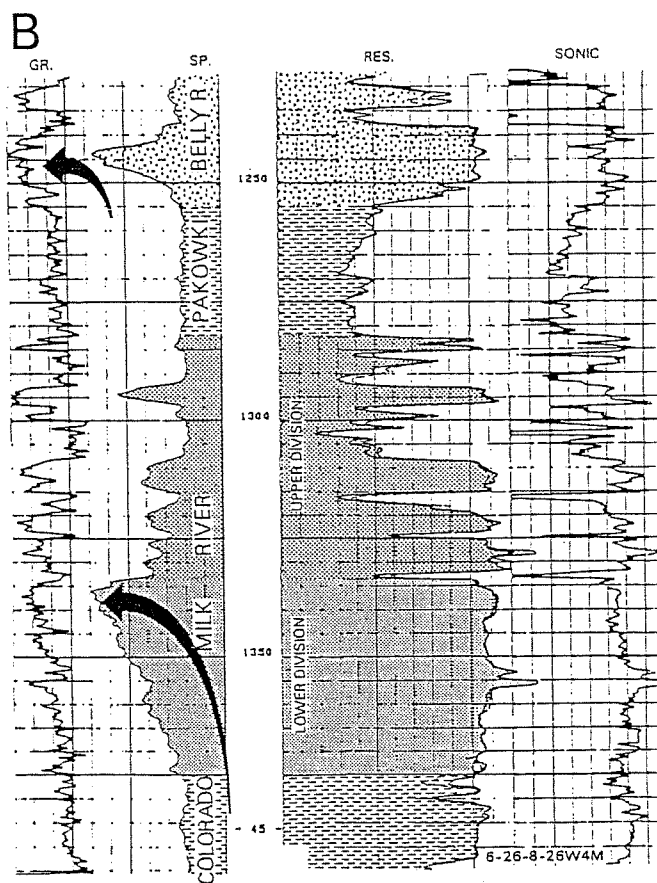


Figure 7A. Measured section of the Chungo Member at Lundbreck Falls. B) Log suite of the subsurface equivalent of the Chungo Member at Lundbreck Falls and Coleman. From Leckie and Rosenthal, 1986.

The thin sandstone beds developed at the base contain combined-flow ripple foresets directed due north, essentially perpendicular to the shoreline and down the regional paleoslope. A thick interval of hummocky cross stratified (HCS) sandstones and mudstones overlies this unit with excellent examples of various shallow-marine trace fossils. The lowermost wave-rippled or HCS bed is considered to represent the first point where the basin was sufficiently shallow that waves could rework the substrate during intense storms. A few sandstone beds exhibiting soft sediment deformation structures are present at the top of the HCS facies. However, in other Chungo outcrops, this loaded or slumped sandstone facies may exceed 10 m thick. The swaley cross stratified (SCS) sandstone is best exposed on the top of the hill where the characteristic flaggy weathering is well developed. Towards the upper part of the SCS zone, a number of thick planar tabular foresets with angle of repose bedding are exposed. These have been interpreted as distributary channel bedforms by other geologists but this is unlikely as the foresets are directed almost due south (onshore). This is exactly the opposite direction which would be expected if they were distributary channel bedforms.

The uppermost part of the coarsening upward Chungo cycle is only well preserved on the north side of the river where parallel lamination is developed. Rooted mudstones ~2 metres above the parallel laminated sandstone indicate emergence and subaerial exposure. On the south side of the river, a 5 m thick channel floored by a clay pebble lag cuts down into the foreshore. The scour may represent either a tidal inlet, or a distributary channel. Parallel laminated sandstones overlying the channel deposit may be swash laminae indicating that the channel became abandoned and was reworked by wave processes.

The coarsening upward sequence developed at the base of the Chungo look similar in most outcrops indicating that it was deposited as a sheet sandstone. This in turn suggests a strong wave influence which would have initiated the longshore currents responsible for transporting the sediment away from the point where it was initially introduced into the basin (by the distributary channel system). The great thickness of the Lundbreck section has been used by some workers as evidence of a distributary channel origin (Lerand and Oliver, 1975).

LOG RESPONSE OF THE CHUNGO-NOMAD IN SUBSURFACE

Figure 7B is a log suite from a well drilled ~50 km east of the Lundbreck outcrop. The coarsening upward cycle at the base of the Milk River (actually a composite of three similar cycles) is equivalent to the Chungo exposed at Lundbreck. The overlying 50 m, labeled the Upper Division on the log, is equivalent to the overlying non-marine strata on the north side of the river. The Pakowki is equivalent to the Nomad. Note the pronounced eastward thickening of this marine unit.

STOP 2: THE TRIANGLE ZONE

The Triangle Zone (Figs. 8, 9) is the leading edge of the disturbed belt and demarcates the boundary between the Interior Plains and the Foothills throughout most of Alberta. The western margin of

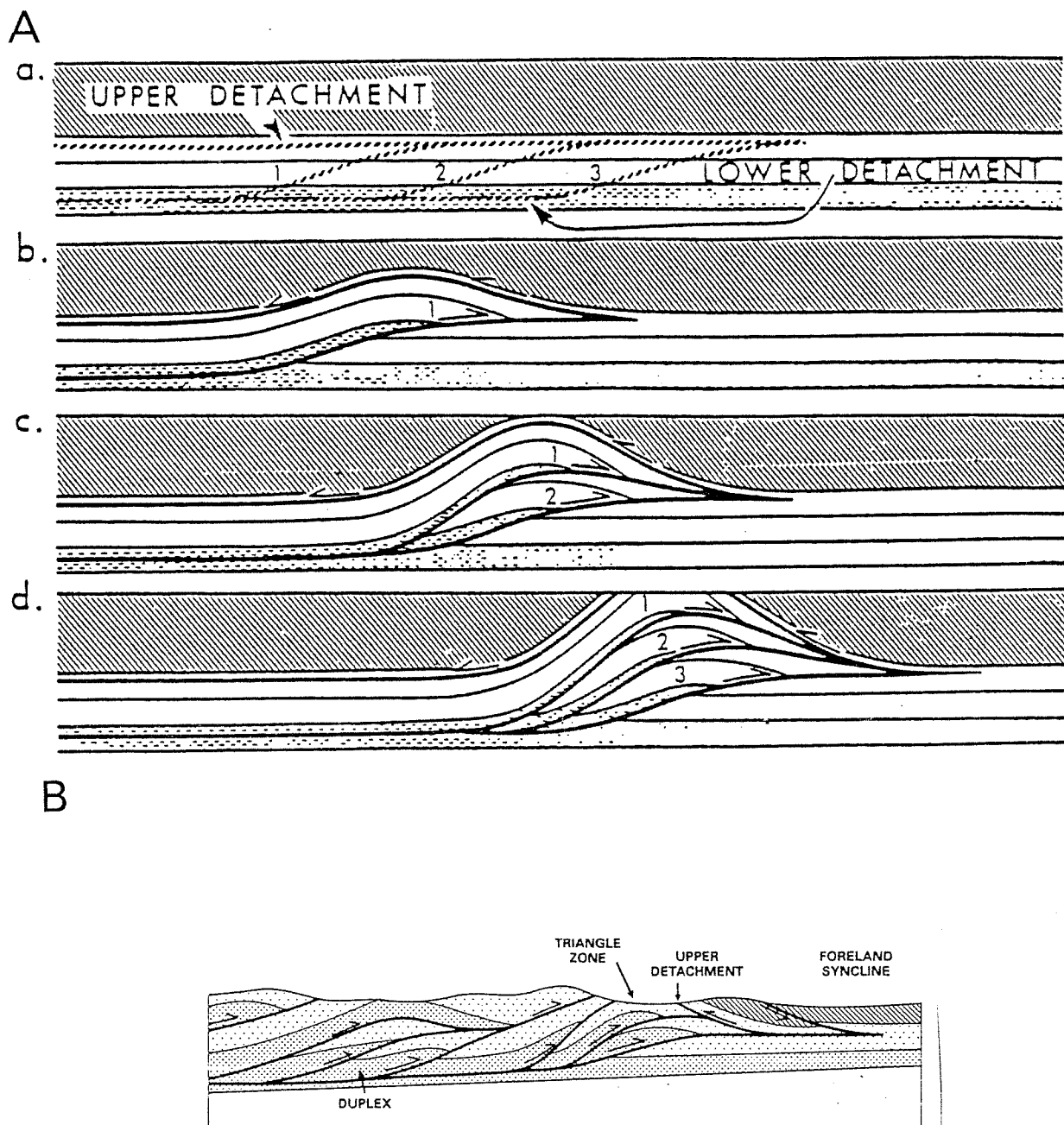


Figure 8. A) Hypothetical computer-generated model of the Triangle Zone. Note that progressively younger thrusts occur eastwards and that the axis of the Triangle Zone also shifts eastwards with greater depth. From Jones (1982). B) Conceptual diagram illustrating a duplex fault structure and a triangle zone. Arrows indicate sense of motion on faults. After Jones (1987)

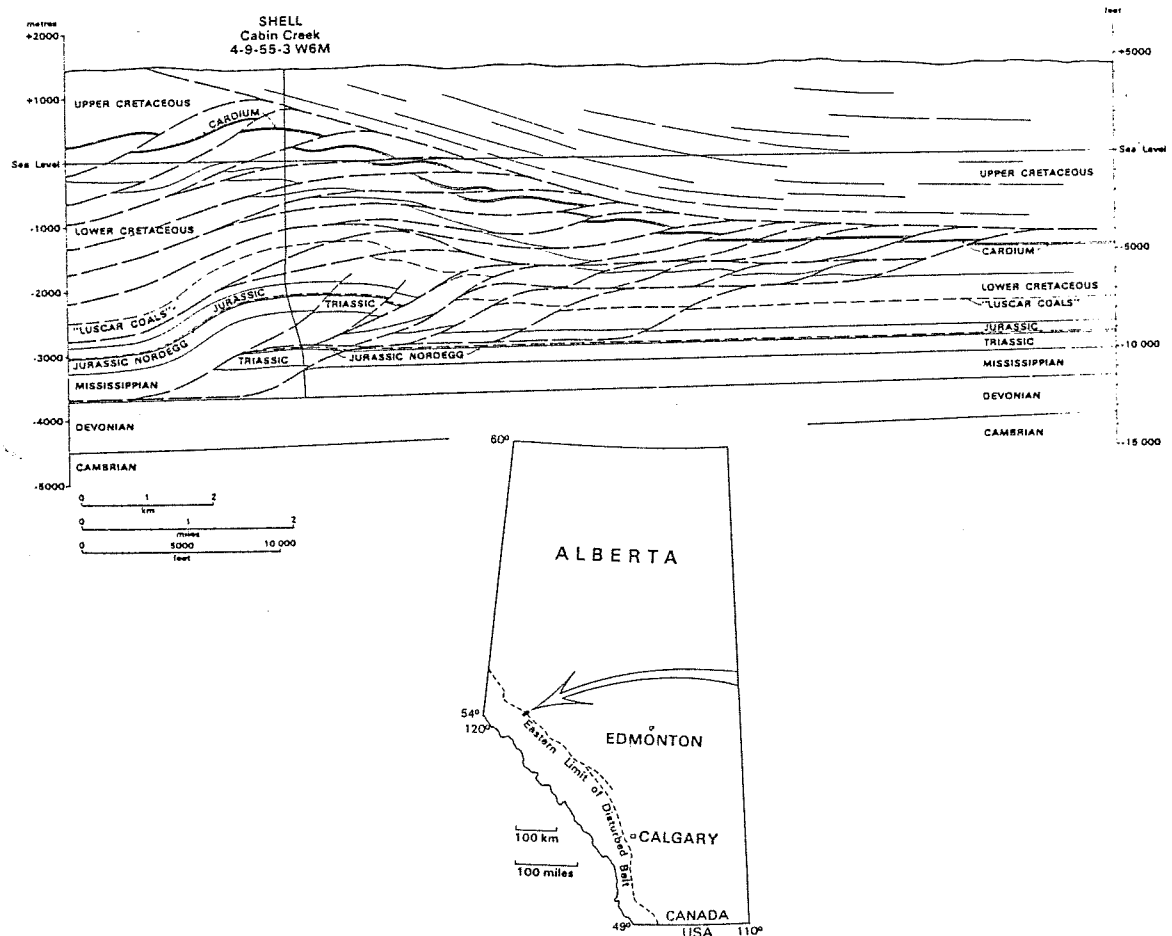
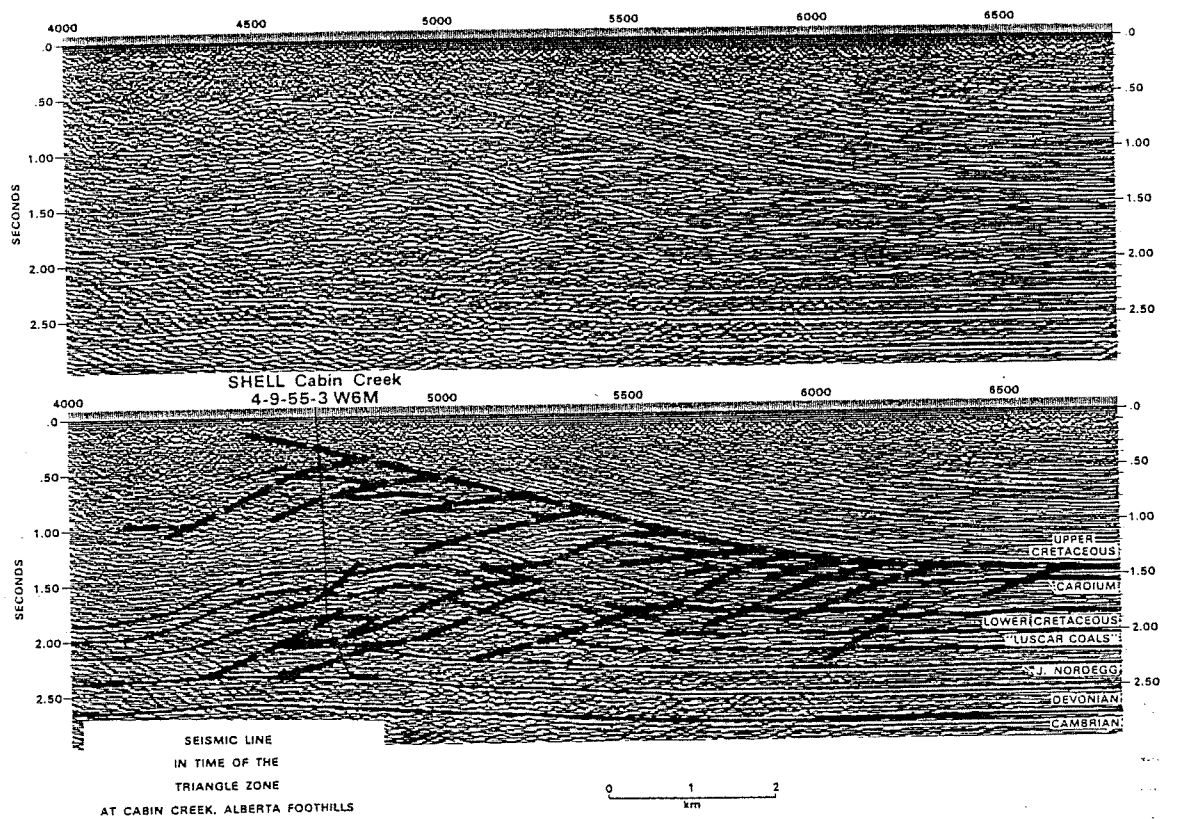


Figure 9. Seismic cross section and interpreted, balanced geological cross section of the Triangle Zone at Cabin Creek, west-central Alberta. Note the upper and lower detachment surfaces of the major wedge of sediment which has been forced eastwards. From Teal (1983).

the Alberta Syncline, which coincides with the eastern side of the Triangle Zone, represents the leading (eastward) edge of Foothills deformation. The west side of the Triangle Zone marks the beginning of the closely spaced, west-dipping imbricate thrusts typical of the Foothills. The stop at Lundbreck Falls is about 3 km west of the apex of the Triangle Zone. Much of the trip north from Burmis to Longview will be along the Triangle Zone.

The term Triangle Zone originated from early observations of east and west dipping strata at the surface underlain by low angle seismic markers (Teal, 1983). The Triangle Zone is characterized by a system of east-dipping beds underlain by the west-dipping, closely spaced, imbricate thrusts typical of the Foothills (Figs. 8, 9). There is eastwards lateral migration of the anticlinal crests with increasing depths: consequently the geographical location of the crest is dependent on the level of erosion. A geological cross section and seismic section across the Triangle Zone at Cabin Creek in west-central Alberta is shown in Figure 9. The figure shows that the Triangle Zone is the result of a large wedge of rock bounded above and below by detachment surfaces that has been injected eastwards into adjacent strata. The east-dipping strata on the east side of the Zone occurs due to the wedging and underthrusting.

A computer generated reconstruction of the triangle zone (Fig. 8) shows that the minimum requirement for the formation of a Triangle Zone is a stratified sequence with upper and lower zones of detachment (Jones, 1982). The sequence of thrusting is from west to east and the east dipping portion of the Zone is the result of underthrusting. The lowermost thrust is the furthest east and the surface position of the apex of the Triangle Zone depends on the level of erosion.

ECONOMIC SIGNIFICANCE

The apparent anticlinal nature of the Triangle Zone made it an obvious target for wildcat wells early in Alberta's exploration history. However, many of these wildcat wells were dusters and commonly bottomed in strata younger than that spudded in. The surface expression of the Triangle Zone does not express the true structural setting which occurs at greater depths. The Triangle Zone overlies and conceals more deeply buried thrust sheets and many potential reservoirs (Jones, 1982). Gas is most common in the overthrust Paleozoic carbonates and gas and oil is most likely to occur in the shallow, more complex structures containing Cretaceous sandstones (Jones, 1982). The Cardium Ricinus and Viking Bearberry fields are examples of hydrocarbon production from the Triangle Zone.

The Triangle Zone may also contain the extremities of several thrust wedges. At Coal Valley, in west-central Alberta, floor and roof thrusts follow the top and bottom of the Mynheer coal seam which has been tectonically stacked to 20 times its stratigraphic thickness (Charlesworth and Gagnon, 1985).

STOP 3: CHUNGO OUTCROP AT COLEMAN

The outcrop at Coleman (Fig. 10) is the lateral equivalent of the Chungo exposed at Lundbreck.

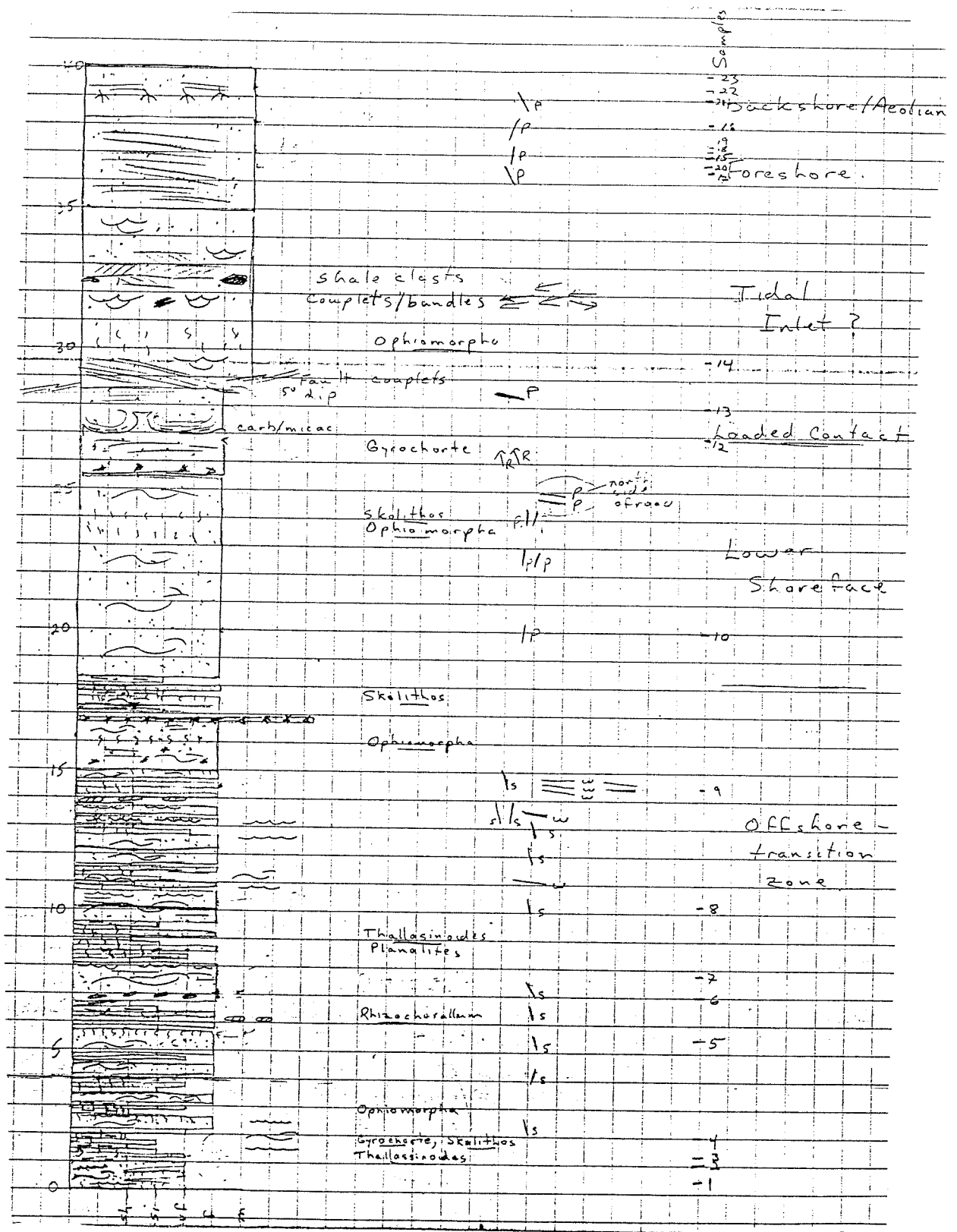


Figure 10. Measured section of Chungo Member at Coleman.

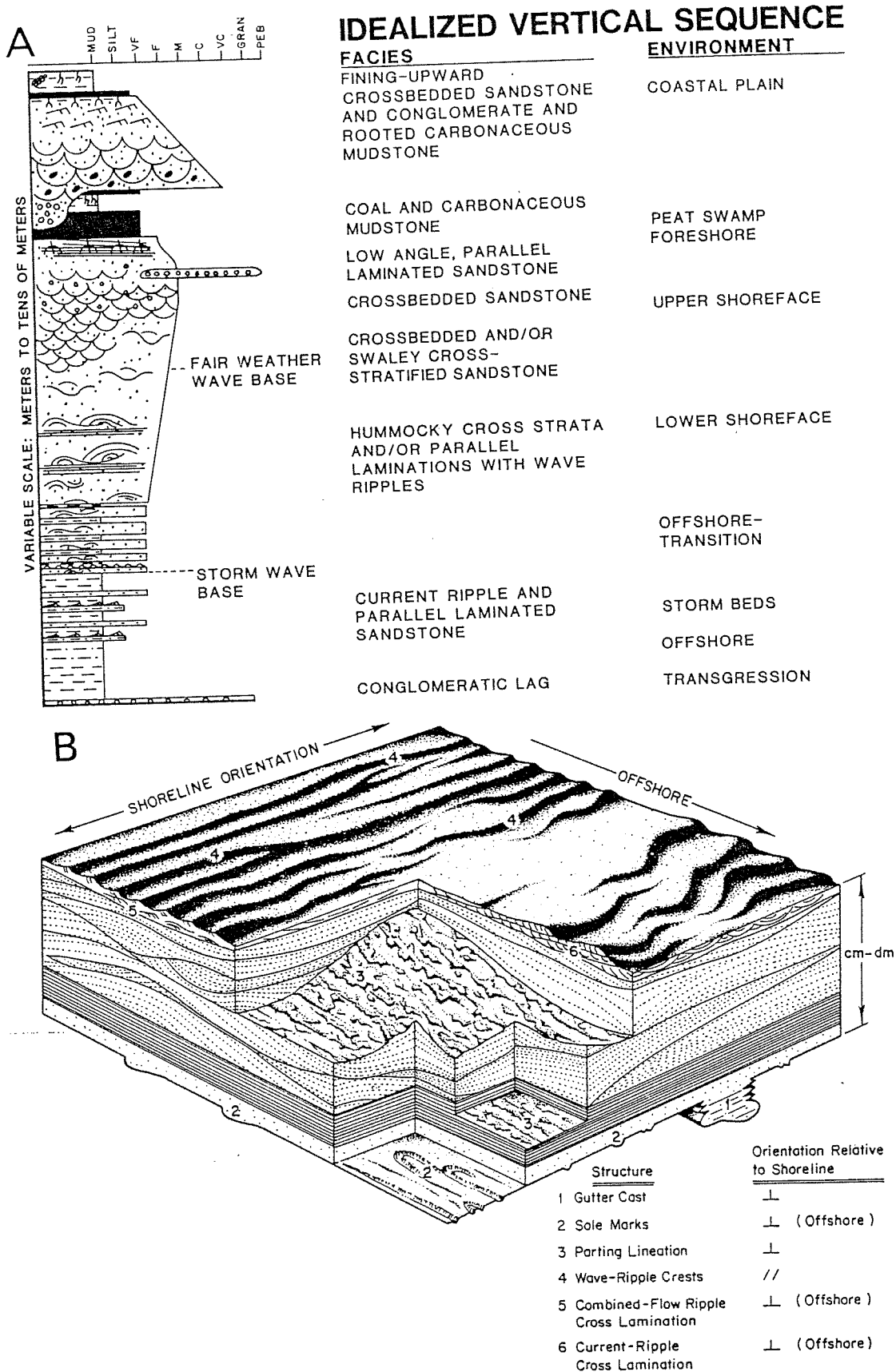


Figure 11. A) Idealized vertical section of wave-dominated progradational succession. B) Paleocurrent relationships of storm beds in high-energy shoreface successions. From Leckie and Krystinik (1989). The observations on paleocurrents can be applied to the Fernie Kootenay Succession, Chungo Member and the Lynx Creek Member of the Mill Creek Formation.

There is only one cycle present but it is superbly exposed demonstrating most of the characteristics of an upward coarsening wave-dominated shoreline succession. Compare this cycle with the wireline log response in Figure 8.

Paleocurrent relationships of sole marks, wave ripple trends and parting lineations in storm beds are shown in Figure 11. Many of these relationships can be seen at this outcrop.

STOP 4: BLAIRMORE GROUP STRATA ALONG HIGHWAY 3 NEAR BLAIRMORE AND COLEMAN

Roadcuts along the highway show well-exposed, non-marine strata of the Beaver Mines Formation consisting of interbedded sandstone, siltstone and shale deposited in a meandering fluvial and floodplain environment. Coal deposits are thin but there is abundant evidence of subaerial exposure including roots and incipient paleosols.

Compare the nature of sedimentation of the Beaver Mines Formation with that of the underlying Cadomin Formation. Mellon (1967) described the Beaver Mines Formation as those strata that lie above the limestone beds of the Gladstone Formation. Thicknesses range from 253 m to 366 m. Lithologies consist of "interbedded green, fine-grained, crossbedded, feldspathic sandstone, dark green laminated siltstone and blocky, varicolored shale (mudstone), the sandstones becoming thinner and finer-grained towards the top of the formation" (Mellon 1967, p. 20). This is in sharp contrast to the lower part of the Beaver Mines which is medium to coarse-grained feldspathic sandstone with volcanic pebbles and thin beds of dark green-grey siltstone. The lower contact of the Beaver Mines Formation is sharp and overlies dark silty limestone beds of the Calcareous Member of the Gladstone Formation.

AGE: The lower part of the upper Beaver Mines Formation is latest Early Albian or early Middle Albian age (E. Burden, pers. comm. 1991).

The upper Beaver Mines Formation consists of interbedded sandstone, siltstone and shale containing abundant *in situ* vertical roots, pedogenic slickensides and peds. Colors vary from olive green to red, and variegated greens and reds. Sandstones are decimetres to 6 m thick and fine to medium grained. Individual sandstones are sharp based, may contain intraformational shale clasts and typically fine upwards. Due to the nature of the weathering, sedimentary structures are generally difficult to discern.

Calcite nodules in calcareous siltstone occur near the top of the Beaver Mines Formation at Mill Creek. The nodules are well rounded, 0.5 to 6 cm diameter, and some occur as vertical rhizocretions.

Paleocurrent indicators were observed at only a few outcrops. At Vicary Ridge, trough crossbeds from point-bar deposits indicate paleoflow towards the northeast. At Ma Butte, grooves from the base of fluvial sandstone and parting lineations indicate flows trending towards north-south.

INTERPRETATION

The sediments of the upper Beaver Mines Formation represent deposition in an alluvial plain setting characterized by point-bar and overbank deposits. *In situ* vertical roots, pedogenic slickensides and peds indicate abundant immature soil horizons, probably indicating time involved between episodes of sedimentation. The presence of dinoflagellate cysts may indicate brackish-water conditions which were unidentifiable using sedimentological criteria because of the way the rocks weather.

STOP 5: THE FERNIE GROUP, KOOTENAY GROUP AND CADOMIN FORMATION AT ADANAC MINES

The section exposed at Adanac Mine on the south end of Hastings Ridge (Fig. 12A) provides a superb exposure of the upper part of the Fernie and Kootenay Groups and the Cadomin Formation (Fig. 6). The "Passage Beds" of the Fernie and lower Kootenay Groups represent an upwards-coarsening, wave dominated, progradational shoreline sequence. The "Passage Beds" consist of interbedded, very fine to fine-grained sandstone and shale. Sandstone beds increase in frequency and thickness upwards due to shoreline progradation and progressive shallowing. Sandstones are sharp based, hummocky cross stratified and wave ripple laminated with light to moderate bioturbation. Several sandstone beds are channeled (gutter casts?) with scours to 1 m. The "Passage Beds" were deposited in the wave dominated offshore-transition zone of a progradation shoreline (Hamblin and Walker, 1979).

The basal sands of the Kootenay (Morrissey Formation) consist of amalgamated hummocky cross-stratified, fine-grained sandstone overlain by medium grained cross-bedded sandstone deposited in the lower and upper shoreface, respectively. The contact between the upper and lower shoreface is sharp, demarcated by a grain size change and concentrations of centimetre thick carbonaceous, micaceous interbeds. Base of the upper shoreface can be considered as representative of fair-weather wavebase. Top of the shoreface is rooted and is overlain by 2 m of coal. The Morrissey sandstones were deposited in a northerly-prograding, wave-dominated strandplain system (Fig. 12B).

The balance of the Kootenay Group (Mist Mountain Formation) is poorly exposed but contains nonmarine, interbedded carbonaceous sandstones, siltstones and shales decimetres thick, deposited on the Kootenay coastal plain. The Kootenay contains coal seams several metres thick. The overlying Cadomin Formation is a 17 m thick upwards fining sequence with a lower 6 m of crudely bedded, poorly sorted conglomerate which is locally cross-bedded. The top 11 m is a coarse to medium grained cross-bedded with decimetre thick conglomerate lenses. There is abundant evidence of channeling within the conglomerate. Angular sandstone clasts, coal clasts and silcrete clasts within the conglomerate indicate erosion of lithified sediment, probably Jurassic in age. Their angular nature indicates a short transport distance. Note the large noncompacted togs at the base of the Cadomin conglomerate. An isolated shale lens 2 m thick sits within the lower conglomerate at the north end of the section. The Cadomin formation

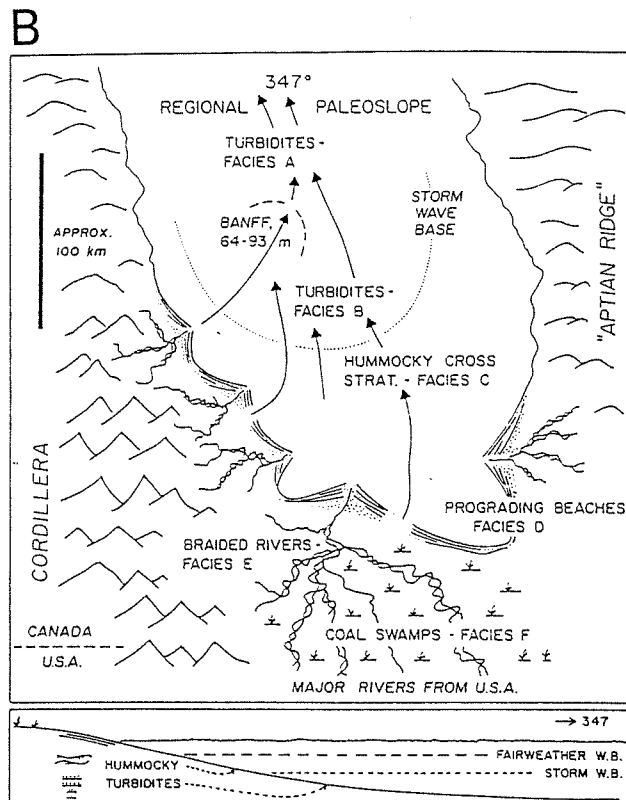
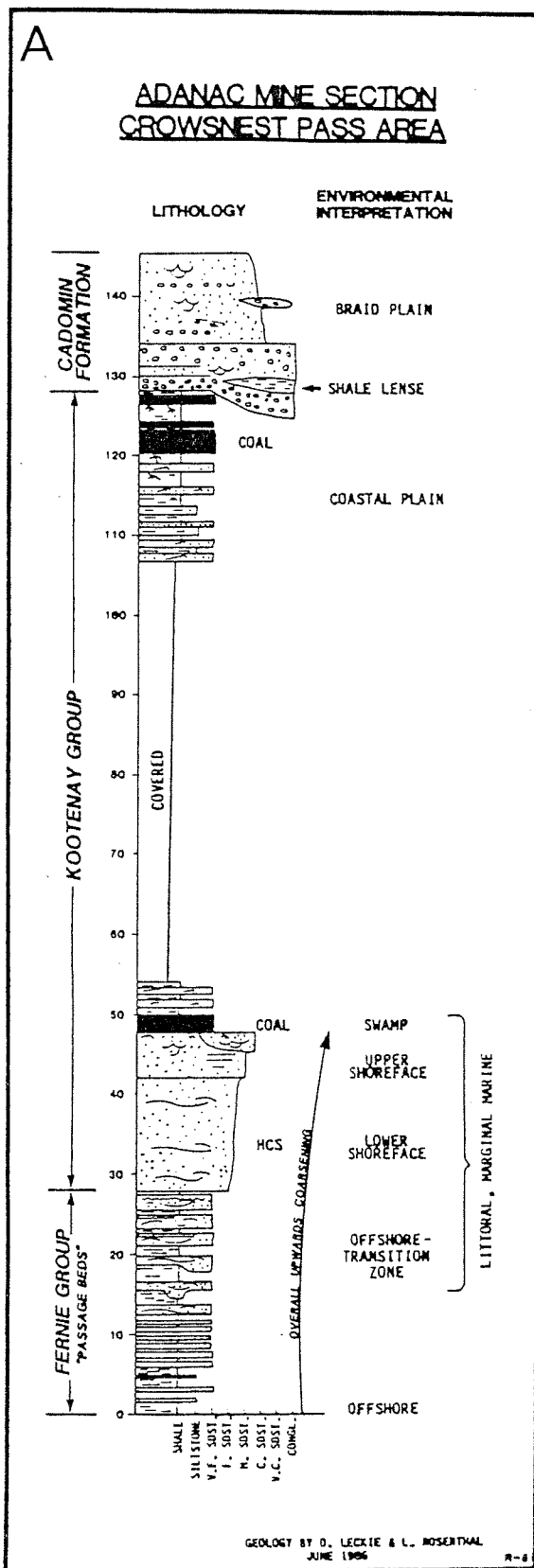


Figure 12. A) Measured section of the Fernie Group (passage Beds), Kootenay Group, and Cadomin Formation. From Leckie and Rosenthal (1986). B) Interpretation of depositional environments during the Fernie-Kootenay transition. From Hamblin and Walker (1979).

represents braidplain deposition at top of Kootenav Group.

STOP 6: CADOMIN FORMATION

The Cadomin Formation is well exposed at several roadcuts in the Crowsnest Pass between Burmis and Coleman. The conglomerate usually sits on coals seams of the Mist Mountain Formation (Kootenay Group). The conglomerate is abruptly overlain by medium to coarse-grained sandstone which has been called the Dalhousie sandstone. Measured sections are shown in Figure 13.

Paleocurrents of the Cadomin Formation indicate a generally northwards paleoflow.

STOP 7: CROWSNEST FORMATION

Volcanic rocks in the Coleman area (Figs. 14, 15) of southwestern Alberta form the Lower Cretaceous Crowsnest Member of the nonmarine Mill Creek Formation (upper Blairmore Group). The volcanics consist of trachytic, analcite-bearing agglomerates, tuffs, rare flows and their water worked (epiclastic) detritus. The lower contact is gradational and the upper contact is believed to be a disconformity (Norris, 1964). The volcanic rocks covered an area of 1800 km² and the volume of volcanic material exceeded 209 km³. Three main volcanic centres have been recognized (Pearce, 1970) (Fig. 16). A palinspastic reconstruction of the Crowsnest Volcanic isopachs places the greatest thickness in what is now the Cranbrook area (Fig. 16).

AGE:

The Crowsnest Formation refers to thick agglomerate, volcanoclastic debris flows and ash-fall deposits at the top of the Blairmore Group (Hage, 1943; Price, 1962; Norris, 1964). The Crowsnest Formation is considered as a stratigraphic unit within the Blairmore Group following Mellon and Wall (1963) and Mellon (1967). The type section is that given by Price (1962), Norris (1964) and measured in detail by Adair (1986) for Crowsnest strata exposed in the Coleman Thrust along Highway 3 and along the railroad west of Coleman (Fig. 14). A reference section, was designated by Mellon (1967) for the formation in rocks exposed at Mill Creek which are distal deposits of the Crowsnest volcanic event; they are not typical of the thick volcanoclastic strata located near Coleman (Ricketts, 1982; Adair, 1986). A second reference section has been assigned by Norris (1964) to the exposure at Ma Butte, but was not described by him. A geological map of the regions surrounding the type-section on Mill Creek and the reference section near Coleman is in Price (1962).

The lower contact of the Crowsnest Formation is gradational (Norris, 1964; Pearce, 1970; Adair, 1986) interfingering with clastics of the Bruin Creek Member. The upper contact with the Blackstone Formation is sharp and has up to 120 ft of relief (Norris, 1964). At Mill Creek (**STOP 10**) the upper contact represented by 1 m of parallel-laminated, coarse grained sandstone. On Lynx Creek (**STOP 12**), the

Figure pending.

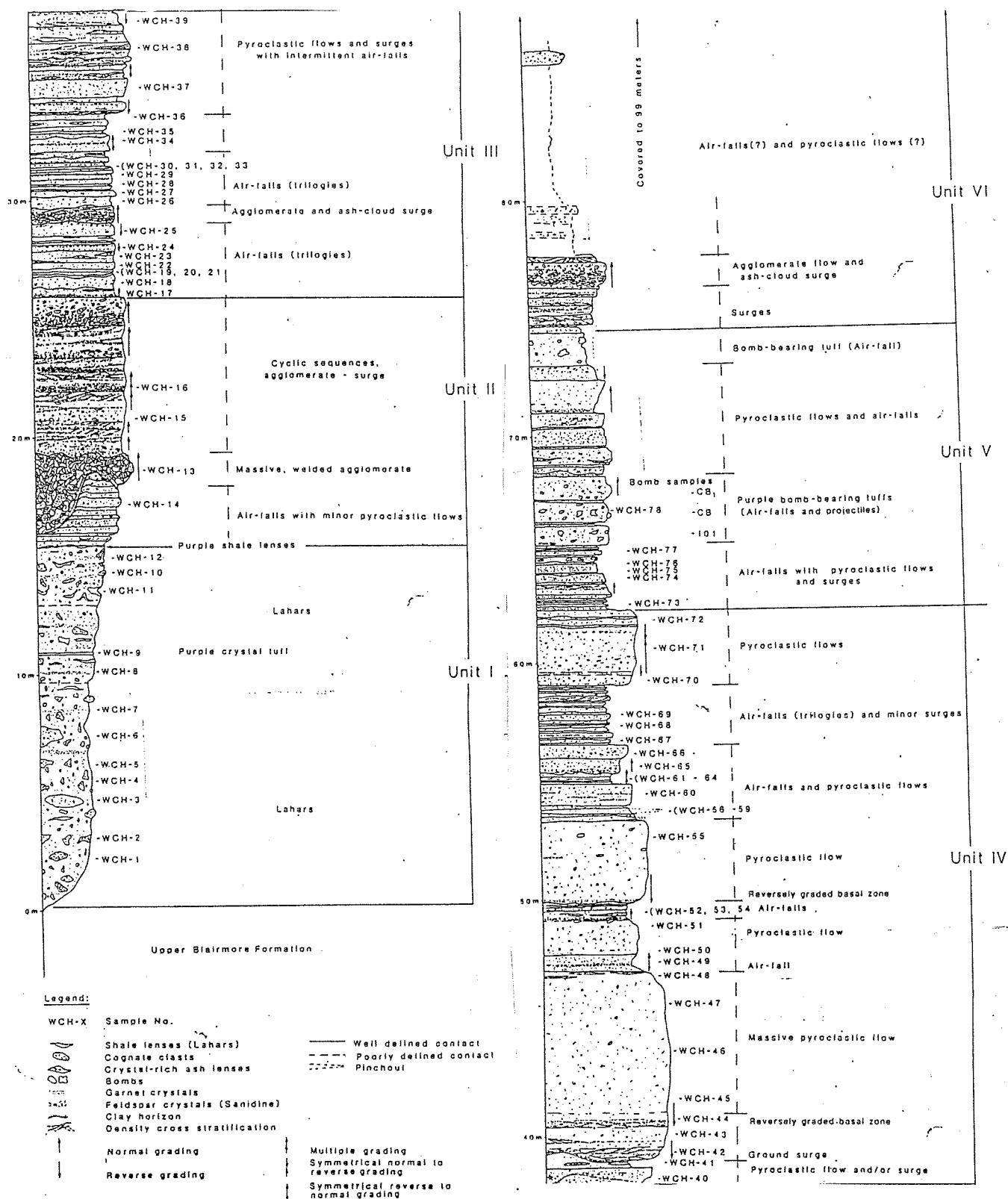


Figure 14. Measured section of the Crowsnest Volcanics along the Highway 3 west of Coleman. From Adair (1986).

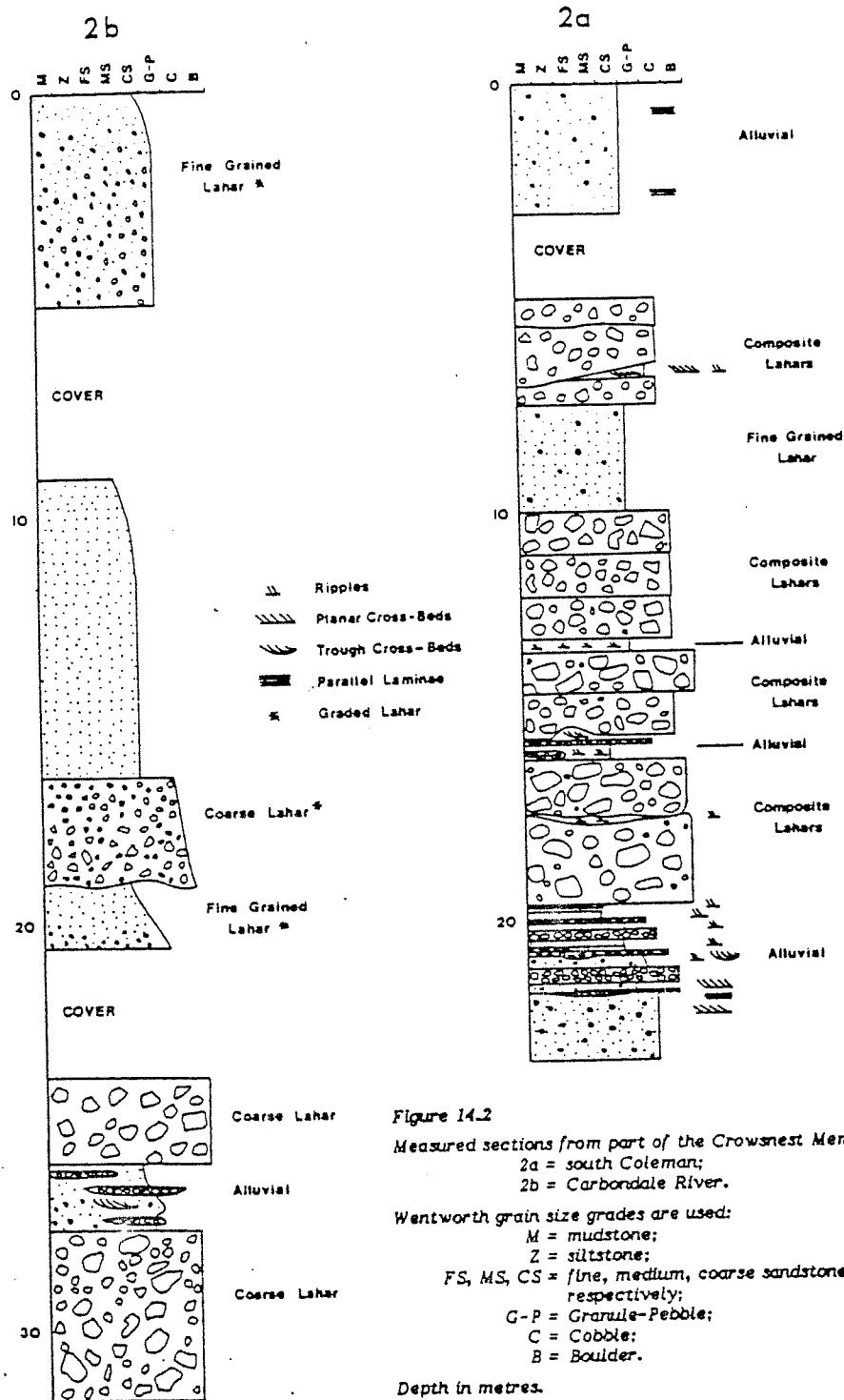


Figure 14.2

Measured sections from part of the Crowsnest Member:

2a = south Coleman;

2b = Carbondale River.

Wentworth grain size grades are used:

M = mudstone;

Z = siltstone;

FS, MS, CS = fine, medium, coarse sandstone respectively;

G-P = Granule-Pebble;

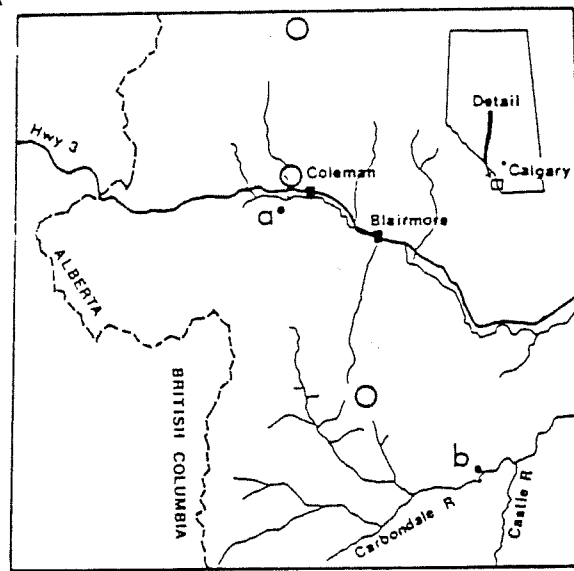
C = Cobble;

B = Boulder.

Depth in metres.

Figure 15. Measured section of the Crowsnest Volcanics near Coleman showing the water reworked (alluvial) and laharc breccias of the volcanic deposits. Location of sections shown in Figure 16A. From Ricketts (1982).

A



B

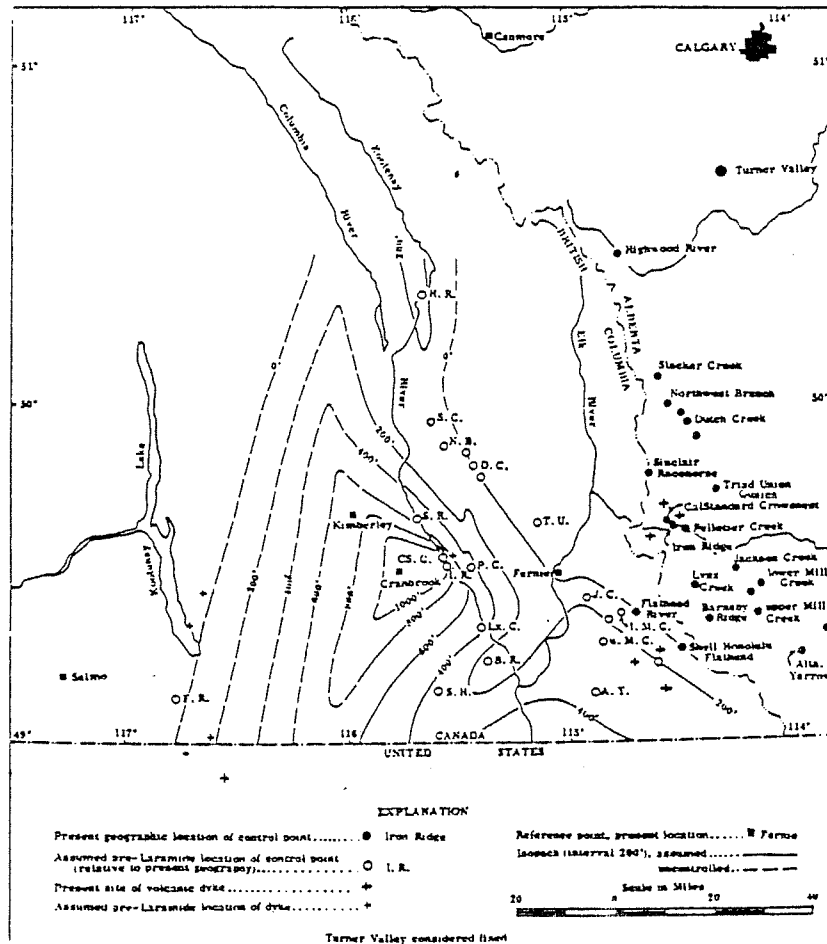


Figure 16. A) Location of outcrops of Crowsnest Volcanics with three volcanic centres (open circles) recognized by Pearce (1970). From Ricketts (1982). B). Palinspastic reconstruction of Crowsnest Volcanics isopachs. From Norris (1974).

contact is marked by 2.5 m of well-sorted, fine-grained, parallel-laminated sandstone. Elsewhere on Mill Creek, the contacts are black marine shale of the Blackstone Formation directly on the Crowsnest Formation/nonmarine Bruin Creek Member. At Willowby Ridge, sediments of the Bruin Creek Member have a mineralogy representative of the Crowsnest Formation as far as 150 m below the first occurrence of unreworked Crowsnest Formation (Adair, 1986). Adair suggested that this and the presence of cognate clasts in the basal deposits indicates volcanic activity elsewhere, before deposition of volcanic sediments took place near Coleman.

The Crowsnest Formation has a maximum thickness of between 426 and 488 m (Price, 1962; Pearce, 1970; Norris, 1964) where exposed on the Coleman Thrust and on Ma Butte. Thickness of the formation, of individual bed thickness and of clast size generally decreases away from this area (Pearce, 1970). The Crowsnest Formation has been mapped in the Foothills as far north as Hidden Creek at about 50° N latitude and as far south as Mill Creek (Price, 1962; Norris, 1964). However, in the more distal regions, the distribution of volcanics is patchy.

DESCRIPTION

The lower part of the Crowsnest Formation is trachytic and contains abundant sanadine phenocrysts, garnet and pyroxene (Pearce, 1970). The formation consists primarily of tuff, lapilli tuff, thin to thickly bedded ash, agglomerates and volcanic sandstone (Adair, 1986). The upper portion of the Crowsnest Formation has a high sanadine, analcite and garnet content with accessory rock fragments. It is primarily a pyroclastic breccia and agglomerate. Blairmorite and analcite are generally more common in the southern part of the outcrop area (Pearce, 1970). Black melanite garnet is common in the formation and can be used as an indicator of the lower gradational contact with the Bruin Creek Member. Volcanic clasts may be several metres wide and weigh up to 15 tons (Pearce, 1970).

INTERPRETATION

The volcanoes which formed the Crowsnest Formation were on an inland flood plain and were probably of high relief (Norris, 1964; Pearce, 1970, Adair, 1986). The magma chamber may have been a hydrous alkaline trachyte (Pearce, 1970) which resulted from crustal melting at about 25 to 35 km depth. Pearce (1970) interpreted the volcanic material to consist of agglomerates and tuffs (partially water reworked), volcanic sandstone, volcanic flows and dykes. Ricketts (1982) indicated that many of the beds had characteristics of laharic breccias (volcanic debris flows). Many beds contain primary sedimentary structures which Ricketts (1982) interpreted to represent alluvial deposition by short-lived streams although Adair (1986) argued that many of the structures are similar to volcanic surge deposits found on modern volcanoes. Many of the textures (plastic deformation structures, suture boundaries, and baked margins) present in the volcanics may indicate that emplacement took place at elevated temperatures although there is not always evidence of welding (Adair, 1986).

LAHARIC BRECCIA

The Crowsnest lavas are interpreted to have been extruded from volcanic domes and retransported as coarse, poorly sorted and nonstratified laharic breccia and alluvial deposits (Ricketts, 1982). A lahar is a mudflow composed chiefly of volcanoclastic materials on the flank of a volcano. Two measured sections are shown in Figure 15. The characteristics of laharic breccias present in the Crowsnest volcanics are:

1. graded and nongraded beds
2. sharp, scoured basal contacts
3. boulders projecting through upper bed contacts and draped by thin mudstone or volcanic sandstone
4. rippled red mudstones between superposed beds
5. lack of internal stratification
6. matrix supported, very poorly sorted clasts
7. variable roundness of individual clasts.

The laharic deposits are interbedded with crossbedded alluvial deposits (Fig. 15) interpreted as ephemeral stream flow deposits which reworked underlying laharic breccias.

LATERAL VARIATIONS

Volcanoclastic rocks at Carbondale appear to have been more distant from the main source area than those at Coleman (Fig. 16A) (Ricketts, 1982) based on:

1. decrease in maximum clast size
2. increase in degree of rounding
3. increase in proportion of fine-grained lithologies
4. decrease in amounts of heavy minerals present
5. change from graded beds at Carbondale to non-graded lahars at Coleman.

The Carbondale River section is at least 30 km from the postulated source of the volcanics.

The paucity of vesicular rock types argues against highly gas-charged magmas. There may have been minor intermittent explosive volcanism accompanying dome formation, since ash deposits (i.e., air fall) occur beneath and laterally adjacent to the Crowsnest Member (Fig. 17). Amajor (1985) studied the size distributions of biotite crystals in bentonites of the Viking Formation and determined that the source of the Viking bentonites was the Crowsnest Volcanics or a source close to them. The paleowind direction would have been northeasterly from the Cranbrook area to distribute the ash with its decreasing particle size in that direction.

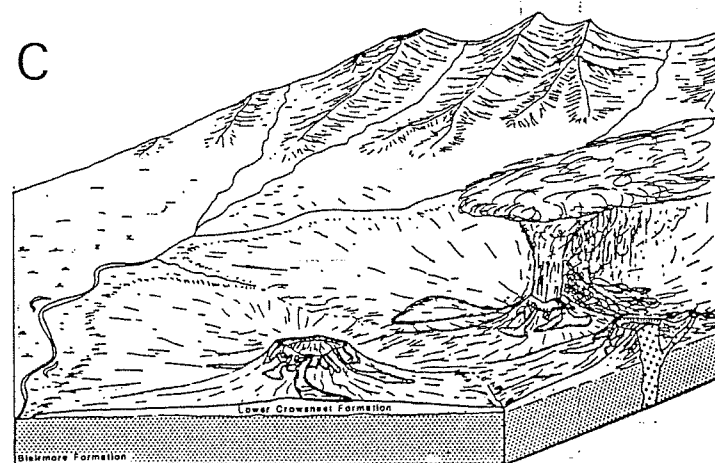
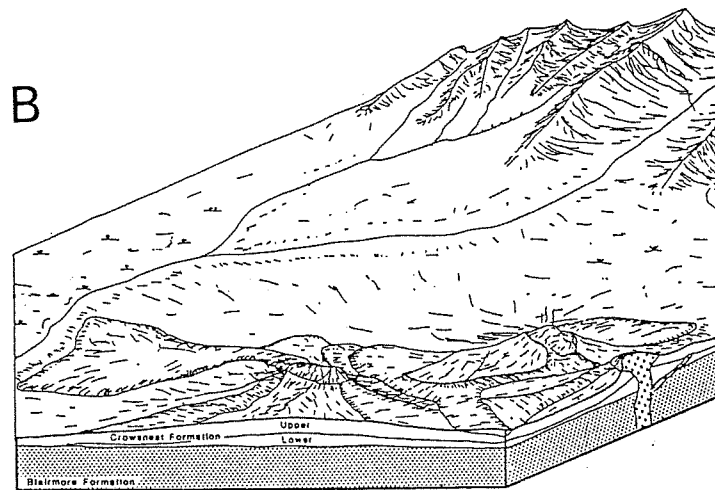
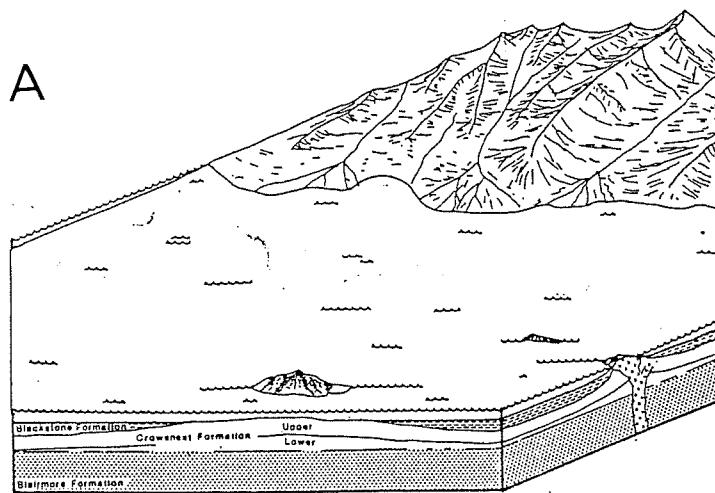


Figure 17. Proposed paleogeography of southwestern Alberta during A) early Crowsnest time; B) late Crowsnest time; C) post Crowsnest time. From Adair (1986).

Nosean trachyte flow rocks are common. Blairmorite occurs as blocks and bombs or as lithic tuffs. Rock fragments comprise up to 73% of the Crowsnest Formation (Adair, 1986). Near Coleman, Adair (1986) estimated that 90% of the Crowsnest deposits were pyroclastic in origin and that the balance was primarily lavas and volcanogenic sediments. Pearce (1970) proposed that the volcanism was primarily the explosive type with only minor flows. Adair (1986) suggested that the style of Crowsnest volcanism changed from highly to moderately gas-charged eruption for the lower Crowsnest Formation which produce air-falls, ignimbrites and lava flows. The upper Crowsnest eruptive style was one of poorly-gas charged and dome building eruptions which resulted in dome growth, collapse and/or disintegration that produces block flows.

The Crowsnest Formation likely formed a paleogeographic high with up to 120 m of relief centred near Crowsnest (Norris, 1964; Glaister, 1959; Adair, 1986, Mellon, 1967). Source areas or pipes for the volcanic detritus is considered to be in the Ma Butte, Coleman, and George Creek areas where maximum sediment thicknesses also occur (Pearce, 1970; Ricketts, 1982).

Age

Bell (1956) assigned an Albian age to the Crowsnest Formation based on flora collections in the area. Melanite garnets in the Crowsnest Formation are reportedly similar to garnets within the Viking Formation in south-central Alberta (M. Dean reported in Adair, 1986). This is consistent with conclusions by Amajor (1985) who inferred that the ash beds in the Viking Formation were derived from the Crowsnest Formation. Radiometric dates of the Crowsnest Formation range from 93.9 m.y. to 101 m.y. (Folinsbee et al., 1957; Folinsbee et al., 1961) indicating an Albian age. Sanadine and biotite from the Viking Formation have been dated at 94 to 105 m.y. which on biostratigraphic grounds is dated as Upper Albian (Stelck, 1958).

STOP 8: CARDIUM FORMATION ON HIGHWAY 3

A single exposure of the Cardium Formation on Highway 3, west of Coleman (Fig. 18) consists of an 8 m thick, upward coarsening, bioturbated siltstone to silty sandstone. No sedimentary structures are preserved due to the intensity of bioturbation, nor are there any thick sandstones. Burrow types include *Skolithos*, *Paleophycus*, *Chondrites* and *Asterosoma*?. The lack of any significant shoreface sandstone development suggests that the Cardium in southwestern Alberta was probably deposited in a large embayment with the sediments at this outcrop deposited far from the shoreline.

STOP 9: UPPERMOST MILL CREEK FORMATION AND SHALES OF THE BLACKSTONE FORMATION AT MILL CREEK BRIDGE (INCLUDES SECOND WHITE SPECKS FORMATION).

This outcrop (Fig. 19) of the Upper Mill Creek Formation and lowermost Blackstone Formation

Figure pending.

Figure 18. Outcrop of Cardium Formation exposed on road cut along Highway 3, west of Coleman.

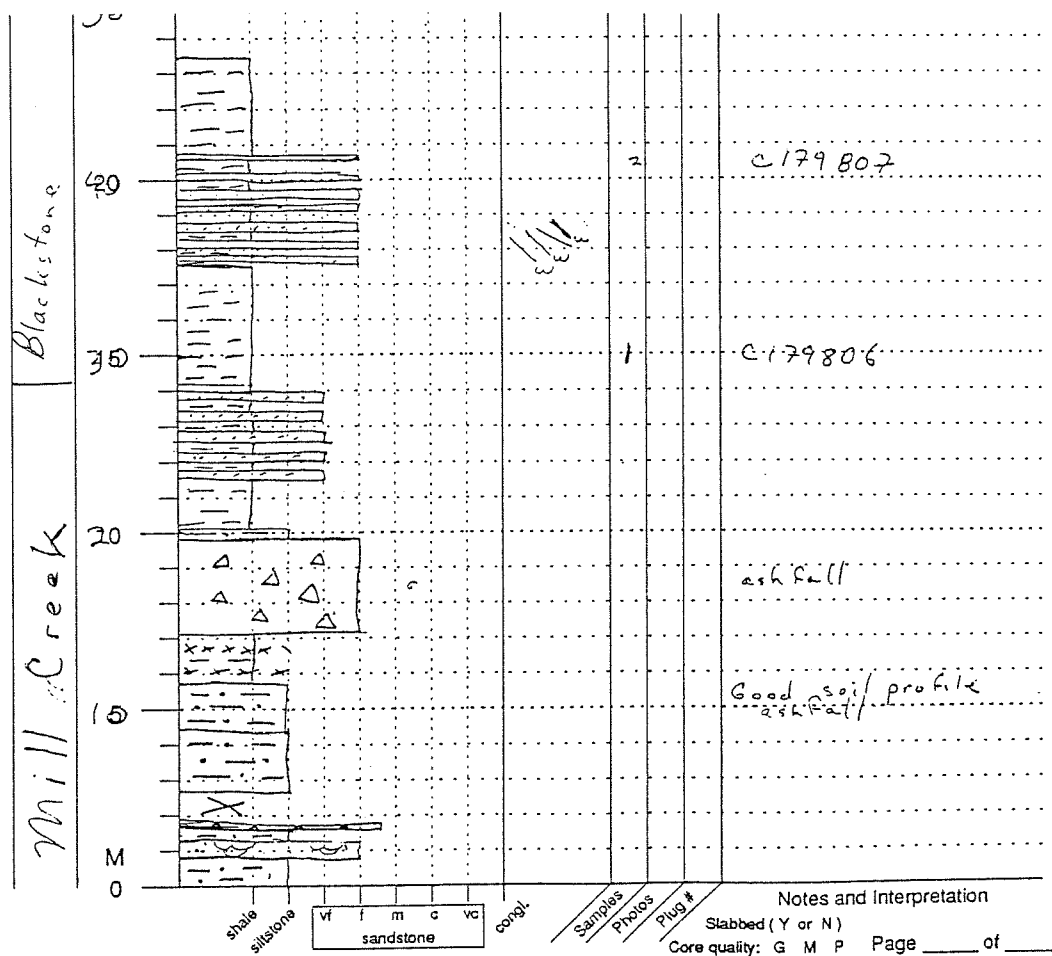


Figure 19. Measured section of the Upper Mill Creek Formation and lowermost Blackstone Formation at the Mill Creek Bridge. Location 49°27'51", 114° 07'57"

including the Second White Specks Formation is well exposed. The Upper Mill Creek Formation contains point bar sandstones, paleosols, reworked deposits and ashfalls of the Crowsnest Volcanics.

The Belle Fourche and Second White Specks formations of the Colorado Group directly overlies the Mill Creek Formation. The Second White Specks Formation is oil stained and intensely fractured. Note the fracture patterns.

STOP 10: THE CALCAREOUS MEMBER, GLADSTONE FORMATION (OSTRACODE EQUIVALENT) AT GLADSTONE CREEK

The term Gladstone Formation was first applied by Mellon (1967) to describe the Lower Cretaceous strata exposed in a series of thrust slices on Gladstone Creek, approximately 0.5 km upstream of its confluence with Mill Creek. Mellon adopted Glaister's (1959) terminology and differentiated a lower Cadomin Member, a middle unnamed sandstone and shale sequence, and an upper Calcareous Member. The complete sequence is not preserved in any of the thrust slices and a composite of the three sections from Gladstone Creek is shown in Figure 20. This exposure is an important section not only because it is the type locality but also because it is one of the best exposed and easily accessible outcrop sections of the Calcareous Member which, with its subsurface equivalent, the Ostracode Zone, forms one of the most important stratigraphic markers in the southern Alberta Plains.

The thin, but laterally very extensive Ostracod-Calcareous interval records a relatively short lived marine transgression on a low relief surface in southern Alberta.

The Calcareous member has largely been studied from a paleontologic perspective and numerous papers have documented that it contains a rich micro- and macro-faunal assemblage dominated by ostracods, pelecypods and gastropods. The sedimentology has been investigated by James (1985).

The Calcareous Member is typically a few tens of metres in thickness and consists of limey bioclastic shale containing distinctive coarsening upward sequences. Wave-ripple lamination and hummocky cross stratification is prominent in the silty, very fine grained sandstones which cap these cycles. Brackish trace fossil assemblages and syneresis cracks indicate deposition in a large muddy standing body of water which was subject to fluctuating salinity. However, in the Sheep and Elbow River sections a black shale containing marine microfauna is observed above the Calcareous Member, suggesting that at the maximum point of transgression most of southern Alberta was inundated by a shallow marine sea. There is no suitable recent analog for the Ostracod-Calcareous Member as most modern brackish standing bodies of water are much more limited areal extent.

STOP 11 MILL CREEK SECTION

MILL CREEK FORMATION

MILL and GLADSTONE CREEKS

Composite section
Tp. 5, R. 2, W. 5th Mer.

MILL CREEK

Sec. 7 - 6 - 1 W. 5th Mer.
Sec. 12 - 6 - 2 W. 5th Mer.

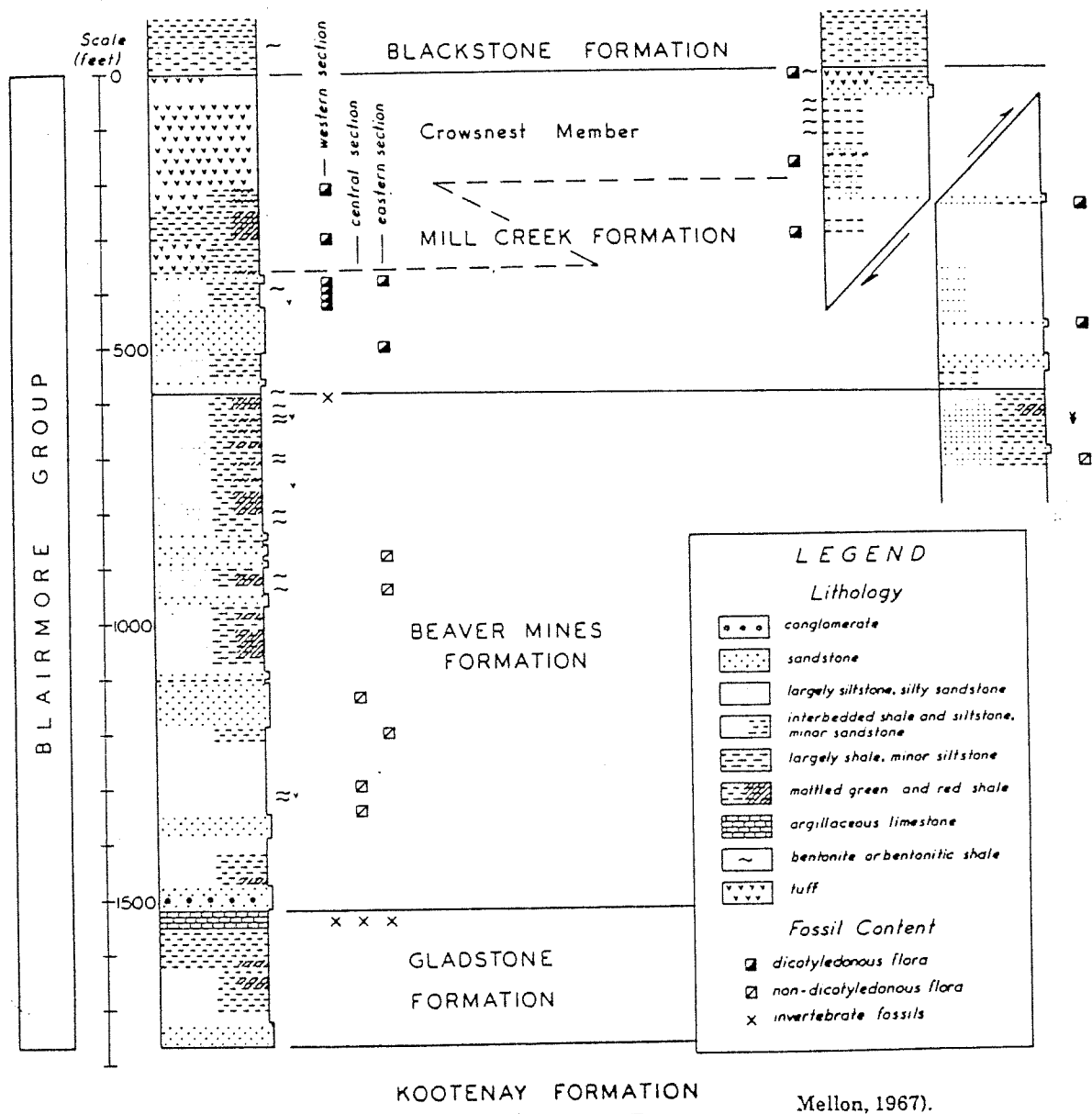


Figure 20. Columnar section showing lithology and fossil content of the Blairmore Group at Mill Creek and its tributaries.

A new and modified stratigraphy for the Mill Creek Formation is being formulated. The new terminology is informally used in this guidebook but has not yet been properly documented and accepted. Figures 21 and 22 show the new stratigraphy based on outcrops in the Rocky Mountain Foothills.

LYNX CREEK MEMBER (NEW NAME — INFORMAL)

The Lynx Creek Member outcrops at Lynx Creek River, Mill Creek and Vicary Ridge (Fig. 23). The Lynx Creek Member contains marine to brackish palynomorphs, microfossils, macrofossils and trace fossils. The palynomorphs (E. Burden, pers. comm., 1991) and micro-fossils (J. Wall, pers. comm., 1991) indicate that correlative horizons in western Canada may be the Hulcross and Harmon Members of northeastern British Columbia and northwestern Alberta. The Lynx Creek Member may in part be correlative with the Basal Colorado of southern Alberta.

Interbedded siltstone and quartzose sandstone of the Lynx Creek Member typically occur in coarsening-upward cycles approximately 10 m thick. Flutes, prod marks, load structures, laminations, trough and hummocky cross beds are common in the sandstones; mudstones are commonly bioturbated. At Mill Creek (Fig. 23), the Lynx Creek Member is approximately 25 m thick; the Member thins and erosional truncated to the north and west where it is absent at Ma Butte. Sedimentary structures and paleontologic specimens indicate that Lynx Creek Member strata probably formed in shallow-marine and shoreline environments.

The contact between the Lynx Creek Member and Beaver Mines Formation is sharp. It is represented by a change from greenish, chloritic-rich sandstones and variegated red/maroon and green siltstones and shale in the Beaver Mines Formation to white quartz-rich sandstone and dark grey/black shale of the Lynx Creek Member.

The uppermost Beaver Mines and Lynx Creek Member strata are thought to be middle Middle Albian or late Middle Albian age. The range of angiosperms has not been fully delineated and Beaver Mines and Lynx Creek are middle Middle Albian.

At Mill Creek, the Lynx Creek Member is 22.9 m thick and consists of two upward coarsening cycles. The lower contact is sharp and marked by a change from the variegated olive greens and reds of the Beaver Mines to the lighter-colored quartz and chert-rich sandstones and dark grey to black shales of the Lynx Creek Member. The peds, pedogenic slickensides and caliche nodules found in the Beaver Mines Formation do not occur in the Lynx Creek Member.

The lowermost upward-coarsening cycle is 7.6 m thick and consists of interbedded sandstone and shale. The sandstone is predominantly fined-grained with lesser amounts of very fine and medium grained. Sandstone beds are 0.9 to 4.3 m thick and are wave-ripple laminated, parallel laminated and

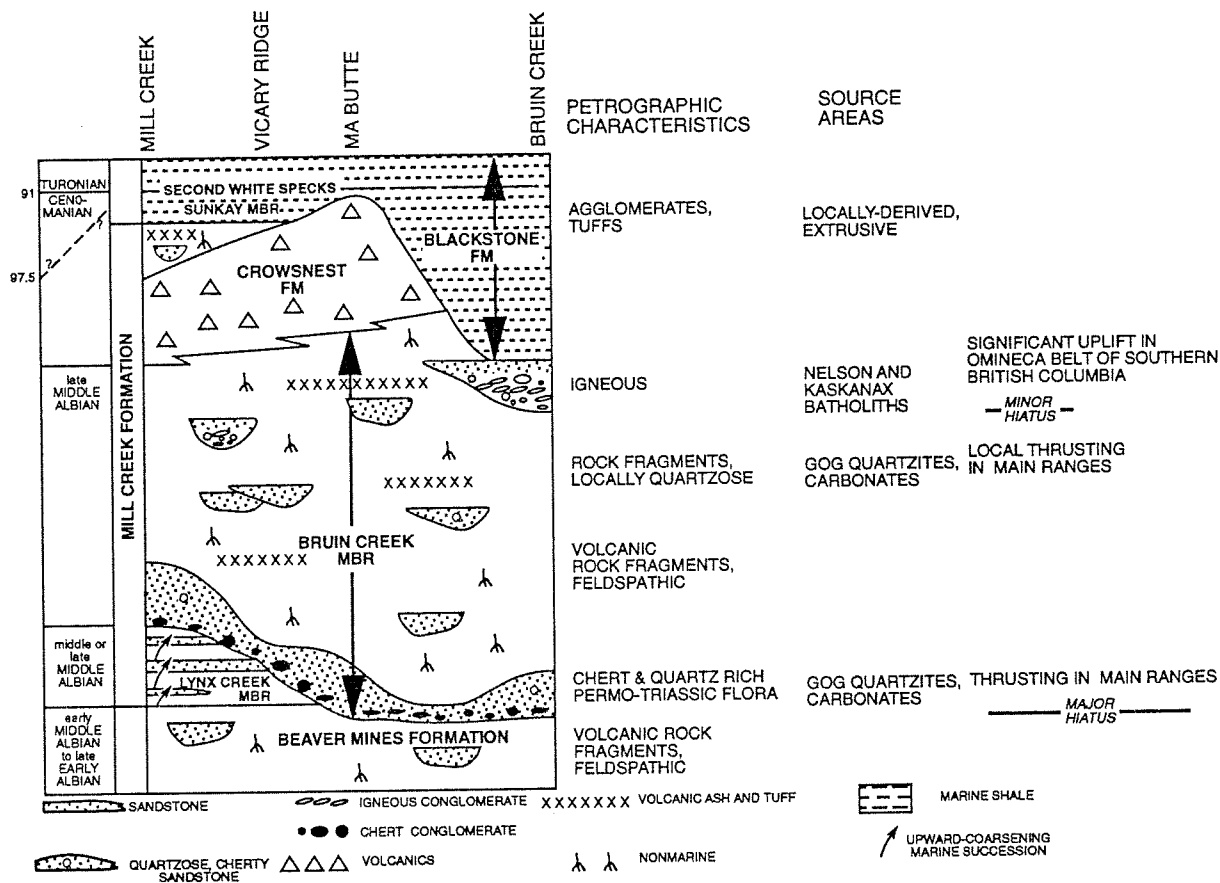


Figure 21. Revised, informal stratigraphy of the Mill Creek Formation of the Blairmore Group in the Foothills of southern Alberta. From D. A. Leckie and E. Burden (unpublished data).

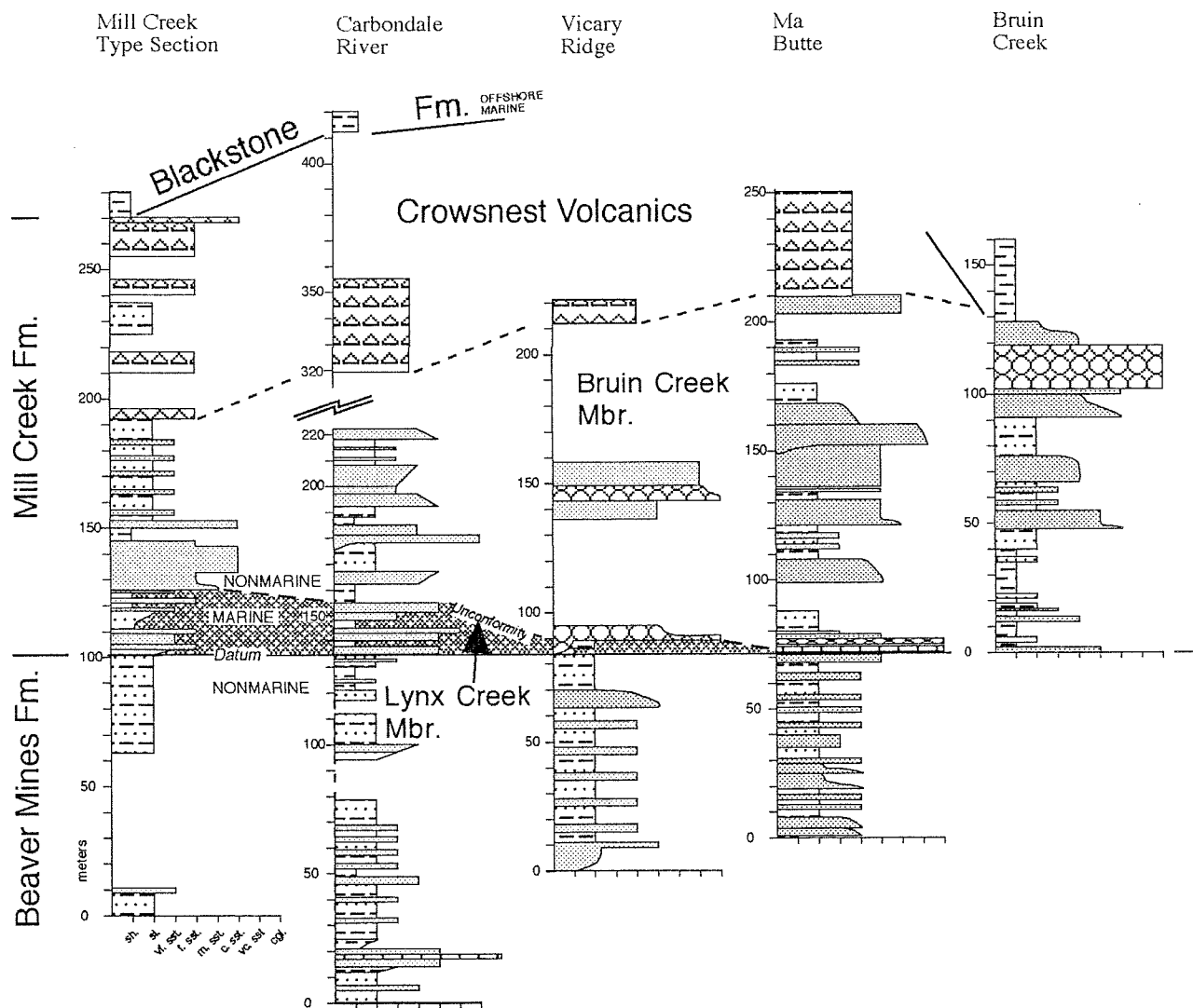


Figure 22. Measured sections of the Mill Creek Formation demonstrating unconformity at the base of the Mill Creek Formation.

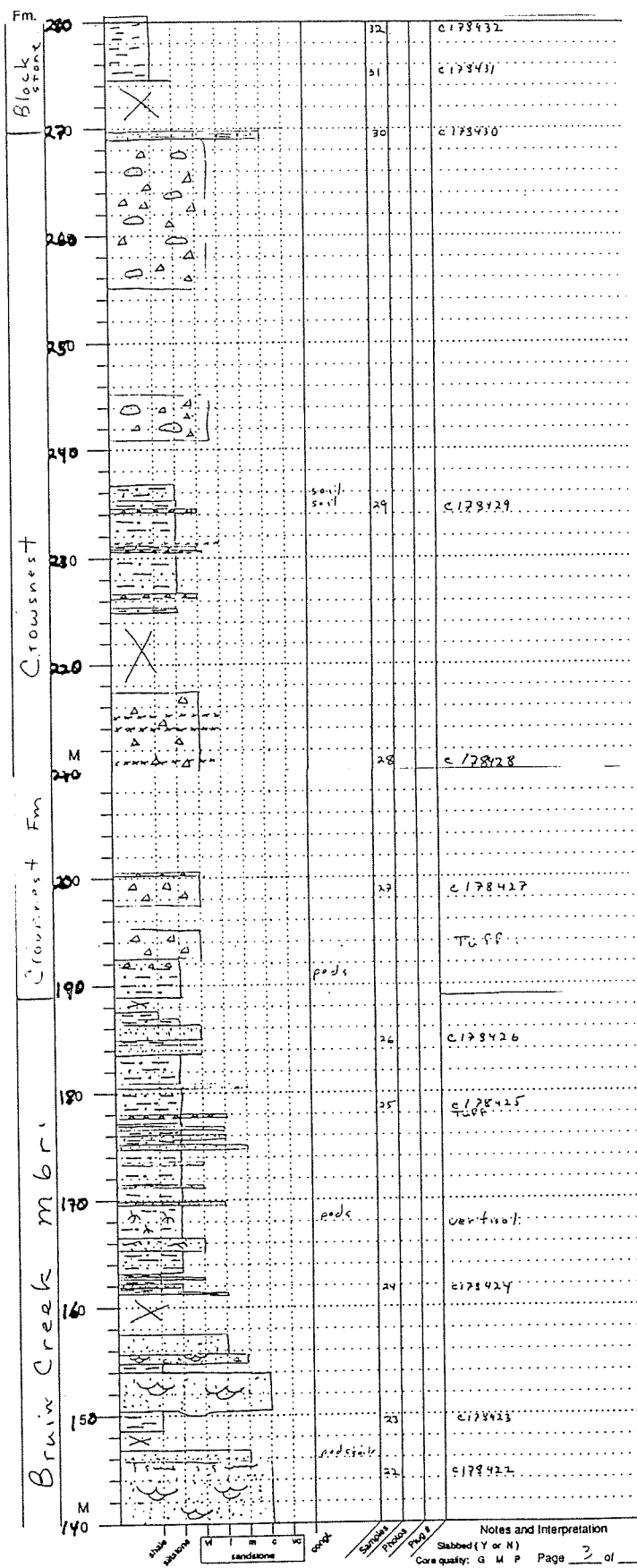
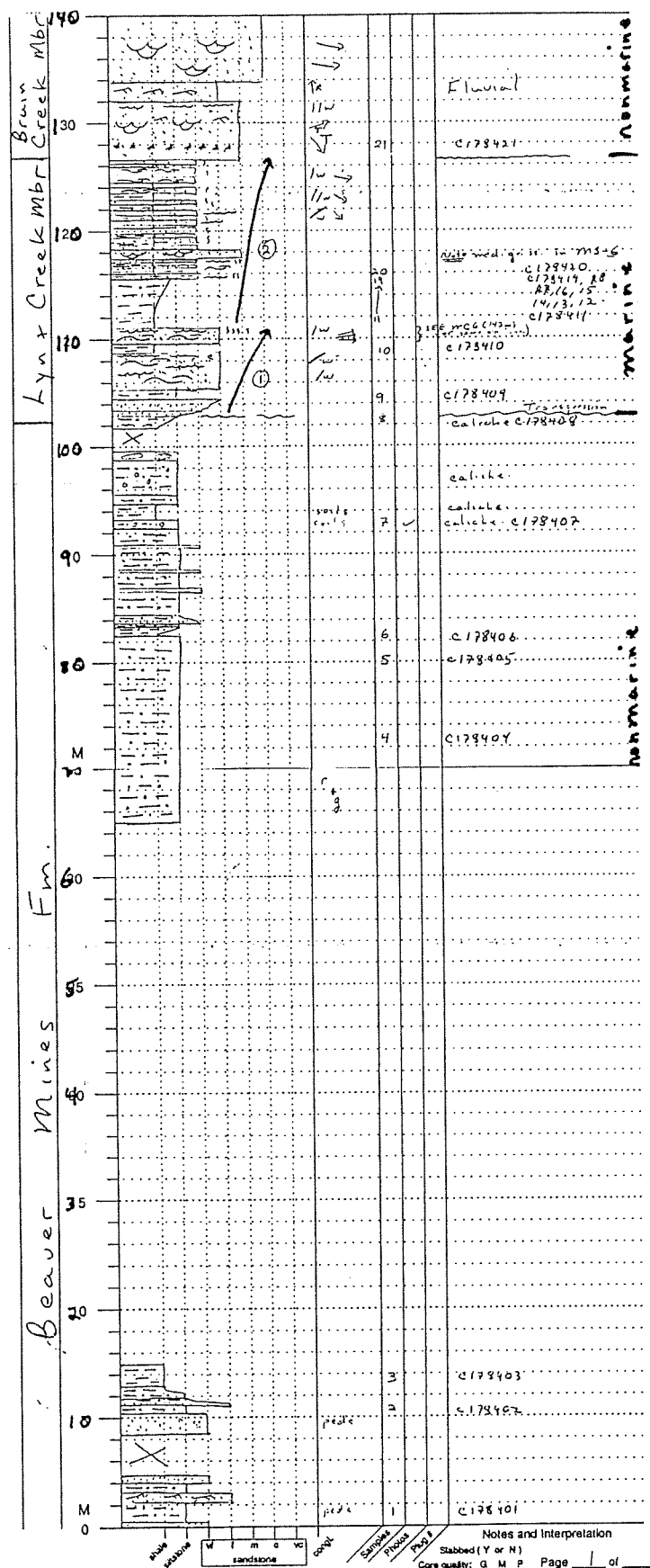


Figure 23. Measured section at outcrop of upper Beaver Mines Formation and Mill Creek Formation at Mill Creek.

hummocky cross stratified. Wave ripple crests have an average trend of 35-215°. At the base of one sandstone bed is a spectacular set of solemarks (Fig. 23; 109.7 m), including prods, brushmarks and tools. The average trend of the solemarks is 82° with the prods indicating flow towards the east.

The second upward-coarsening cycle, which is 15.3 m thick, consists of 4.4 m of black, platy, fissile shale and silty shale overlain by 10.9 m of interbedded sandstone and shale. Sandstone beds are 10 to 70 cm thick, very-fine grained and contain hummocky cross stratification and wave ripple lamination. At 118 m (Fig. 23), there is a 70 cm thick, trough-crossbedded, medium-grained sandstone. The sandstone beds are sharp based and the tops of the beds are intensely bioturbated. The sandstone beds generally increase in thickness upwards to about 30 cm maximum. The wave ripples have an 8 cm wavelength and amplitude of 0.5 cm. Wave ripple crests have a trend of 43-223° (Fig. 23); solemarks at the bases of hummocky beds indicate flow towards the east (towards 116°).

Bruin Creek Member (new name)

INTERPRETATION OF THE LYNX CREEK MEMBER

The sediments of the Lynx Creek Member represent the progradation of two and possibly three shoreline successions (1, 2 and 3, Figure 24). The outcrop on the Lynx Creek contains a lower, poorly-defined upward coarsening succession (1, Fig. 24) overlain by a flooding surface. Cycles 2 and 3 coarsen upward from sandstone and siltstone of the offshore-transitional through to lower shoreface zones. The low-angle, divergent lamination in the sandstone is interpreted as foreshore deposits which is capped by rooted siltstone and shale.

At Mill Creek, the two upward-coarsening cycles are interpreted to represent the more distal portions of Cycles 2 and 3 at Lynx Creek River. (paleo here).

The predominance of HCS and wave ripple lamination at Mill Creek and Lynx Creek River indicate sedimentation primarily by wave processes. The orientation of wave-ripple crests in fine-grained sandstone and coarser-grained sediment can be used to establish the general trend of local shorelines (Leckie and Krystinik, 1989). As such, the orientation of wave-ripple crests occurring with the Lynx Creek Member at all three outcrops indicates a local shoreline trend of north northeast-south southeast. Sole marks from the bases of hummocky beds indicate sediment transport to the southeast.

The thickness of the shoreface successions at Lynx Creek River is 9 and 4 m which is comparable to the thickness of low-energy shorefaces on the northeast coast of the United States. It is in marked contrast to the high-energy shoreface deposits of the modern California coast (Howard and Reineck, 1981), the Albian Falher Member (Leckie and Walker, 1982; Leckie, 1986) or Campanian/Santonian Milk River shoreline (Meijer Drees and Mhyr, 1981; Cheel and Leckie, 1990) which may be up to 30 m thick. Consequently, the shorelines of the Lynx Creek Member are interpreted to have been somewhat low-

energy forms such as exist along the modern Georgia coast.

Tintinids in the Lynx Creek Member indicate a brackish-marine environment (J. Wall, pers. comm., 1990) as do the broken and disarticulated macrofossil assemblage (J.W. Haggart, pers. comm. 1990). The Mill Creek sections contain fewer tintinids than the section on Lynx Creek River and some foraminifera. The Lynx Creek section contains no foraminifera. The Lynx Creek section is interpreted to have been deposited in a more proximal or landward direction.

BRUIN CREEK MEMBER (NEW - INFORMAL NAME)

The Bruin Creek Member of the Mill Creek Formation is named after Bruin Creek, near which the type section crops out (Fig. 25). The type section of the Bruin Creek Member is located on the Livingston River, south of the junction with Bruin Creek on the east side of the Forestry Trunk Road. The Bruin Creek Member occurs throughout the Rocky Mountain Foothills from the Lynx Creek River, north through to the Livingston River. Reconnaissance observations indicate that the member may extend north at least to the Bow river and possibly beyond. Subsurface equivalents of the Bruin Creek Formation in southwestern Alberta include the marine and nonmarine sediments of the Bow Island Formation. The type measured section is shown in Figure 25.

A reference section for the Bruin Creek Member is assigned to the Ma Butte section for several reasons (not illustrated here). The Ma Butte reference section illustrates some of the variability of the Bruin Creek Member including: 1) there is no conglomerate of the McDougall Segur Conglomerate present, 2) the top of the Bruin Creek Member is in contact the volcanic strata of the Crowsnest Formation rather than marine shale of the Blackstone Formation, and 3) the lower contact of the Bruin Creek Member is in direct contact with the Beaver Mines Formation and, as at Bruin Creek, there is no indication of the Lynx Creek being present. The geology of the region surrounding the type section is shown in Douglas (1950) and that of the reference section is shown in Price (1962).

The basal contact of the Bruin Creek Member is sharp and the lowermost unit consists of medium to coarse-grained sandstone and locally conglomerate, which rest erosively on the Lynx Creek Member. The Bruin Creek Member varies from 87 m at Mill Creek to 133 m thick at Bruin Creek.

The Bruin Creek Member is restricted to include interbedded cherty sandstone with abundant rock fragments, varicolored mudstone, conglomerate and ash. It is in part laterally equivalent to the Crowsnest Formation and contains the McDougall-Segur conglomerate.

The subsurface equivalent of the Bruin Creek strata is the lower portion of the Bow Island Formation (Burden, pers. comm., 1991).

Age: A late Middle Albian age is favoured for Bruin Creek strata.

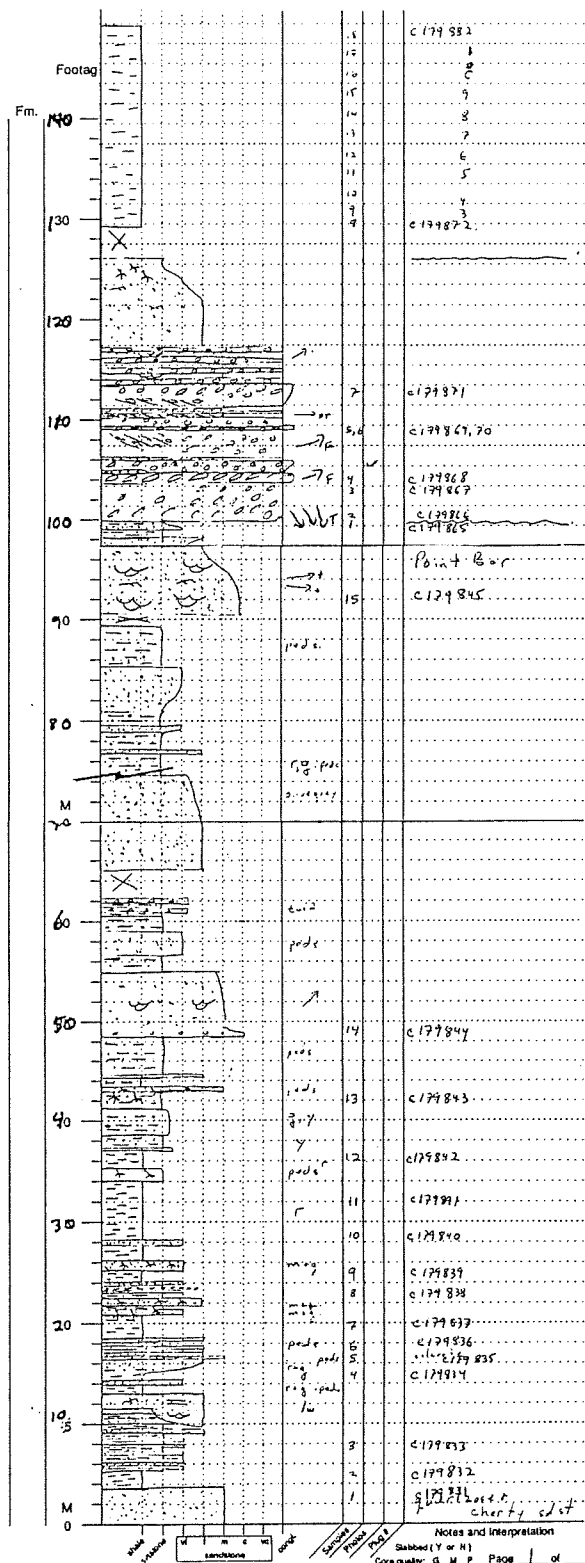


Figure 25. Measured section of outcrop of upper Beaver Mines Formation, Mill Creek Formation and McDougal Segur Conglomerate at Bruin Creek on the Livingston River.

DESCRIPTION

This basal sandstone of the Bruin Creek Member is regionally extensive, occurring at all outcrops where the lower contact with the Bruin Creek was observed. On the Carbondale River and Ma Butte, the basal sandstone pinches out laterally. The basal sandstone may be correlative with the McDougall-Segur sandstone described by Douglas (1950).

The basal unit is a medium to very coarse grained, pebbly sandstone which scours into underlying Beaver Mines Formation or Lynx Creek Member strata. A chert-pebble conglomerate may be locally present with clast sizes ranging from 1 to 5 cm. Clasts are subangular to subrounded. Shale clasts to 5 cm are common. Wood debris is locally present at the base of the sandstone and in some outcrops is abundant. On Lynx Creek (**STOP 12**; Fig 24), abundant tree casts are oriented north-south. This basal sandstone and conglomeratic unit varies from 2 to 20.4 m thick. The basal contact exhibits up to 1.6 m of relief along the outcrop at Vicary Ridge (**STOP 13**; Fig. 25) and Carbondale River (**STOP 12**). Where the Lynx Creek Member is not present, the basal unit of the Bruin Creek Member rests with marked lithologic contrast upon sediments of the Beaver Mines Formation.

The basal sandstone fines upward in several sections from a shale-clast or chert-pebble conglomerate to fine or medium-grained sandstone. Sedimentary structures are predominantly trough cross-stratification in sets ranging from 20 to 80 cm. The upper portion of the sandstone may be rippled and contain *in situ* vertical roots. The trough cross beds in this unit all indicate flow in a generally towards the east. At Mill Creek (**STOP 10**), the basal sandstone is 20.4 m thick. Within the sandstone are a few occurrences of wave ripples which are oriented north south. Wave ripple crests have a 3 cm wavelength and 3 mm amplitude.

Sediment overlying the basal sandstone of the Bruin Creek Member consists of interbedded sandstone, siltstone and shale with sandstone. The sandstones are fine to coarse-grained, and several metres to 32 m thick. They commonly pinch out laterally. A stacked, or composite sandstone body on Ma Butte is 32 m thick. Paleocurrent indicators are most evident in the quartzose and chert-rich sandstone found near the base of the Bruin Creek Member. Upwards, within the member, as sandstones become more arkosic, sedimentary structures are more difficult to discern. Trough crossbeds from the fluvial sandstones persistently indicate paleoflow in an easterly direction. On Mill Creek (**Stop 10**; Fig. 23, at 116 m), a coarse-grained sandstone has a conglomeratic lag with volcanic and chert clasts to 6 cm. Siltstone and shale beds are olive green, grey and maroon colored. *In situ* vertical roots, pedogenic slickensides and peds are common. The upper few tens of metres of the Bruin Creek Member contain isolated beds of volcanic debris. For example, on Mill Creek there are beds of tuffaceous volcanic debris containing of feldspar lathes within siltstone groundmass.

Interpretation

The apparent lateral continuity of the lowermost sandstone with an absence of siltstones and clays may suggest that the fluvial systems which deposited the sandstone was not meandering, or if it was, may have been a low sinuosity system.

Sediment above the basal sandstone exhibit a marked increase in rock fragment content and quartz and chert content decreases. Siltstones and clays are interpreted as floodplain and overbank deposits which were pedogenically altered. Sandstones were deposited by high sinuosity meandering rivers. The water table was probably relatively low, or fluctuated as only minimal organic matter has been preserved.

In most measured sections, Bruin Creek Member rocks are nearly devoid of sedimentary structures. Peds commonly occur in the mudstones; sandstones rarely show fining upward successions with very rare crossbedding. A terrestrial fluvial and pedogenic setting similar to the Beaver Mines Formation is inferred for these rocks.

STOP 12: CARBONDALE RIVER SECTION

The type section of the Lynx Creek Member (Fig. 24) is situated on the Carbondale River upstream, near the junction with Lynx Creek. Access to the outcrop can be obtained by parking in the Alberta Forestry Service Lynx Creek Campground.

The Lynx Creek Member at the type locality is 42.3 m thick and consists of three upward-coarsening cycles. The lowermost upward-coarsening succession is not as well defined as the upper two. The basal contact is sharp and represented by a bioturbated, very fine-grained, light colored sandstone, which in turn is overlain by a mixed bioclastic/siliciclastic bed 1.8 m thick. The bioclastic component consists of poorly-sorted, broken and disarticulated shell debris of *Ostrea?* sp., nuculid bivalve fragments, unidentified bivalve fragments, *Tancredia?* sp., *Melania* sp., and gastropod fragments (J. Haggart, pers. comm., 1990). Bioturbation is moderate and includes *Pelecypodichnus*. Wave-ripple crests at the top of the bed trend northeast-southwest and oriented wood debris at the base trends northwest-southeast (Fig. 24).

This basal bed is overlain by a 5.5 m thick, upward-coarsening succession. The base of the succession consists of a 1 m thick shale containing dinoflagellates and tintinids. Sandstone beds are very fine to fine-grained and increase in frequency and thickness upward. The sandstone beds are hummocky cross stratified and wave-ripple laminated. The top of the cycle is characterized by a 60 cm thick, medium-grained sandstone bed, containing coarse-grained wave ripples having a wave length of 20 cm and amplitude of 2.2 cm. The wave ripple crests are well rounded with anastomosing crestal pattern. There is also a box-like interference pattern. The ripple crests trend 23-203°.

Five metres from the base of the Lynx Creek Member is a 1.9 m thick sandstone bed which has

spectacular solemarks at its base (Fig. 24). The relief on the base of the bed is up to 30 cm and sole marks include flutes which are up to 2 m long and 1 m wide. The large flute flares out towards 55°. Other solemarks trend 28-208° and 26-206°. Within the fluted surface are prod marks and brush marks, several of which cross cut one another. The brush marks range from 1 mm to 10 cm wide. The sandstone is fine grained, and hummocky cross stratified. The upper 30 cm contains possible wave-ripple lamination.

The second upward coarsening succession is 12.9 m thick and consists of 3.4 m of interbedded sandstone and shale. The sandstone contains hummocky cross stratification and wave-ripple lamination. Bioturbation is light to moderate consisting of *Thalassinoides* and unidentified forms. The upper 9.3 m of the succession is a very fine-grained sandstone coarsening to medium grained. The lower 6.5 m is an amalgamated HCS sandstone. Wave-ripple crests trend northeast-southwest. The upper 2.6 m consists of parallel laminated medium-grained sandstone with individual 10 to 15 cm thick bed sets exhibiting low-angle divergences. One metre from the top of the sandstone is an isolated 9 x 5 cm chert cobble. The upper 15 cm of the sandstone is very carbonaceous and contains *in situ* vertical roots, some of which appear to have horizontal rhizomes spreading from a vertical root. The exhumed upper surface of the sandstone has irregular with relief up to 30 cm. The top of the second cycle consists of 1 m of rooted and pedogenically altered shale and siltstone.

The third upward-coarsening cycle is 9 m thick and generally similar to the second cycle. Wave-ripple crests from the tops of hummocky beds trend north-northeast (21-201°).

The upper 11.5 m of the Lynx Creek Member consists of interbedded sandstone, siltstone and shale. Siltstone and shale beds vary in color from green, grey and maroon. *In situ* vertical roots, and pedogenic slickensides are common. Isolated sandstone bodies pinch out laterally.

The contact between the Lynx Creek and Bruin Creek Member is erosional. Forty-four metres of the Bruin Creek Member are exposed along the Lynx Creek River and the rest of the section is covered. Exposures of the Crowsnest Formation outcrop approximately 144 m above the base of the Bruin Creek Member. The contact between the Crowsnest Formation and Bruin Creek Member is obscured.

STOP 13: VICARY RIDGE

At Vicary Ridge, only 3 m of the Lynx Creek Member are preserved (Fig. 26). Here, the member consists of 30 cm of black silty shale overlying rooted siltstone of the upper Beaver Mines Formation. The shale is overlain by up to 1.8 m of very fine-grained sandstone containing wave-ripple lamination and vaguely-defined hummocky cross stratification. Wave-ripple crests trend northeast-southwest. There is minor bioturbation (burrows unidentified) at the base of the sandstone. This sandstone thins to 0.2 m along the length of the outcrop due to erosion by the overlying unit. Overall, the Lynx Creek Member thins laterally towards the top of the Ridge and is truncated by the basal sandstone of the Bruin Creek Member.

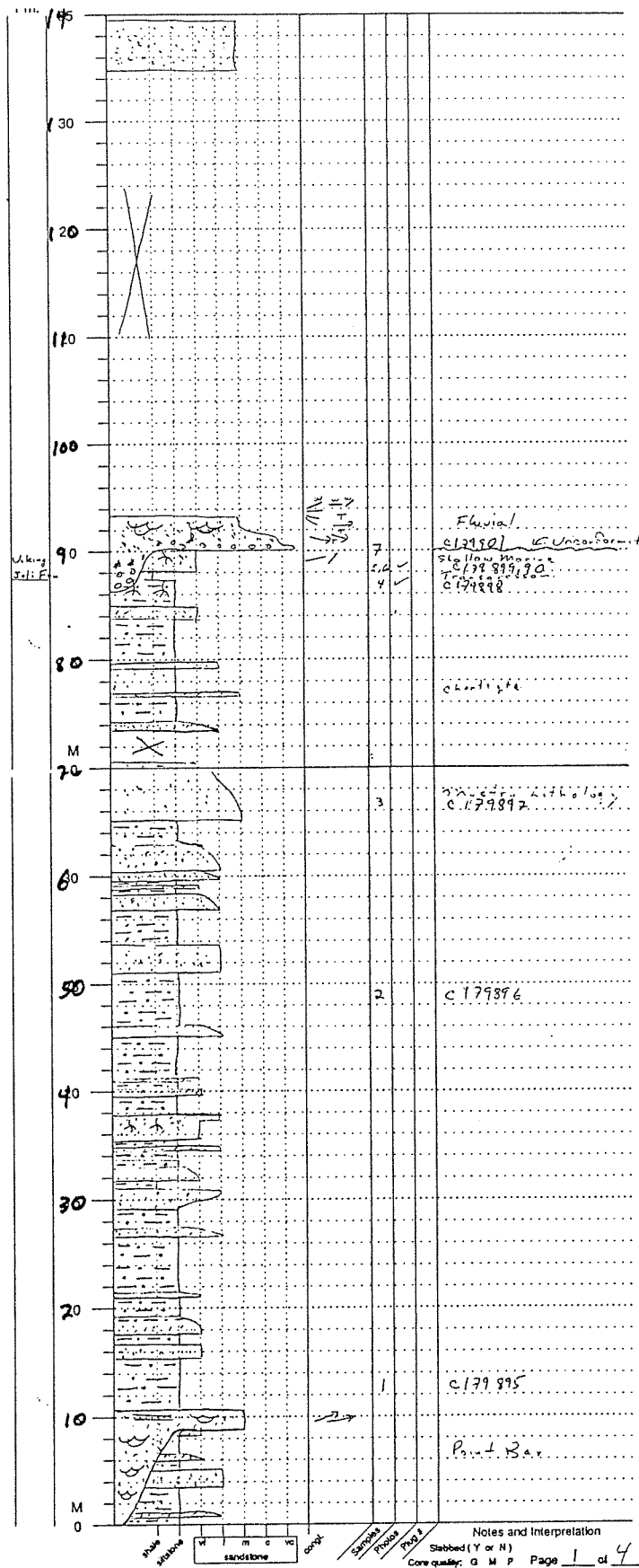


Figure 26. Measured section of outcrop of Upper Beaver Mines Formation, Mill Creek Formation and McDougall Segur Conglomerate at Vicary Ridge.

The Lynx Creek Member is not preserved, but has been eroded by the unconformity at the base of Bruin Creek Member on the thrust sheet at Ma Butte, west of Vicary Ridge.

STOP 14: FRANK SLIDE INTERPRETIVE CENTRE, BLAIRMORE

The side road from Highway 3 to the Frank Slide Interpretive Centre traverses outcrop of the Beaver Mines, possibly Mill Creek Formation (Fig. 27). North of the parking lot, the top of the hill is formed on 30 m of McDougal Segur Conglomerate.

STOP 15: MCDUGALL-SEGUR CONGLOMERATE

The Bruin Creek Member contains laterally discontinuous beds of conglomerate up to 30 m thick and 3 km wide, which are rich in igneous and volcanic clasts with lesser amounts of cherts and quartzites set in a medium-grained, greenish-grey, arkosic matrix. In the Turner Valley area, the McDougall Segur interval was described to be locally conglomeratic, containing chert, quartz and, most significantly, igneous pebbles (Hume, 1938, Anderson, 1951). Hume (1938, 1939) originally described the McDougall-Segur as an oil-bearing sandstone within the upper part of the Blairmore Group in the subsurface of the Turner Valley area. Anderson (1951) described the conglomerate as a lithological variant of the informally-named McDougall-Segur member which normally occurs as a sandstone along 125 miles of Foothills outcrop. Norris *et al.* (1965) proposed that all igneous-bearing conglomerates within the Blairmore Group be referred to as belonging to the McDougall Segur interval. Norris *et al.* (1965) indicated that the McDougall Segur conglomerate represented a single depositional event and could be used as a correlatable time line. This conclusion was criticized by Mellon (1967) who suggested that igneous-bearing conglomerates occurs at different stratigraphic intervals in the middle and upper Blairmore Group. Urbatt (1988) indicated that the McDougall-Segur conglomerate was only found in Beaver Mines Formation. However, the conglomerate also occurs at the top of the Mill Creek Formation (Fig. 24).

The pebble to boulder-sized clasts consist of grey chert, grey, pink and green quartzite, argillite, igneous and volcanic lithologies (Norris *et al.* 1965). The plutonic clasts consist of leucoalkali-granites, leucogranite, leucogranodiorite, leucoquartz-monzonite, leucoquartz-diorite and syenite (Urbatt, 1988). Volcanic clasts are predominantly leucorhyolite and leucodacite (Urbatt, 1988). At Bruin Creek, the conglomerate contains green clasts of volcanic debris which is similar to that of the Crowsnest Volcanics.

The conglomerate is typically clast-supported with a medium-grained sandstone matrix. The matrix consists of chloritic, quart-chert-feldspar sandstone and can be variably classified as feldspathic litharenite, lithic arkose or arkose (Norris *et al.*, 1965; Urbatt, 1988). Feldspars are sodic plagioclase and sericitized and kaolinitized orthoclase. The lower contact of the conglomerate is typically irregular and deeply scoured into underlying sediments. There is considerable lateral variation in clast size and bedding is poorly defined or nondiscernable. Individual beds are up to 40 cm thick and vary from poorly

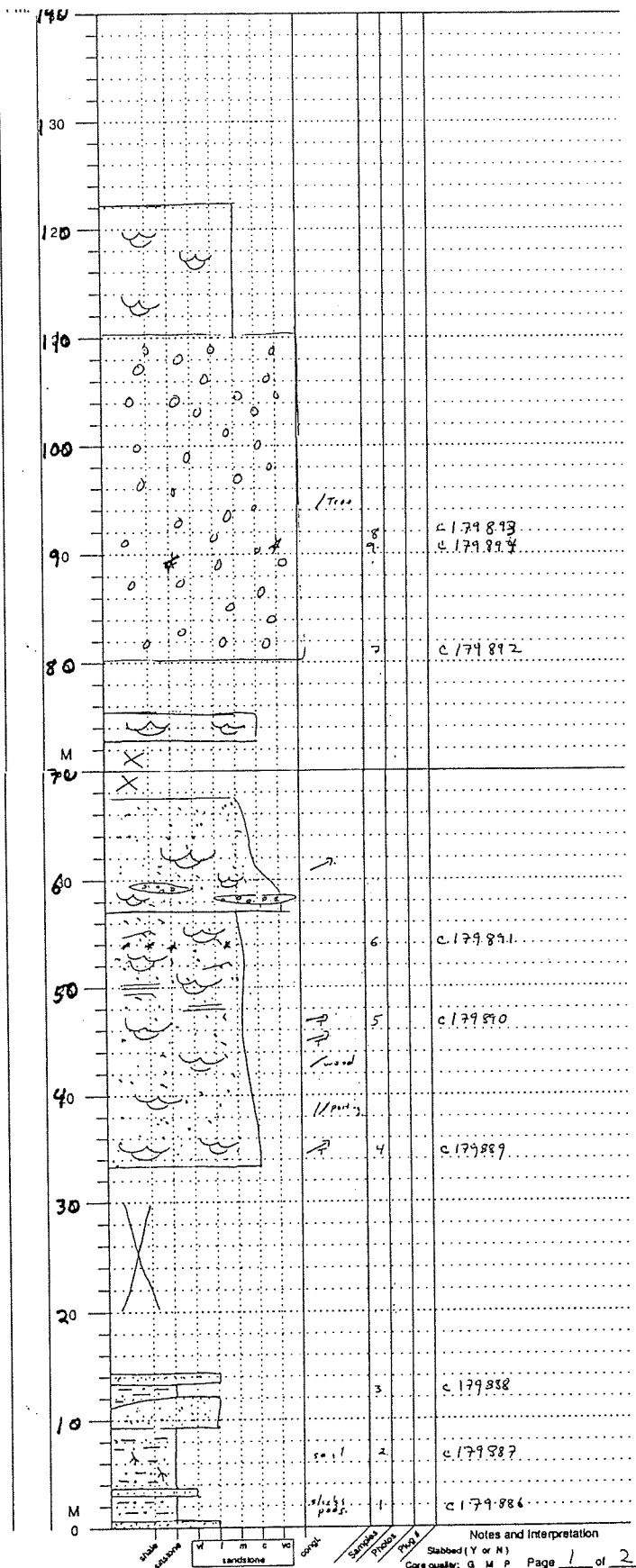


Figure 27. Measured section of Upper Beaver Mines Formation and McDougal Segur Conglomerate at the Frank Slide Interpretive Centre.

sorted, to well sorted; some beds contain clasts several decimetres in size, which are abruptly overlain by beds containing clasts with a maximum size of a few centimetres. Other than the occurrence of large intraformational clasts at the base of the conglomerate, there is no discernible vertical grain size variation. At Bruin Creek, (**STOP 17**) the top 4.5 m of the conglomerate consists of interbedded sandstone and conglomerate with beds 0.25 to 1 m thick. Lenses of medium-grained sandstone decimetres thick and up to a few metres long are common. The conglomerate typically pinches out laterally into medium to coarse-grained sandstone. Intraformational mudstone clasts up to 2 m in size locally occur at the base of the conglomerate. Tree casts occur but are rare. Stratification within the conglomerate consists predominantly of crude parallel bedding with bed sets up to 40 cm. Pebble clasts are typically well imbricated. Planar-tabular crossbeds with set up to 50 cm thick are not uncommon, defined by clasts lying on foresets. Pressure solution features are a characteristic of the conglomerate.

In the Crowsnest Pass area, the conglomerate occurs near the top of the Blairmore Group within the Bruin Creek Member (Fig. 21). At several localities such as Ginger Hill, York Creek, and Frank Slide Interpretive Centre, it is not possible to ascertain the exact stratigraphic position of the conglomerate as reliable markers are not present. However, further north, near Turner Valley, the conglomerate occurs lower in the section, as far as 220 ft below the top of the Blairmore Group (Hume, 1939). Petrography indicates that the McDougall Segur conglomerate was sourced in the Selkirk and Purcell Mountains of southeastern British Columbia, possibly the Nelson and Kaskanax Batholiths (Anderson, 1951; Mellon, 1967; Norris *et al.*, 1965; Urbatt, 1965). Norris *et al.* (1965) considered the McDougall Segur conglomerate to be at least partly correlative with the Crowsnest Formation. They came to this conclusion because of a perceived association of the McDougall Segur conglomerate with the sedimentary strata derived from the Crowsnest Formation.

The McDougall Segur Conglomerate is commonly overlain by medium to coarse-grained, arkosic sandstone several tens of metres thick. At Bruin Creek and on Dutch Creek, the sandstone is about 8 m thick and contains minor bioturbation and possibly roots. In individual outcrops, the conglomerate can be traced for 750 to 3000 m. At some outcrops the channeled nature of the conglomerate is evident with up to ~60 m of relief.

Based on age and mineralogical similarities Urbatt considered that the McDougall Segur conglomerates were derived from the Kuskanax and Nelson Batholiths (Read and Wheeler, 1976) in southeastern British Columbia. These Kuskanax Batholith has been dated at 173 ± 5 my (Parrish and Wheeler, 1983) and the Nelson Batholith at 164 my (Nguyen *et al.*, 1968), dates which are comparable to the 174 to 113 my K-Ar dates obtained by Norris *et al.* (1965) from seven pebbles in the McDougall Segur Conglomerate. Urbatt (1988) considered that the variations in quartzite content within the McDougall-Segur conglomerate were the result of differences in exposure of the Kootenay Terrane in the source areas. Because of the similarities in composition, Urbatt considered that the volcanic and plutonic clasts were genetically related to the same magmatic events.

STOP 16: MILL CREEK FORMATION AND SECOND WHITE SPECKED SHALE OF THE BLACKSTONE FORMATION AT BRUIN CREEK AND LIVINGSTON RIVER

This outcrop (Fig. 25) illustrates the unconformity at the base of the Mill Creek Formation. The basal quartzose sandstone is important petrographically as it is different from overlying and underlying units. Other important aspects of this outcrop include the paleosols of Bruin Creek Member, the tuffaceous and resistant soil and the McDougal Segur Conglomerate. Note the overlying shale of the Blackstone Formation.

STOP 17: SECOND WHITE SPECKLED SHALE: HIGHWOOD RIVER

This outcrop (Fig. 28) illustrates the oil-impregnated fractures of the calcareous Second White Specks Formation. Note the oil-impregnated sediments of the overlying and underlying sediments.

STOP 18: MILL CREEK FORMATION AND BARONS SANDSTONE EQUIVALENT AT THE HIGHWOOD RIVER

This outcrop (Fig. 29) examines the Mill Creek Formation (Bruin Creek Member) and shale of the Lower Colorado Group. Of particular interest is a granulestone which is likely the outcrop equivalent of the Barrons Sandstone in the subsurface. Figure 30A shows an isopach map of the Barrons Sandstone in the subsurface. The Barrons Sandstone includes a series of isolated pods of sandstone and conglomerate up to 7 m thick, 3 to 5 km wide and 5 to 15 km long. The sandstones thicken westward and become more continuous toward the Rocky Mountain Foothills. Figures 30B and 30C show a core and wireline log from Canhunter Keho 6-16-11-22W4. The oil-stained sands from the Keho well was derived from fur

In southwestern Alberta subsurface, the Cenomanian Barrons Sandstone overlies the organic-rich, radioactive shales of the Fish Scales Zone. In the outcrop, the Barrons overlies the Mill Creek Formation. There is a significant unconformity at the base of the Barrons Sandstone.

STOP 19: MCDOUGAL SEGUR CONGLOMERATE: RIO ALTO RANCH

The exact stratigraphic position of the McDougal Segur Conglomerate at the Rio Alto Ranch, west of Longview is not precisely known yet — is it in the Beaver Mines Formation or the Mill Creek Formation. Two conglomerates form dominant ridges in the hill slope. There is no indication of the conglomerate in correlative strata in the Highwood River

The ~30 m thick conglomerate has a scoured base cut down into the underlying grey-green mudstone. The conglomerate extends laterally for ~0.5 km and grades upwards to sandstone. Shale clasts are up to 100 x 40 x 20 cm at the base of the conglomerate. Clasts contain feldspar lathes as well as solution pits. Fine to medium-grained sandstone interbeds are decimetres thick and are trough-

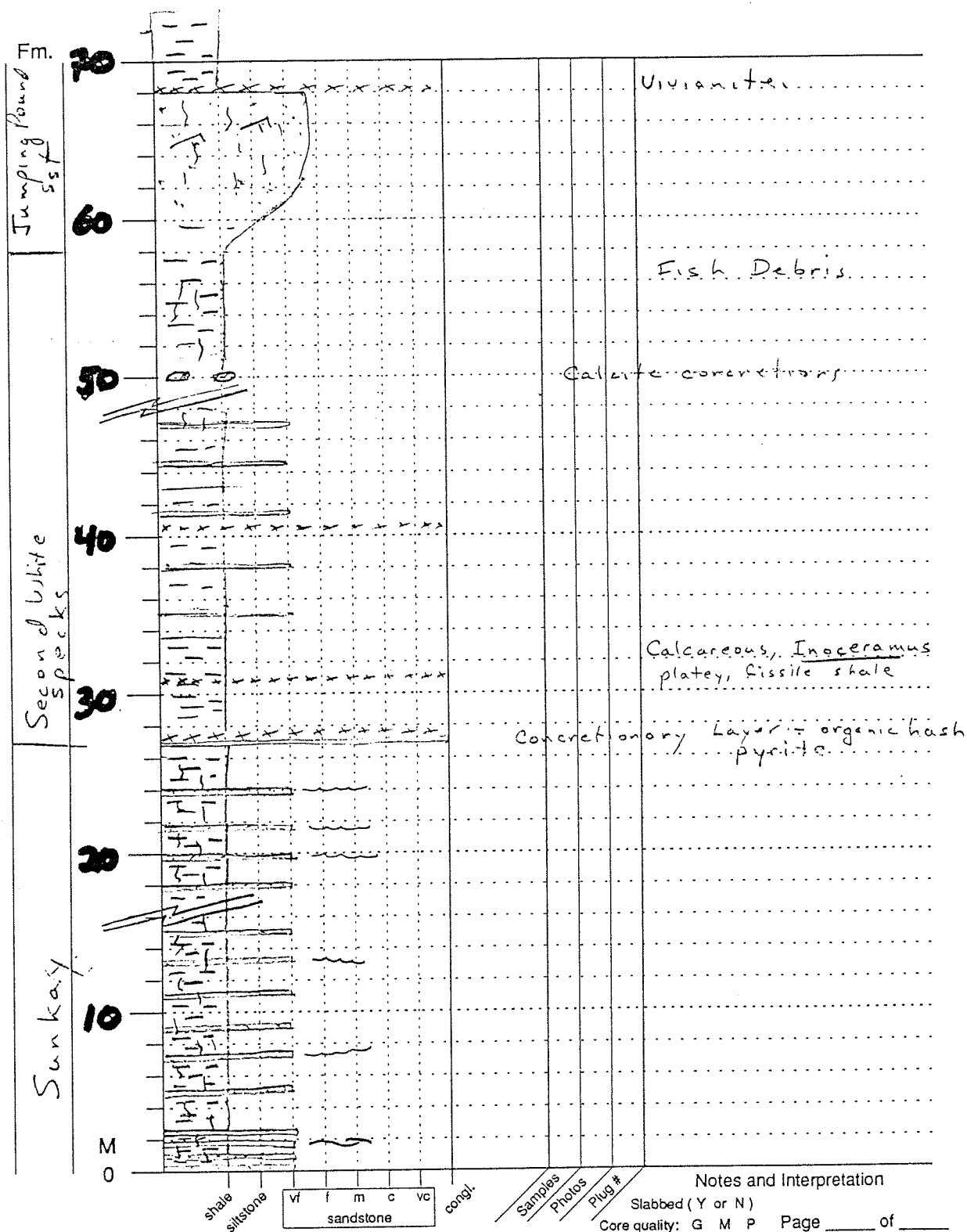


Figure 28. Outcrop of the Second Whites Specks Formation on the Highwood River.

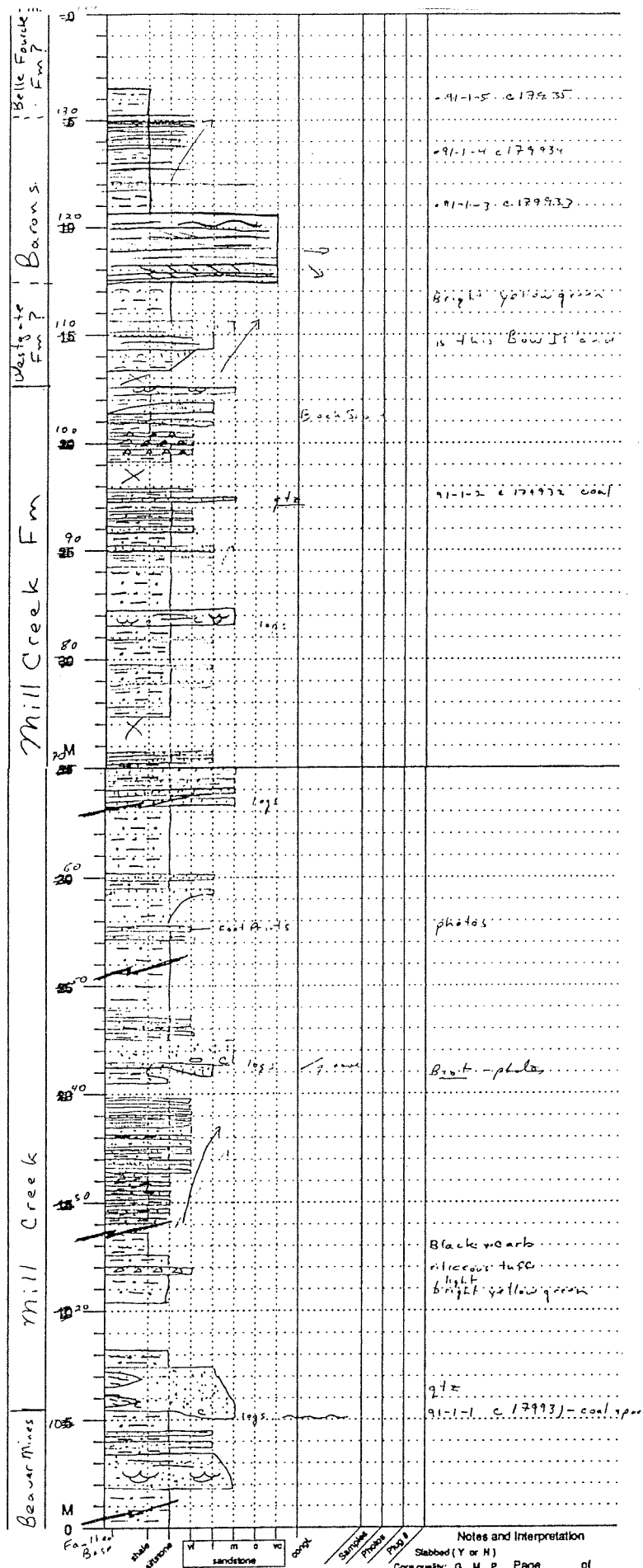


Figure 29. Outcrop of the Mill Creek Formation, Westgate Formation and Barrons Sandstone. Location NW1/2,S27, T18,R3W5.

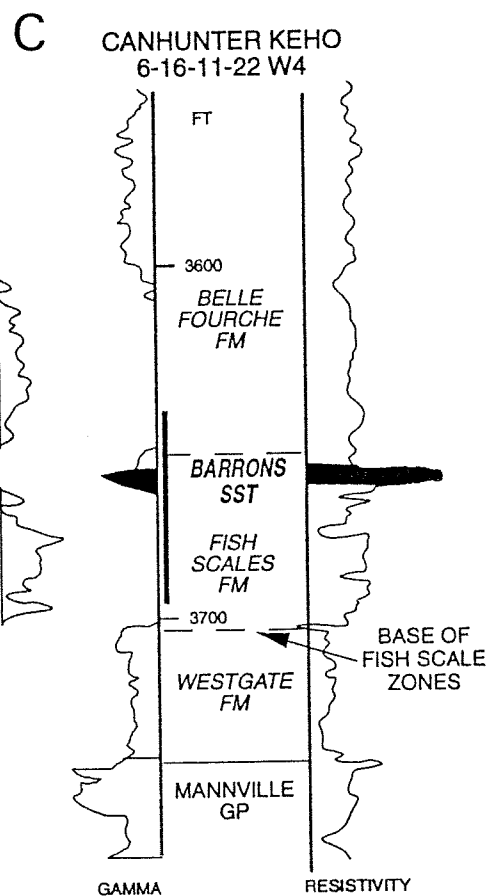
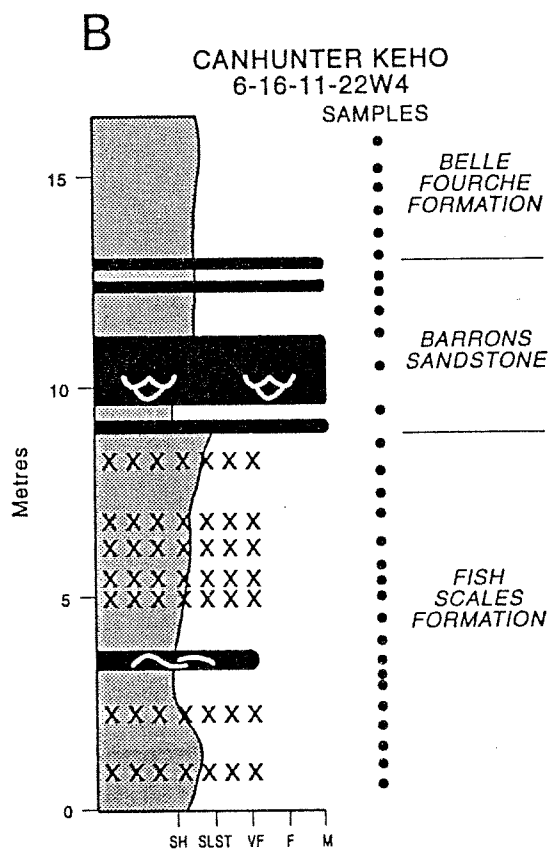
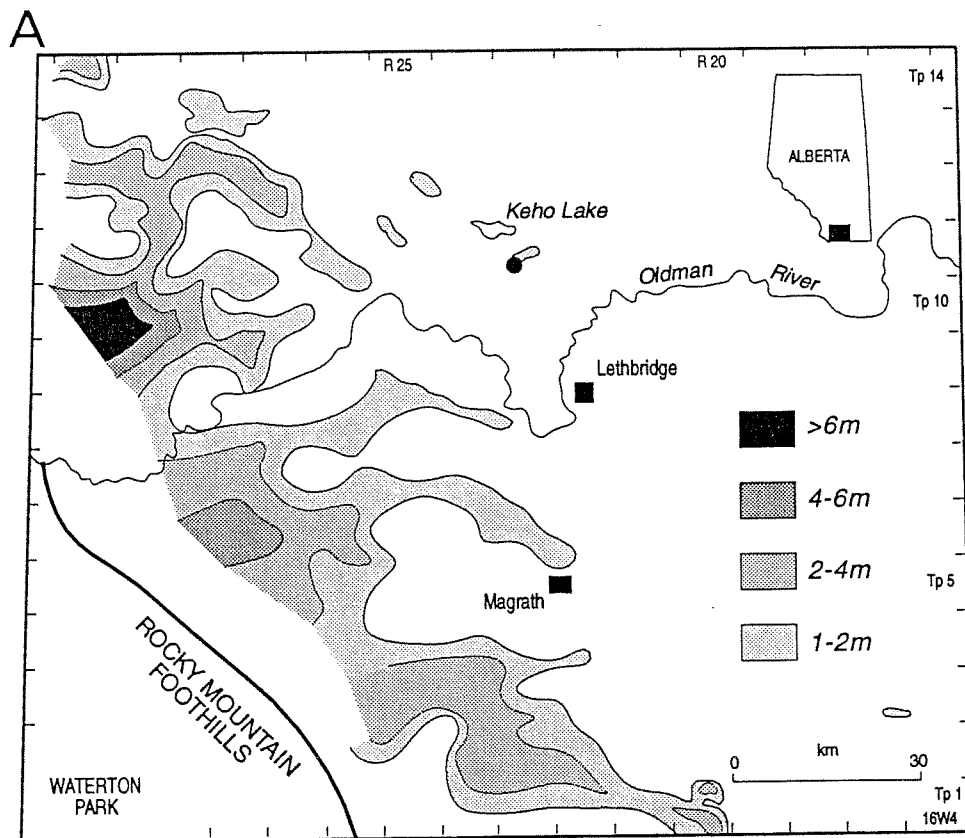


Figure 30. A) Isopach map of the Barrons Sandstone in the subsurface. B) Core from Canhunter Keho 6-16-11-22W4. C) Wireline log from Canhunter Keho 6-16-11-22W4.

crossbedded and parallel laminated. In the underlying sandstone you see no precursors of the conglomerate. About 10 m from the base the conglomerate consists of parallel-bedded gravels about 30-40 cm thick alternating with 10-15 cm thick pebbly, sandier layers parallel laminated. The conglomerate is overlain by about 20 m of fine to medium grained, chloritic sandstone. Wood at base of conglomerate is oriented ENE; basal grooves are oriented 70° and 65°. Crude imbrication indicating flow towards 130°. From ridge to ridge consider an approximate trend of the channel is about due east which would project eastwards to the north side of Longview hill.

HYDROCARBON PROSPECTS IN SOUTHERN ALBERTA

Large reserves of gas and oil have been discovered in southern Alberta and this area is still being actively explored. Most of the gas is produced from either very shallow Upper Cretaceous reservoirs in the Medicine Hat area or from either very deep Paleozoic reservoirs in the Foothills. Most oil is derived from either the Glauconite or Lower Mannville intervals in the Lower Cretaceous. Additional production is also developed in sandstones of the Bow Island (Viking equivalent), the Jurassic Sawtooth and Swift sandstones, and from the Devonian Nisku and Wabamun carbonates but these reservoirs will not be discussed in this article.

SHALLOW GAS PRODUCTION IN SOUTHERN ALBERTA

The Upper Cretaceous shallow gas fields of southern Alberta were first discovered in 1883 when the CPR encountered gas flows in a water well drilled near Medicine Hat. At present, approximately 20000 wells produce gas over a 9266 square km area. In excess of 10.5 tcf of gas (approximately 10% of Canada's reserves) are hosted in the Milk River, Medicine Hat, and Second White Specks sandstones.

Initial production from typical wells is from 7000-9860 m³ per day (250-350 MCFD) but these rates typically decline by 50% after the first year and an additional 25% after the second year. Because of limited permeability, up to 4 wells per section may be required to drain the reservoir. Although gross pays typically exceed several tens of meters, the net pay is on the order of 1-5 m as most reservoirs consist of thin siltstone and fine sandstone and laminae interbedded with shale. Most of the gas is produced from an offshore facies equivalent of the sandstones we will be examining at Milk River outcrops.

Porosities are typically very low (8-10%) and the high clay content creates very low permeabilities which are particularly susceptible to formation damage. The chemical and isotopic composition of the gas indicates that it is of biogenic origin (i.e.) it is generated by anaerobic bacteria at a very low level of maturation (prior to the onset of oil generation). Porous west sandstones are located updip from the field and the trapping mechanism is apparently related to relative permeability of gas and water in a low permeability strata, analogous to that described by Masters (1979) in the Deep Basin of northern Alberta.

FOOTHILLS GAS IN SOUTHERN ALBERTA

Some of the most prolific gas reservoirs in Alberta are located in the southern Foothills. Although the 1913 Turner Valley discovery demonstrated that large accumulations of hydrocarbons were trapped in some of the Foothills structures, it was almost 40 years before additional fields were discovered in southern Alberta. The advent of refined seismic techniques was in part responsible for these discoveries as the structures were much deeper and had less obvious surface expression than Turner Valley. These fields are characterized by very thick pay zones but relatively low porosity and permeabilities. This point is best illustrated by discussing the history of the discovery well at Waterton, which is the largest of these foothills fields. The well was almost abandoned due to poor DST results as it tested flows of only 340 MCFD which decreased to 240 MCFD after only 30 minutes. A decision was made to run pipe and after cleanup and acidization, this well flowed at 4 MMCFD with a CAOF of 37.5 MMCFD. Many of the subsequent wells drilled on the structure had CAOF exceeding 100 MMCFD and a few had CAOF exceeding 1 BCFD.

LOWER CRETACEOUS OIL AND GAS IN SOUTHERN ALBERTA

Significant reserves of medium gravity crude oil and gas have been proven in the Lower Cretaceous Glauconite and Taber-Cutbank (Basal Quartz) intervals of southern Alberta. The Lowermost Cretaceous unit exposed in most of south central Alberta is the Taber or Cutbank Sandstone. This unit may be equivalent to the conglomerates of the Cadomin Formation, which we will see in outcrops at the Gladstone Creek and Adanac. It is a blanket-like, clean sandstone which is considered to have been deposited by a northwesterly flowing braided river system. The Cutbank is disconformably overlain by bentonites, marls and fossiliferous limestones of the Calcareous Member (Ostracode equivalent) which were deposited in a large brackish standing body of water termed the Calcareous Sea. Two stages of channeling postdate deposition of this Calcareous-Ostracode unit. The first stage is represented by immature feldspathic sandstones which were deposited in a deltaic complex which prograded northeasterly into The Calcareous Sea. The clean highly quartzose sandstones of the Glauconite member were deposited in a series of northwest trending channels which were probably incised into the floodplain during a subsequent major drop in sea level. Blocky and fining upward sandstone bodies up to 30 metres in thickness form discontinuous reservoirs in these incised channel trends and oil may also be trapped in the Lower Mannville where an impermeable channel facies truncates the porous Taber sandstone updip.

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CrowsnestAssay

Sample #	Formation	Au	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U	Th	Sr	Cd
c178410	Mill Creek	10	6	5	11	9	0	4	1	28	1	7	5	1	2	1
c178421	Mill Creek	0	1	6	11	45	0	10	5	481	1	8	5	1	116	1
c178422	Mill Creek	0	1	14	15	86	0	16	6	109	1	3	5	2	8	1
c178428	Mill Creek	0	1	9	27	42	0	1	6	513	2	2	5	1	468	1
c178430	Mill Creek	0	1	30	16	38	0	3	4	325	1	7	5	3	91	1
c178434	Mill Creek	0	9	10	11	41	0	16	5	322	1	29	5	1	77	1
c178437	Mill Creek	50	1	9	14	56	0	18	5	421	2	9	5	3	91	1
c178439	Mill Creek	10	1	12	35	85	0	13	9	714	3	2	5	2	99	1
c178441	Mill Creek	0	1	16	17	31	0	3	5	660	2	52	5	2	84	1
c178442	Mill Creek	45	1	5	19	47	0	2	3	374	1	4	5	3	155	1
c178448	Blackstone	10	1	5	16	10	0	2	1	144	0	2	5	9	37	1
c179813		0	1	33	10	79	0	32	13	831	4	14	5	5	35	1
c179814		0	1	39	4	87	0	20	12	955	4	22	5	3	49	1
c179815		20	1	43	9	92	0	25	14	906	5	21	5	2	39	1
c179818		15	1	22	6	79	0	17	9	821	4	13	5	2	25	1
c179819		0	1	24	12	91	0	20	9	504	4	15	5	2	23	1
c179831		25	1	9	9	19	0	6	3	53	1	4	5	1	3	1
c179835		0	1	15	14	69	0	13	5	88	1	2	5	1	8	1
c179844		0	1	13	15	61	0	17	10	686	2	14	5	1	20	1
c179845		0	1	11	11	75	0	18	9	384	2	74	5	2	55	1
c179846		0	1	11	13	51	0	14	5	1363	2	12	5	3	74	1
c179847		0	1	9	12	34	0	9	3	2240	1	12	5	2	111	1
c179848		10	1	11	8	45	0	6	2	10252	1	2	5	2	124	1
c179863	Mill Creek	0	1	5	9	41	0	5	3	530	2	5	5	3	147	1
c179864	Mill Creek	0	3	7	10	13	0	4	2	30	2	12	5	2	23	1
c179866		0	1	20	19	90	0	19	10	2310	3	15	5	3	85	1
c179867		0	1	18	11	54	0	13	4	1848	2	4	5	3	86	1
c179869		0	1	20	9	39	0	7	4	2531	2	6	5	4	233	1
c179870		40	2	7	669	100	5	11	6	115	2	260	5	5	24	1
c179871		10	1	31	12	80	0	18	8	822	4	22	5	5	67	1
c179885		10	1	22	9	56	0	19	7	416	2	11	5	3	20	1
c179890	Mill Creek	0	1	20	10	67	0	18	8	576	3	11	5	2	129	1
c179892	Mill Creek	0	1	30	11	94	0	19	10	628	5	25	5	2	57	1
c179893	Mill Creek	0	2	63	10	122	0	26	12	709	6	25	6	3	25	1
c179901	Mill Creek	20	3	7	7	42	0	12	4	2276	1	20	5	1	60	1
c179902	Mill Creek	0	1	16	18	87	0	9	5	1129	3	19	5	5	30	1
c179903	Mill Creek	0	1	5	15	55	0	4	2	892	2	2	5	1	39	1
c179904	Mill Creek	80	1	4	15	48	0	5	3	1200	1	2	5	9	115	1
c179918	Mill Creek	0	1	23	11	84	0	23	9	506	4	2	5	2	184	1
c179922	Mill Creek	0	2	11	14	87	0	28	5	153	1	20	5	1	32	1
c179923	Mill Creek	0	8	9	13	64	0	14	4	556	1	210	5	2	205	1
c179924	Mill Creek	0	9	2	13	4	1	3	1	30	1	12	5	1	162	1
bottom	Crowsnest	0	1	70	16	31	0	1	1	820	1	2	5	3	2244	1
middle	Crowsnest	10	1	220	66	156	0	1	11	1308	5	11	8	18	769	1
top	Crowsnest	10	1	249	61	135	0	1	11	1344	5	7	5	17	576	1
c179889	Mill Creek	0	7	15	9	74	0		10	470	3	15	5	1	20	1

CrownsnestAssay

Sb	Bi	V	Ca	P	La	Cr	Mg	Ba	Ti	B	Al	Na	K	missing
2	2	8	0.02	0.01	2	121	0	15	0	8	0.4	0.01	0.03	
2	2	23	4029	0.07	3	80	0.4	47	0	8	364	0.01	0.07	
2	2	22	0.19	0	8	79	0.1	68	0	6	0.8	0.01	0.09	
2	2	13	1.19	0.03	77	9	0.2	408	0	2	1.2	0.04	0.08	
2	2	78	1.04	0.02	18	14	0.2	143	0	5	0.9	0.01	0.13	
2	2	24	3.11	0.05	4	78	0.2	53	0	10	0.5	0.01	0.06	
2	2	24	2.64	0.07	9	57	0.4	90	0	8	0.9	0.01	0.08	
2	2	27	1.21	0.04	14	41	0.4	281	0	8	1.5	0.03	0.15	
2	2	54	1.1	0.02	25	45	0.4	166	0	7	1.1	0.02	0.11	
2	2	10	0.73	0.02	18	36	0.4	327	0	6	1.1	0.02	0.08	
2	2	3	0.62	0	18	35	0.1	138	0	5	0.5	0.01	0.07	
2	3	85	0.52	0.07	17	71	0.1	251	0.1	5	202	0.02	0.07	
2	2	101	0.81	0.06	8	59	0.1	418	0.2	9	2.3	0.03	0.07	
2	2	111	0.56	0.06	10	60	0.4	423	0.1	10	2.5	0.02	0.09	
2	2	83	0.59	0.06	13	68	0.9	82	0.1	7	2.1	0.02	0.08	
2	2	88	0.54	0.07	16	75	0.9	157	0.2	10	2	0.02	0.09	
2	2	18	0.05	0.01	2	142	0.1	28	0	6	0.2	0.01	0.03	
2	3	15	0.08	0	2	66	0.1	154	0	6	0.6	0.01	0.02	
2	2	26	0.24	0.05	8	135	0.4	363	0	6	1.1	0.01	0.05	
2	2	35	0.66	0.07	7	65	0.5	982	0	6	1.2	0.01	0.1	
2	2	22	3.59	0.05	10	71	0.5	149	0	6	1.2	0.01	0.11	
2	2	15	6.14	0.03	6	63	0.2	252	0	5	0.7	0.01	0.09	
2	2	22	10.3	0.04	10	49	0.3	192	0	6	0.8	0.01	0.11	
2	2	20	2.54	0.09	18	64	0.2	113	0	12	0.6	0.01	0.12	
2	3	20	0.8	0.07	8	61	0.2	34	0	10	0.6	0.02	0.11	
2	2	38	3.98	0.04	12	67	0.4	715	0	7	1.4	0.02	0.09	
2	2	35	4.48	0.05	13	73	0.3	198	0	8	1	0.01	0.11	
2	2	36	12.7	0.04	15	48	0.3	264	0	8	0.9	0.01	0.11	
2	2	11	0.48	0.07	17	36	0.1	70	0	9	0.3	0.01	0.15	
2	2	95	1.29	0.06	19	82	0.8	220	0	9	1.9	0.01	0.12	
2	2	40	0.26	0.06	9	92	0.6	109	0	9	1.3	0.01	0.11	
2	2	58	1.29	0.05	10	50	0.7	106	0.2	9	2.9	0.02	0.12	
2	2	110	0.58	0.06	9	48	1.4	348	0.2	7	2.6	0.03	0.08	
2	3	129	0.52	0.06	8	50	2	110	0.2	5	3.1	0.01	0.11	
2	2	23	4.59	0.07	5	71	0.1	65	0	9	0.4	0.01	0.05	
2	2	61	0.77	0.03	24	54	0.5	182	0.1	6	1.7	0.02	0.12	
2	3	55	1.53	0.02	41	35	0.3	144	0.1	4	0.9	0.03	0.05	
2	3	8	3.94	0.03	44	44	0.3	180	0	3	0.9	0.02	1	
2	3	75	0.59	0.01	46	43	0.6	392	0	2	2.5	0.01	1	
2	3	29	0.2	0.05	3	74	0.3	51	0	9	1	0.01	1	
2	3	27	6.38	0.09	6	62	0.3	56	0	2	1	0.01	1	
2	2	13	0.05	0.01	7	122	0	50	0	2	0.1	0.01	1	
2	2	33	2.63	0.03	40	13	0.1	304	0.1	2	1.3	0.19	2	
2	2	222	2.14	0.08	65	14	0.3	108	0.1	6	1.2	0.03	2	
2	2	216	2.86	0.08	74	15	0.3	76	0.1	2	2.3	0.65	1	
2	2	33	0.52	0.07	14	47	0.4	217	0	2	1.7	0.02	1	