The Sedimentary Environment of the Late Cretaceous St. Mary River Formation, Southwestern Alberta

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Honours Thesis

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TABLE OF CONTENTS

LIST OF FIGURES

List of Figures (Cont'd)

LIST OF TABLES

Abstract

It is the purpose of this study to interpret the sedimentary environment which produced the St. Mary River Formation (SMRF). This study attempts to expand on the preliminary sedimentological work of previous authors by integrating outcrop and subsurface data.

The data base used includes the formation in outcrop where a 95m vertical section was measured, well logs, seismic profiles and published reports. The interpretation is based on the geological setting as established from the literature, the stratigraphic relationships as determined from well logs, and a facies analysis from sedimentary facies identified in the measured section.

A review of the structural setting from the literature is undertaken as a prerequisite to interpreting the sedimentary environment. A new structural cross-section is presented based on seismic profiles and exploratory oil wells.

The SMRF is identified on well logs by characteristic resistivity and sonic log character. From logs the formation is subdivided into two members, a thick upper member (405m-470m) and a much thinner basal member (about 30m).

The SMRF is well established in the literature as a terrestrial deposit and is interpreted as a fluvial sequence. Four sedimentary facies are recognized; 1) a mudstone facies, representing overbank deposition from suspension; 2) a trough cross-bedded sandstone facies, representing channel deposits; 3) a rippled sandstone facies, representing overbank deposition of coarse grained sediments onto the flood plain; and 4) a coarsening upward facies, representing the overbank deposits of crevasse splays.

In attempting to interpret a specific fluvial system for the SMRF, several established models were used for comparison. The SMRF shares many attributes of both meandering and low-sinuosity river systems, making a specific system difficult to determine. However, a low-sinuosity river system is preferred.

1. INTRODUCTION

The Saint Mary River Formation (SMRF), of late Campanian-early Maastrichtion age (Wall and Rosene, 1977), is composed of grey, grey-brown and greenish sands, variably well indurated to soft, and interbedded grey and greenish shales and mudstones. The type section is 88 km east of the study area, along the banks of the St. Mary River east of Magrath, where the formation is 354m thick (Williams, 1951). In the study area, the SMRF was recognized on the basis of similar lithology, the occurrence of freshwater bivalve shells, and the identification and dating of fossil flora (Douglas, 1950).

The study area is located in southwestern Alberta in the area of the leading edge of the Rocky Mountain thrust belt (Fig. 1). The outcrop is located along the Oldman River about 25 km north of Lundbreck on Route 22. The measured section is immediately downstream from the Lundbreck Road Bridge, on the north bank of the river. The wells used in the study are located in the Alberta Syncline to the east of the outcrop (Fig. 2). The seismic lines used cross the margin of the Thrust Belt and the syncline, one 18 km north of the outcrop and another in the immediate area of the outcrop (Fig. 2).

The first detailed work in the study area was published by Douglas (1950), as part of a regional study in the Callum Creek, Langford Creek and Gap areas, in the Foothills of southwestern Alberta. Douglas described the SMRF in outcrop, and made the important observation that the section is broken by thrust faults, and the formation is not complete in any one fault slice. Rahmani and Schmidt (1975) measured a small section of the upper SMRF on the south bank of the Oldman River, the first detailed sedimentological study of the SMRF. Lerand (1982[a]) published work on a similar section downstream from the section of Rahmani and Schmidt but slightly higher stratigraphically. Zaitlin (1983) published work on a section which included the section

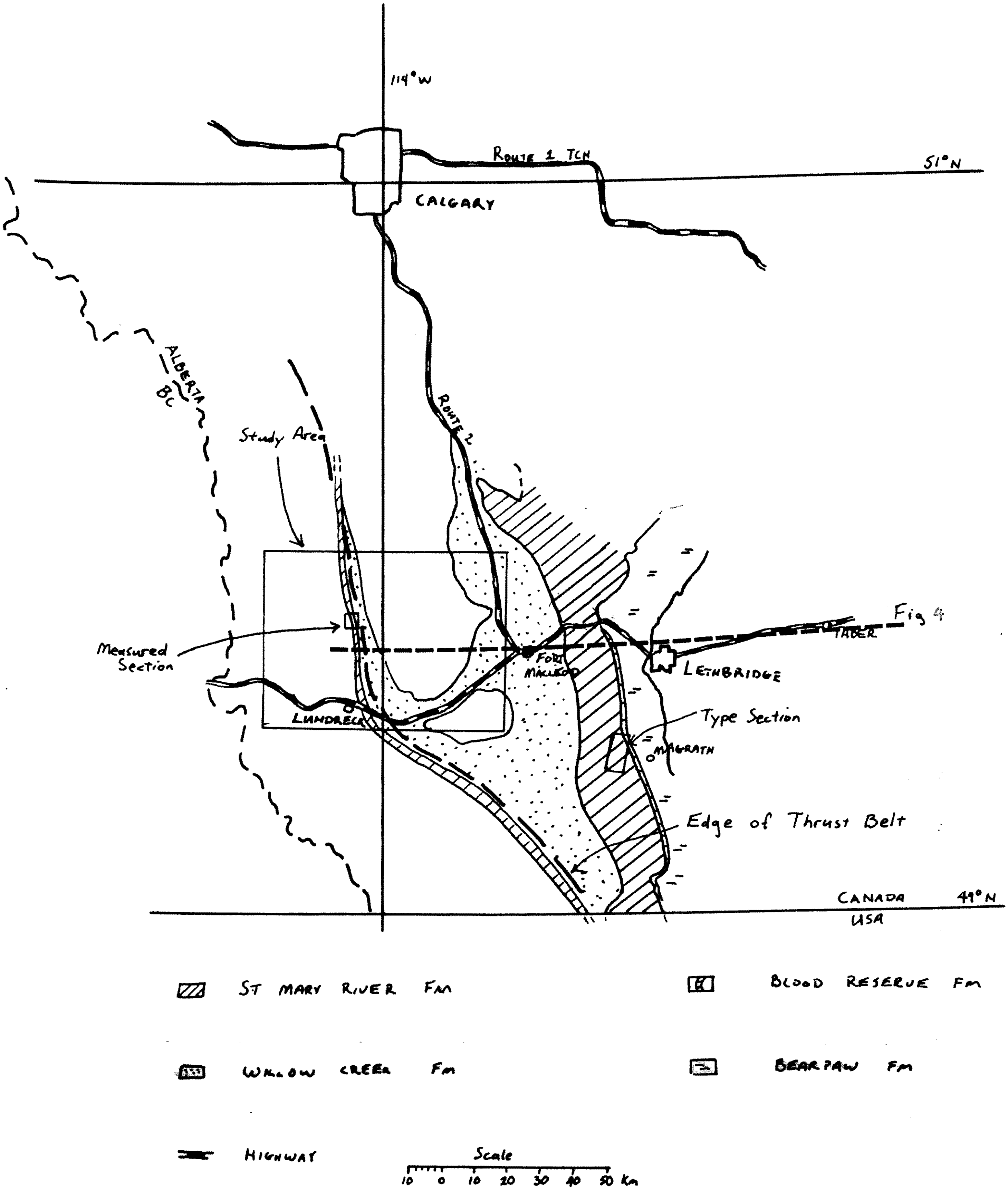
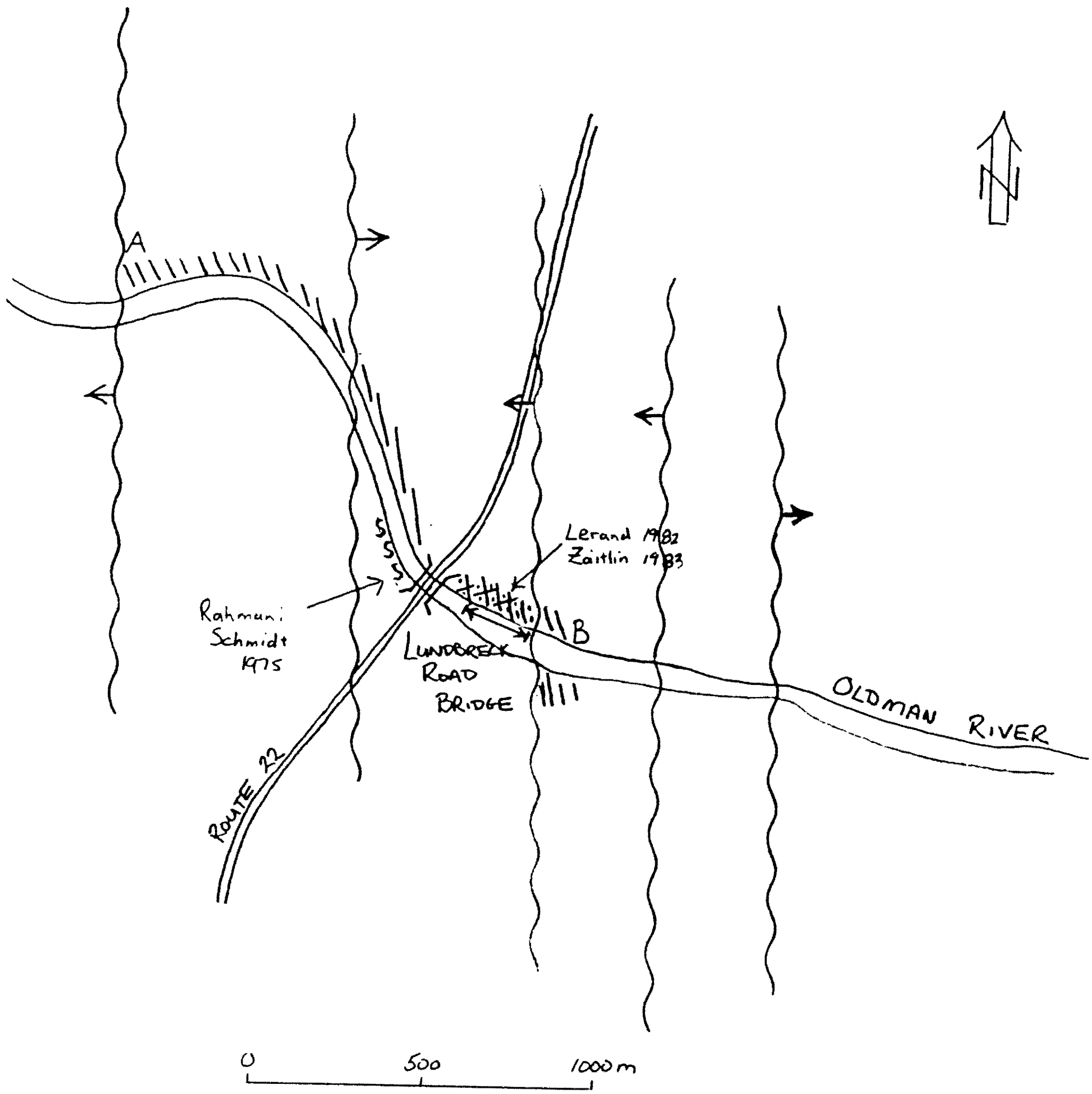


Figure 1. Location map, southwestern Alberta with surface geology. The study area is indicated. (Modified after Canadian Society of Petroleum Geologists, Alberta Geological Highway Map, 1983).

measured by Lerand. Figure 3 shows the measured sections of the previous workers as well as the measured section of this report. It is the purpose of this study to interpret what sedimentary environment produced the sediments of the SMRF based on a sedimentary facies analysis, an understanding of the tectonic setting, and the stratigraphic relationship of the underlying units which preceded the SMRF. The specific data base used is the SMRF in outcrop (along the Oldman River near the Lundbreck Road Bridge), well logs from nearby oil exploration wells, a limited number of seismic lines, and published papers.



A-B The measured section of Douglas (1950).

sss Rahmani and Schmidt (1975).

xx Lerand (1982).

:: Zaitland (1983).

|←→| The measured section of this report.

Figure 3. Sketch map showing locations of SMRF in outcrop studied by previous workers and the measured section of this report.

2. METHODS

This research is based on four sources of information:

1) the formation in outcrop;
2) well logs;
3) seismic profiles and structural maps;
4) published reports.

A reconnaissance of the SMRF, in outcrop in the study area, was undertaken before a detailed examination was started. The entire exposure was scrutinized to observe general lithology, sedimentary structures, and fossils. A section was measured containing representative facies observed over the entire outcrop. Although this section was studied by two previous workers, slight discrepancies and different interpretations prompted this re-examination.

Logs from eleven wells were examined for log character, from which an interpretation of lithology and internal lithologic style, (e.g. fining-upward, coarsening upward), can be made. Well logs are also very useful for stratigraphic studies. The SMRF was identified using the SP, Resistivity, Gamma and Sonic Logs.

The outcrop is located in the Foothills, near the leading eastern edge of the Thrust Belt just to the west of the Alberta Syncline (Fig. 4). Several wells are located within the syncline east of the outcrop (Fig. 2). An interpretation of the current structural geometry allows a correlation between the SMRF in the syncline, where the wells are located, and the SMRF in outcrop, where the rocks are accessible for fieldwork. Although detailed structural mapping was not undertaken by the author, maps are available (Douglas, 1950), from which a geological cross-section has been constructed (Fig. 5). Seismic profiles were interpreted, aided by well control and surface control, that were utilized in constructing the geological cross-section. Using all available data the geological cross-section prepared differs from previously published and commonly used sections (Fig. 6).

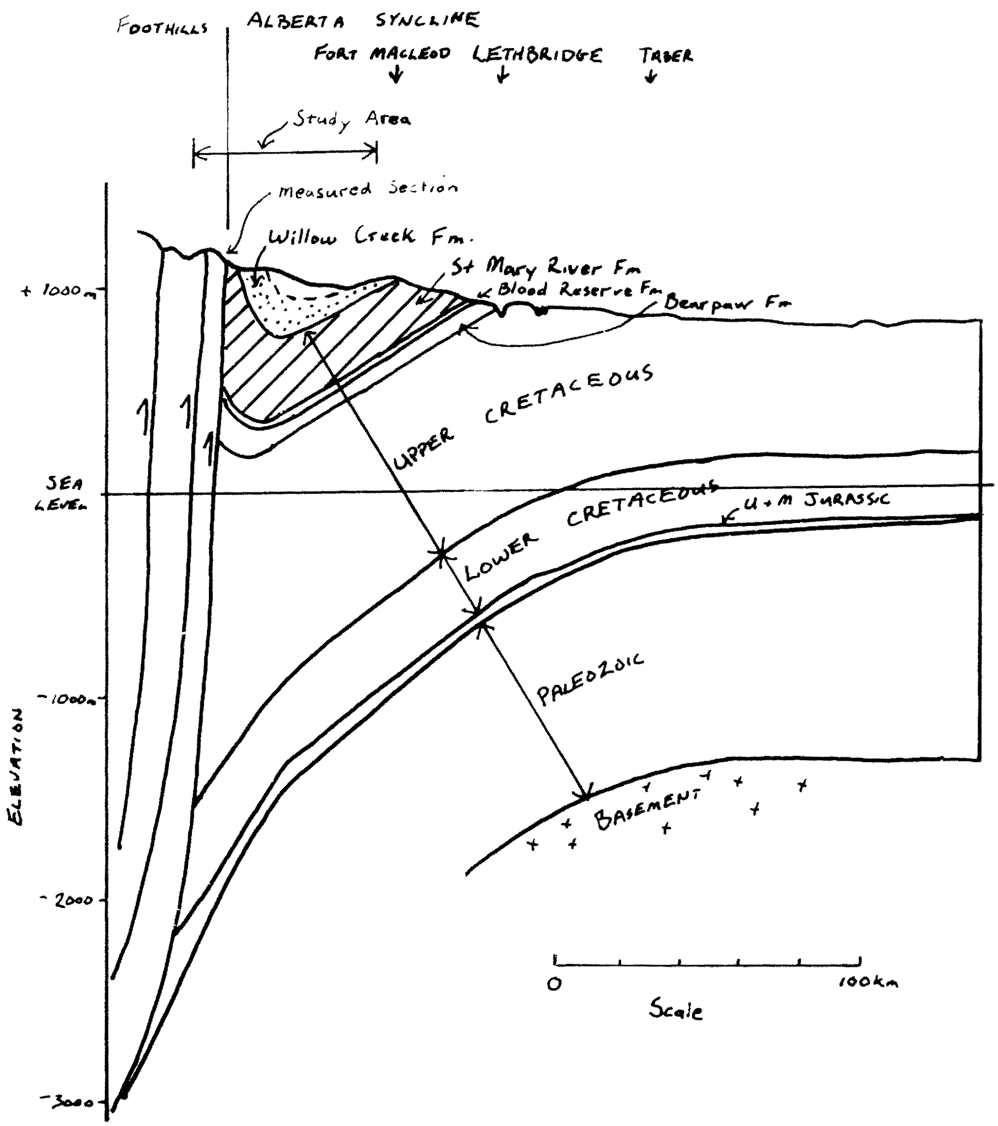


Figure 4. Schematic cross-section of the Alberta Syncline (modified after Canadian Society of Petroleum Geologists, Alberta Geological Highway Map, 1983).

Figure 5. Structural cross-section through the study area constructed using well control, seismic, and surface mapping.

Figure 6. The structural cross-section of Douglas (1950).

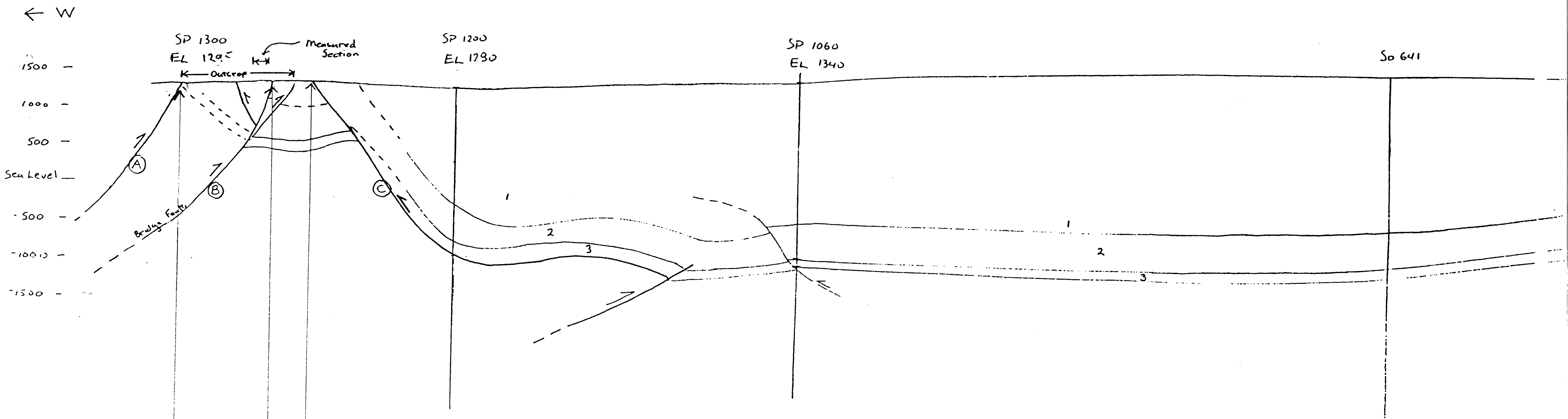
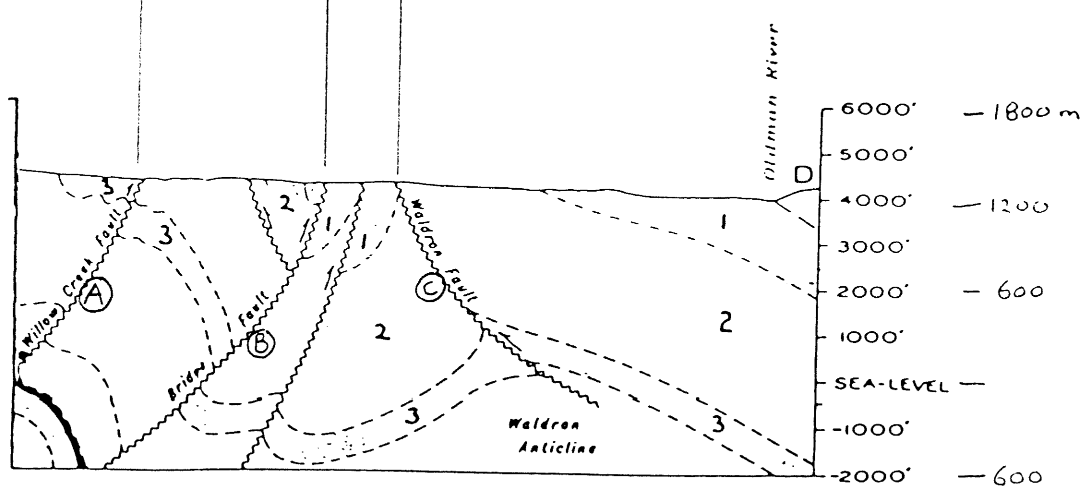


Figure 5.



1) Willow Creek Formation

2) SMRF

3) Bearpaw Formation

(A) Willow Creek Fault

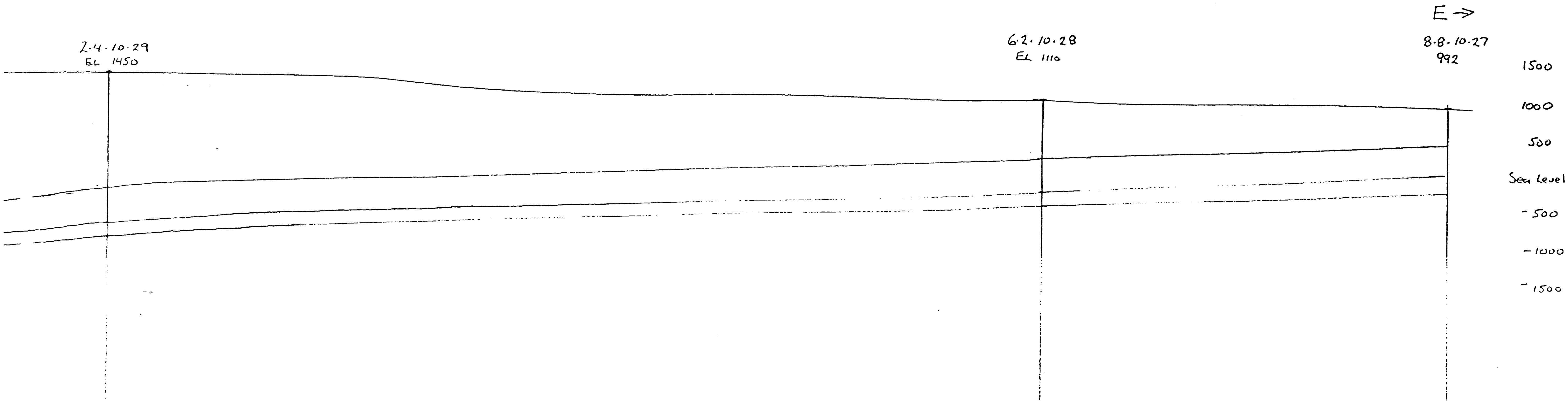
(B) Bridge Fault

(C) Waldron Fault

0 0.5 1.0 2.0 3.0 km

1:50,000

Figure 6. The structural cross-section of Douglas presented at the same scale with three faults lined up for comparison.


E →
2·4·10·29
EL 1450
6·2·10·28
EL 1110
8·8·10·27
992
1500
1000
500
Sea Level
-500
-1000
-1500

A review of previous work done on the SMRF was undertaken, in the study area specifically, and in southwest Alberta more generally. Several workers have studied various parts of the SMRF in outcrop along the Oldman River: Douglas, (1950); Rahmani and Schmidt (1975); Lerand, (1982[a]); Zaitlin, (1983). Other studies elsewhere in the Foothills and in the plains to the east were also reviewed: Russell, (1940); Williams, (1951); Wall and Rosene, (1977). Although each previous worker made reference to various aspects of the geological setting of the SMRF, no attempt was made to synthesize additional information available from seismic and well data.

3. GEOLOGICAL SETTING

Regional structural information on the geological setting of the SMRF is taken from the literature and is based primarily on Douglas (1950), Bally et al., (1966), Campbell (1973), Eisbacher et al., (1974) and Price (1981). It is important to establish the tectonic setting, for the SMRF, as certain settings favour different fluvial systems. The Cretaceous tectonics of the eastern Cordillera is intricately related to the deposition of the SMRF. A review of the major physiographic elements of the Canadian Cordillera is useful to demonstrate the inter-relationships that exist. Figure 7 illustrates the major elements of the Cordillera including the Coast Belt, the Interior Plateau, the Columbia Mountains, the Rocky Mountain Belt and the Interior Plains. Figure 8 is a schematic cross-section through the Cordillera. Figure 9 and 10 provide more detail of the eastern Cordillera which is more directly relevant to the deposition of the SMRF.

During the Paleozoic, and up to mid-Jurassic time, the western flank of the North American craton was a shallow marine platform (Lerand, 1982[b]). Plate movement in mid-Jurassic and early Cretaceous time resulted in a compressional regime which thrust older platform deposits over the western margin of the craton. This period of tectonism produced intrusions, folding, and thrusting which resulted in a tectonically thickened section and created the mountains of the western Cordillera. In addition, a foreland basin, the Alberta Syncline, formed in response to crustal loading (Fig. 4). In this manner, a sedimentary basin was formed, while at the same time an area of high relief was created which discharged an enormous amount of clastic material into the basin. Throughout most of Cretaceous time, a thick clastic wedge prograded eastward filling the foreland basin. The SMRF was one of the latest components of this wedge. Tectonic forelands favour the subaerial accumulation of sediment where fluvial depositional systems may become a dominant component of basin fill (Galloway, 1983). It was in this tectonic setting that the SMRF was deposited in late Campanian - early Maastrichtian time.

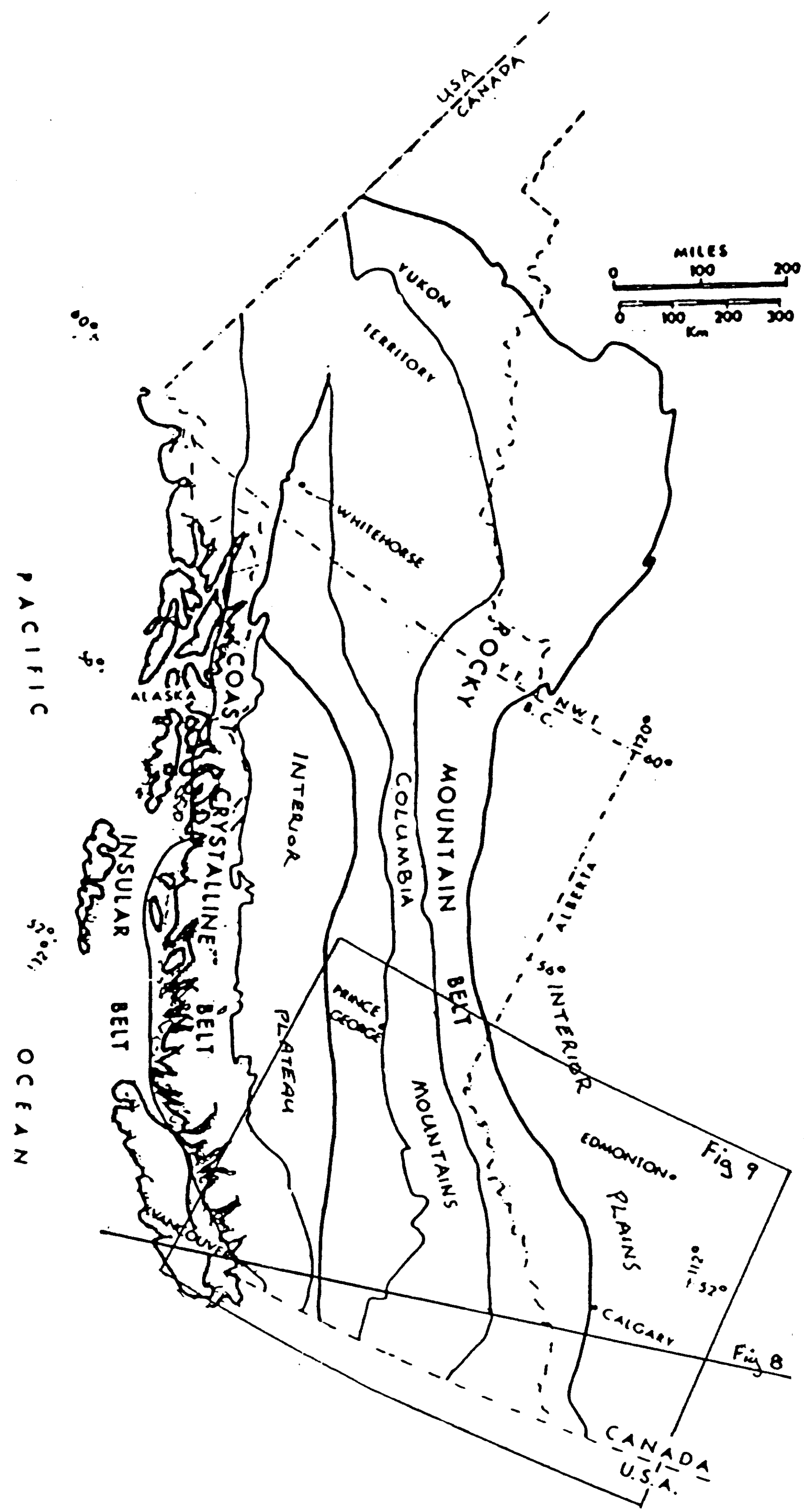


Figure 7. Major physiographic elements of the Canadian Cordillera (after Eisbacher,1974).

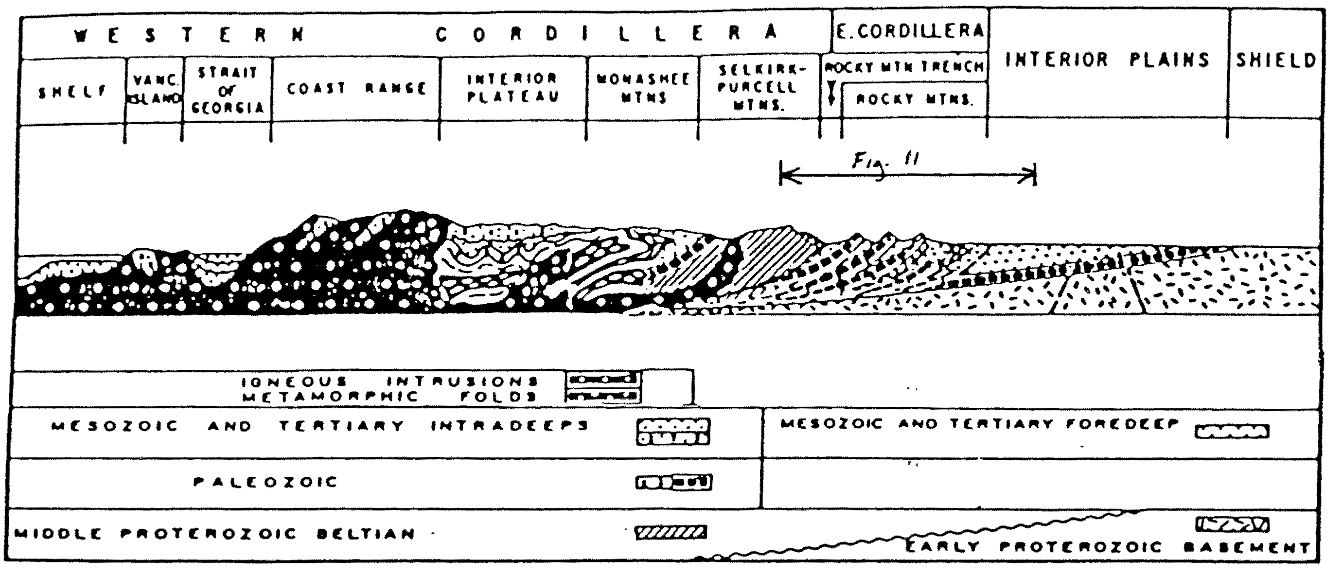


Figure 8. Schematic cross-section of the major structural elements of the Canadian Cordillera (after Bally, 1966).

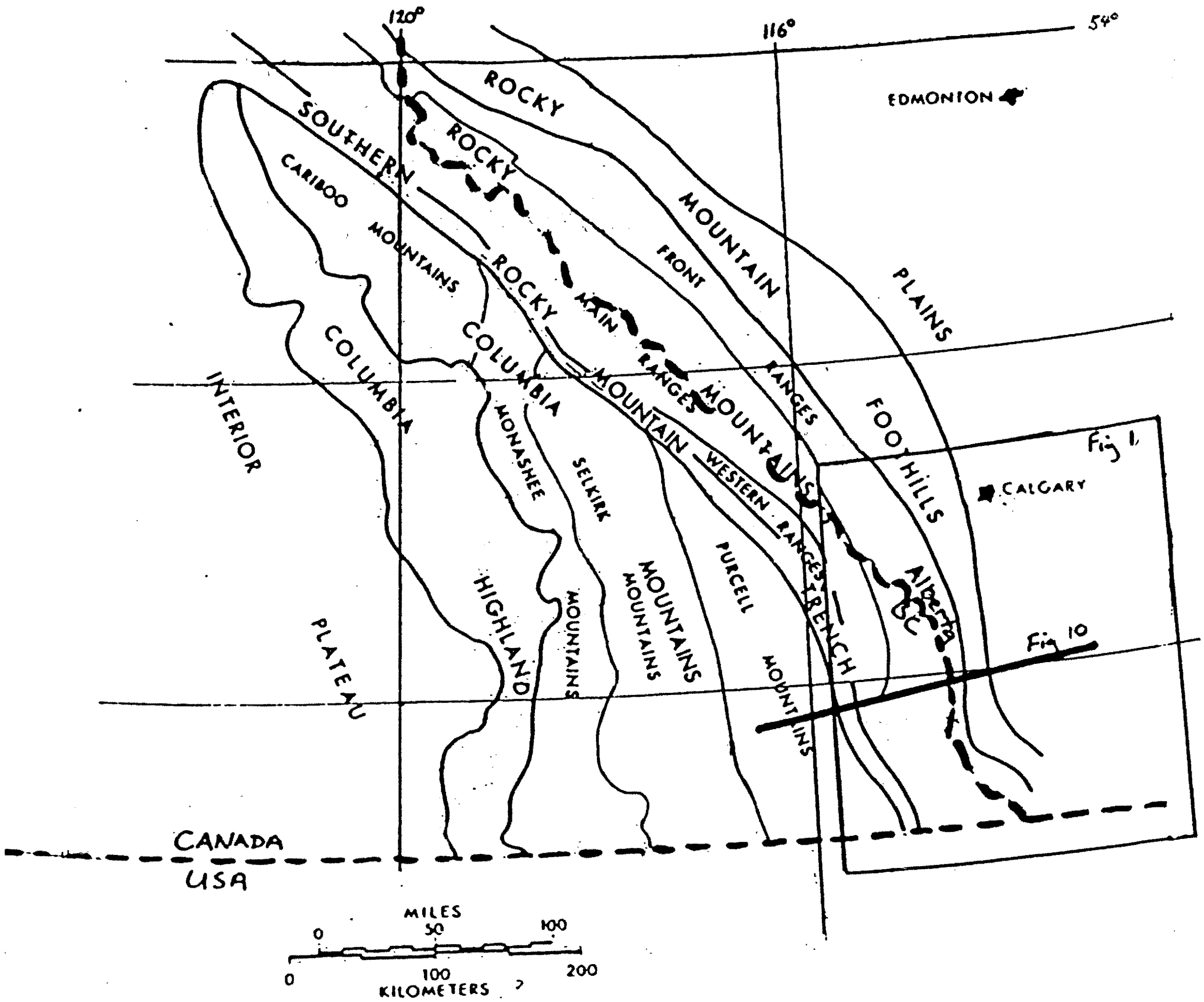


Figure 9. Tectonic framework of the southeastern Canadian Cordillera (after Campbell,1973).

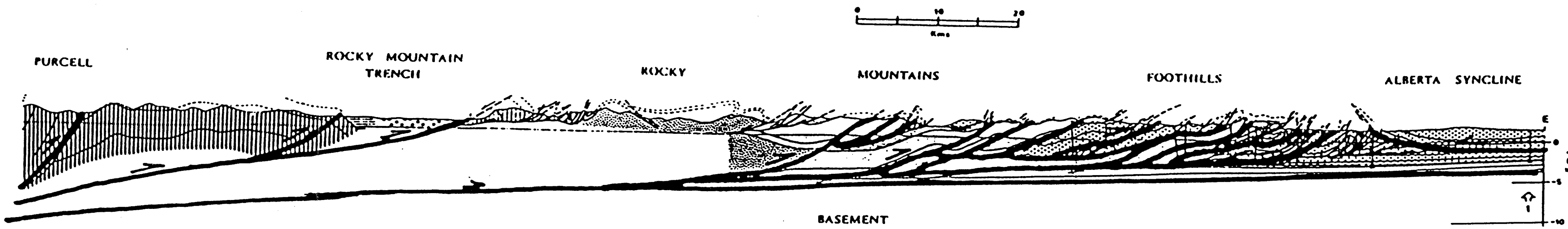


Figure 10. Structural cross-section through the southeastern Canadian Cordillera (after Price,1981).

As plate convergence recommenced in the late Cretaceous, the foreland basin migrated eastward (Fig. 11). It was during this second episode of tectonism that the Rocky Mountains and the Alberta Foothills were formed and the deposits of the SMRF were deformed.

Heavy minerals present in the SMRF indicate that Upper Paleozoic sediments and metamorphic rocks of the western Cordillera and older Mesozoic rocks of the ancestral Rocky Mountains provided clastic material (Rahmani and Schmidt, 1975) (Fig. 12). In figure 11, the upper Mesozoic clastics shown to be derived from the Monashee Mountains (Fig. 8 and Fig. 9) include the SMRF.

During deposition of the SMRF the area of the southern Alberta Foothills lay near the western margin of a broad epeiric sea (Wall and Rosene, 1977). The base of the Upper Cretaceous marks the climax of the transgression of the Cretaceous epeiric sea, which had started in the late Jurassic (Bally, 1966). The final transgression is recorded in the sediments of the Bearpaw Formation after which time marine sediments were overlain by the continental deposits of the late Cretaceous and Tertiary.

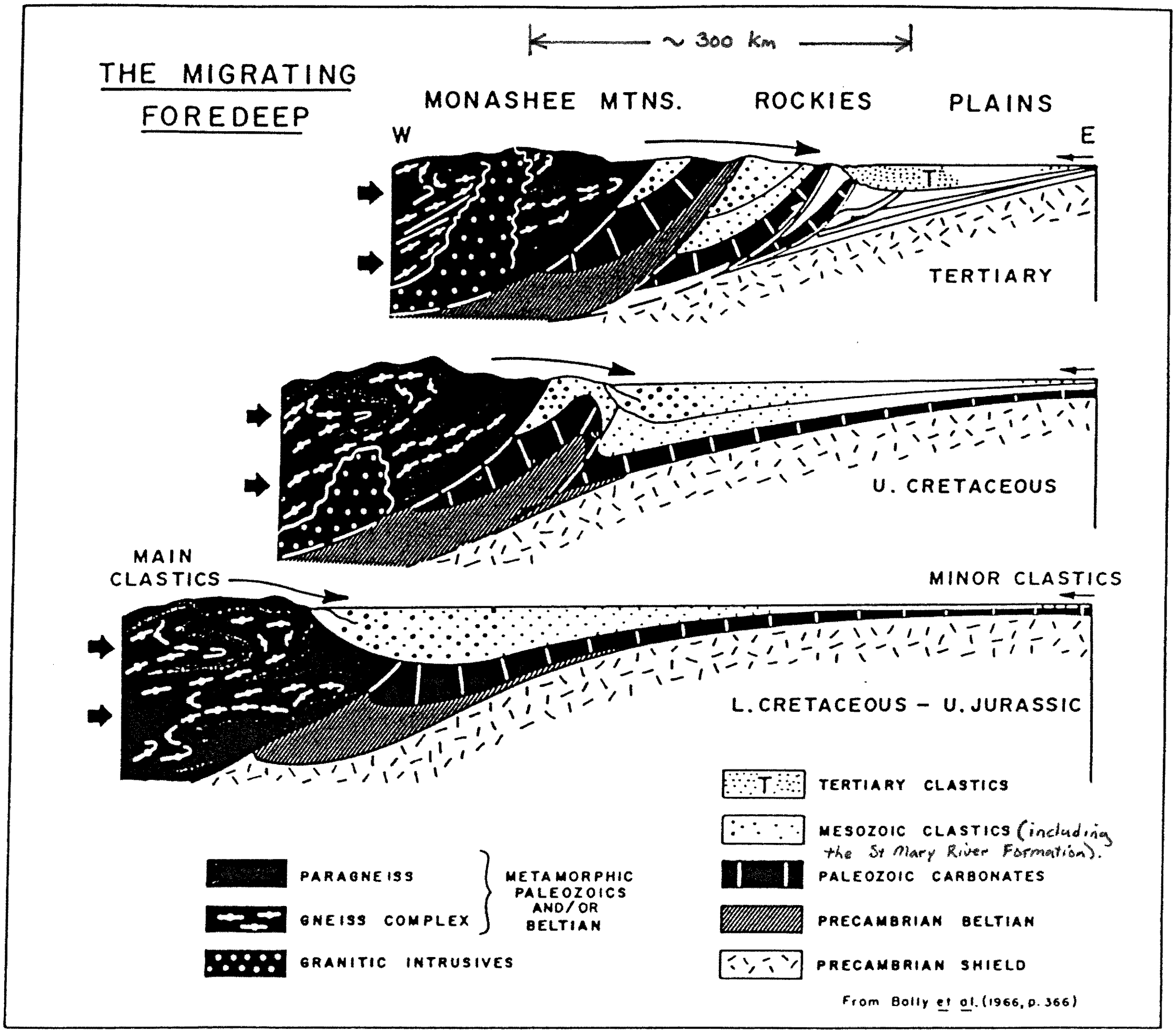
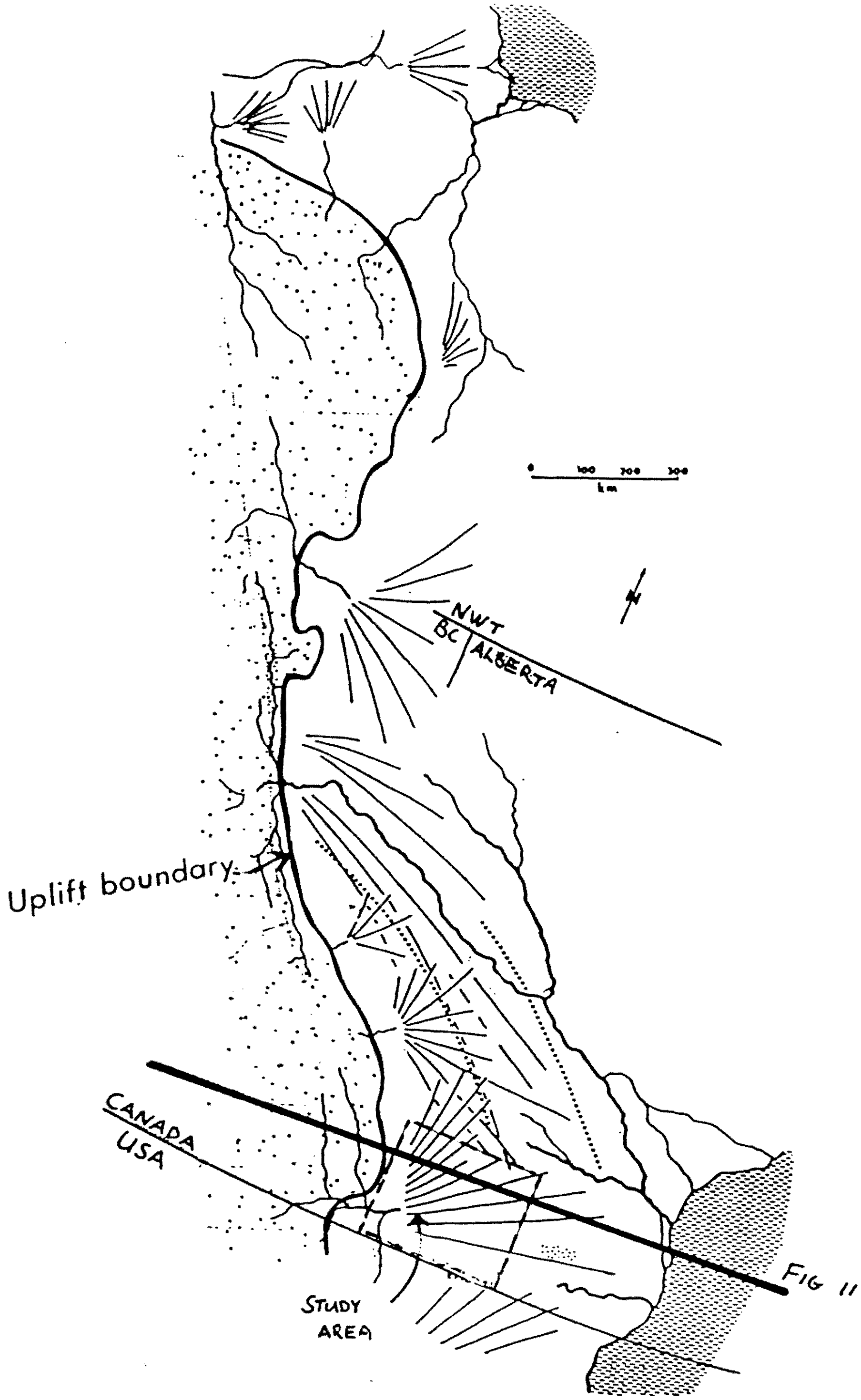


Figure 11. Schematic cross-section showing the development of the foreland basin and the Cretaceous clastic wedge (Bally,1966).



Highland areas developed in the Cretaceous.

Cretaceous epeiric seas.

Figure 12. Provenance area and inferred paleodrainage systems during deposition of the Cretaceous clastic wedge (after Eisbacher, 1974).

4. STRATIGRAPHY

The stratigraphy of the Western Canadian Basin is well documented in the literature. A stratigraphic column illustrates the position of the SMRF in the Upper Cretaceous of southwestern Alberta (Table 1). Although the stratigraphic column provides good background information, the stratigraphic sequence in the study area has been determined more precisely from well logs. The wells, which are located in the relatively undisturbed syncline to the east, contain a complete section, unbroken by faulting. This is in marked contrast to the formations in outcrop which are incomplete and broken by faulting.

Bearpaw Formation

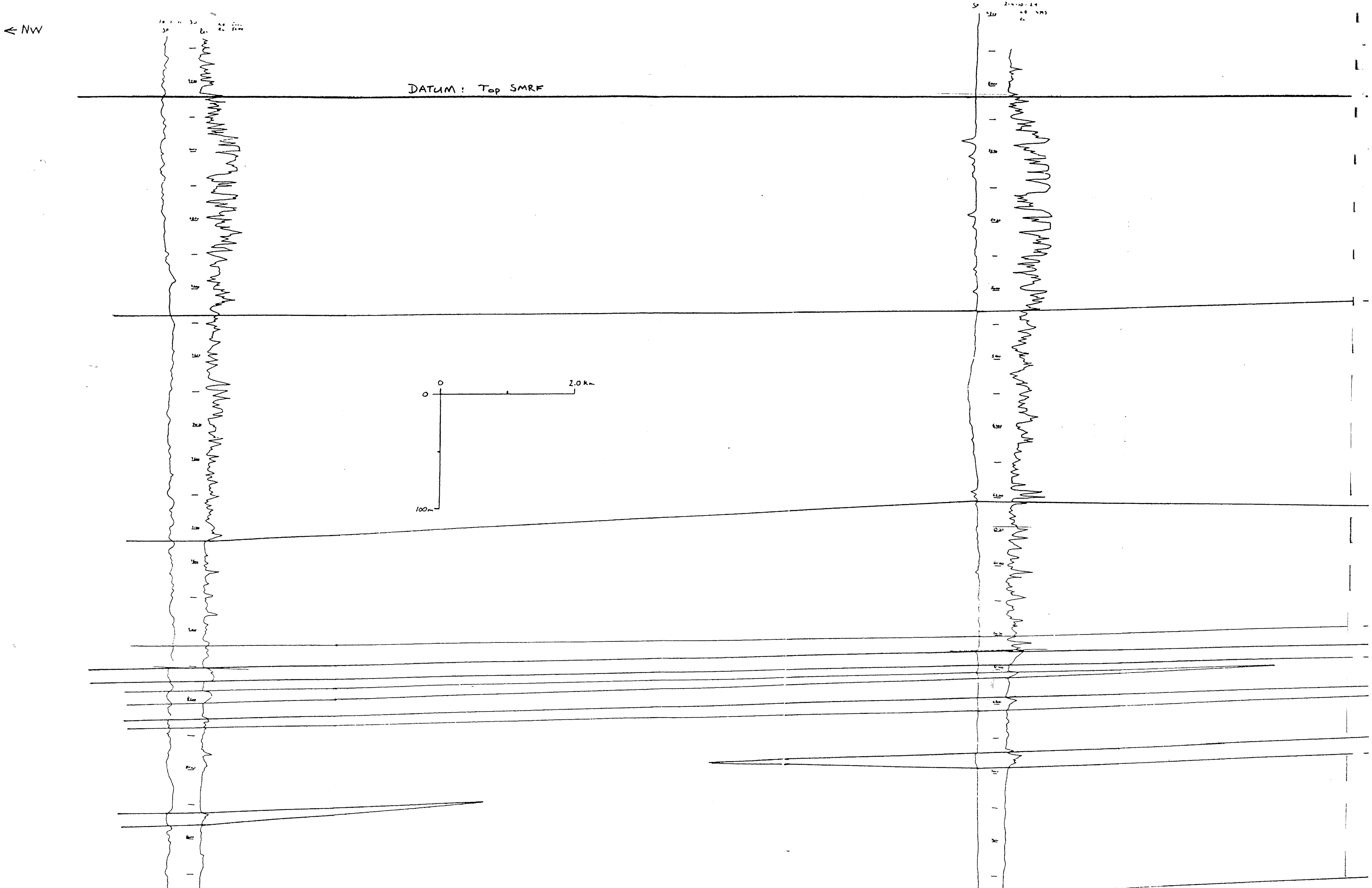
The Bearpaw Formation is described generally as dark grey or brownish grey shale with commonly occurring ironstone concretions and thin bentonite beds (Lexicon, 1960). (The lower part of the SMRF as described by Douglas includes dark grey and brown shales, and thin bentonite beds and some nodular ironstones). Distinctive sandstone members are reported in various localities within the Plains (Wall and Rosene, 1977). These sand bodies are visible on logs in the study area (Fig. 13) and are generally confined to the upper half of the Formation. The lower half of the Formation is composed exclusively of shale. This relatively thick shale provides a good log marker for correlation purposes (Fig. 13).

The Bearpaw Formation represents marine conditions which preceded deposition of the SMRF. In the Oldman River area the regression of the Bearpaw epeiric sea is recorded in the subsurface as a transition zone marking a gradational change from marine shales to continental sandstones and shales. On logs, several coarsening upward sandstone bodies are present in the transition zone which is otherwise predominantly shale. The thickest sandstone unit is at the top of the transition zone. The top of this sandstone is picked as the base of the SMRF on logs (Fig. 13).

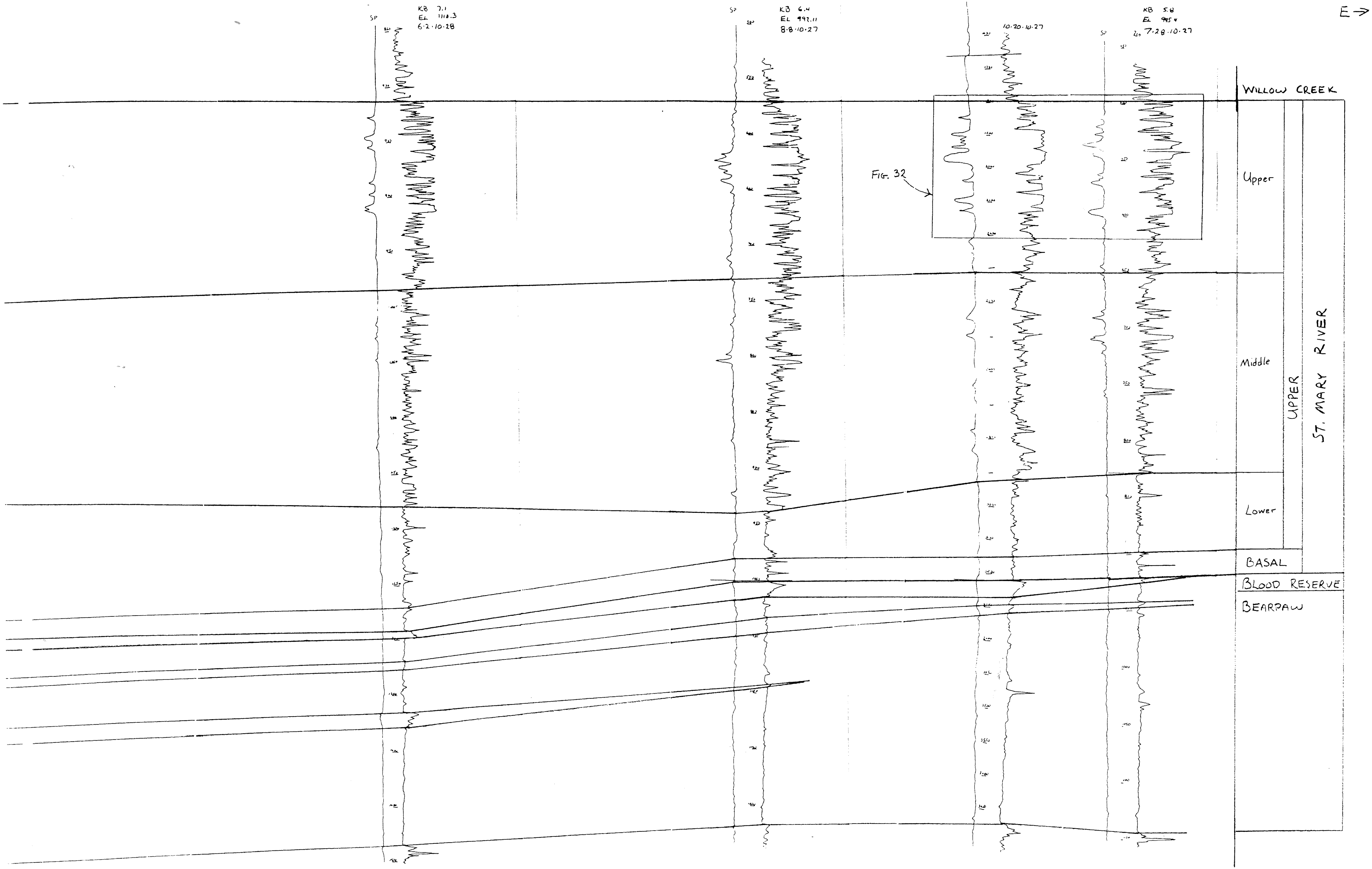
AGE	FORMATION	MEMBER OR UNIT	LITHOLOGY
MAESTRICHTIAN	WILLOW CREEK (LOWER PART)	D	SH, GRN, RED & SS, GY
		C	SS, GY, C.G.
		B	SH, GRN, RED & SS, GY
		A	SH, GY, GRN, PURP & SS, GY
	ST MARY RIVER	UPPER	SS, GY, CAL SH, GY & CARB BEDS
CAMPANIAN		BASAL	SH, GY; SS, GY; COQUINAS, COAL
	BLOOD RESERVE		SS, MASSIVE
	BEARPAW		SH, DKGY, SILTY; CONCRETIONS & BENT SEAMS

Table 1. Stratigraphic table of the Upper Cretaceous formations of southwestern Alberta (modified after Wall and Rosene,1977).

Figure 13. Stratigraphic cross-section constructed using well logs, SP and Resistivity.



← NW
DATUM: Top SMRF
0
0
2.0 km
100m


SP
KB 7.1
EL 1118.3
6-2-10-28
SP
KB 6.4
EL 992.11
8-8-10-27
10-20-10-27
SP
KB 5.8
EL 945.4
7-28-10-27
E →
FIG. 32
WILLOW CREEK
Upper
Middle
Lower
UPPER
ST. MARY RIVER
BASAL
BLOOD RESERVE
BEARPAW

Blood Reserve Formation

In the Syncline, the Blood Reserve Formation, a massive, medium grained, light grey, cross-bedded sandstone, 30-40m thick, occurs between the Bearpaw Formation and the SMRF (Lexicon, 1960). Douglas (1950) did not recognize this unit on the Oldman River, but noted that the interbedded sandstones and shales in the lowest part of the section, below a bivalve fossil marker, may be its equivalent. This is consistent with the observation that the shales of the lower part of the SMRF, as described by Douglas (1950), resemble shales of the Bearpaw Formation. It is possible that a 10m thick sandstone near the base of the SMRF, as measured by Douglas, may be equivalent to the top sand in the transition zone visible on logs, which is taken as a Blood Reserve equivalent. The presence of coal, in Douglas' measured section, about 21m above this unit corresponds very closely to coal present in the wells just above the top sand of the Transition Zone.

St. Mary River Formation

In the study area, Douglas picked the top of the Bearpaw shale as the base of the SMRF. It is important to note that the SMRF is in fault contact with the underlying Bearpaw Formation, on the Oldman River (Douglas, 1950) (Fig. 6).

The measured section of this study is within the upper part of the SMRF. Although the sedimentary facies present in this section are typical of the formation, all facies are not represented. In the absence of a measured section over the entire SMRF exposed on the Oldman River, an attempt has been made to fill in the gaps by synthesizing published reports and subsurface data from wells (Table 2). On the basis of lithological descriptions from the literature and log character, the SMRF has been divided into two members, an upper member and a basal member. The upper member contains an upper, middle and lower part (Table 2).

A formation, being a lithostratigraphic unit by definition, should be recognizable on logs, which measure the physical properties of rocks. Changes in lithology, on which formations are identified, should be reflected in the various curves on the logs. As mentioned above, the upper SMRF is characterized by calcareous sandstones and shales. Such lithologies commonly

Foothills (after Douglas, 1950) lithology		Plains (after Williams, 1951) lithology		Study Area	lithology	log character
Upper ±797m	Sandstones, 1) fine to medium grained, grey, cross-bedded, massive to thinly bedded; 2) medium to coarse grained, grey, commonly cross-bedded, poorly indurated, occur mainly in middle part of formation. Shales, olive-green, grey, carbonaceous, silty, calcareous. Ironstones, dark grey, fine grained, argillacious limestone.	Upper ±326m	Sandstone, fine grained, well indurated, cross-bedded. Sandstone, shaly, poorly indurated. Shale, greenish-grey, green, light grey. Shale, dark carbonaceous minor. Ironstone concretions, calcareous nodules. Freshwater bivalves.	Upper 150–200m	Sandstone, grey, very fine to coarse grained, grey, locally cross-bedded, calcareous, well indurated. Ironstone concretions. Freshwater bivalves.	Highly resistive with corresponding low delta t.
				Middle 175–200m	Shale, greenish grey, sandy, silty, calcareous, carbonaceous. Sandstone, light grey/grey, well indurated, calcareous. Shale, grey, calcareous.	Delta t increases downward within the formation.
				Lower 80m	Shale, dark grey, grey, brown, thin coal laminations. Sandstone, grey, friable in part.	Delta t increases downward within the formation.
Lower ±175m	Sandstones, coarse to medium grained, grey, reddish brown weathering. Shales, dark grey, green, carbonaceous, coal seams. Ironstone beds, oyster coquinas.	Basal ±27m	Sandstone, fine-very fine grained, shale, brownish grey, soft, fissile, minor greenish grey, carbonaceous. Ironstone, coal, fresh-water bivales.	Basal 30m	Shale, dark grey, brown. Sandstone, light grey, fine grained, with chert fragments, coal seams, oyster coquina.	Coal seams with high delta t and high resistivity.
±972m		±350m		435–500m		

Table 2 Characteristic lithologies of the SMRF.

have a higher resistivity and a shorter sonic transit time, (e.g. higher velocity), than noncalcareous clastics. Using these characteristics, the top of the SMRF can be readily identified on the Dual Induction log which measures resistivity of the formation rocks to an electric current, and on the Sonic log, which records sonic travel time through formation rocks. The lower SMRF appears to be less calcareous, is less resistive and has a lower velocity.

The characteristic increase in resistivity, one of the parameters used to pick the top of the formation, is clearly shown on the stratigraphic cross-section, (Fig. 13). The sonic travel time delta t, which increases significantly at the top of the SMRF is not as obvious on logs in the standard presentation. However, three sonic logs have been digitized and reproduced by computer, at a reduced time scale rather than the depth scale used on well logs. This presentation clearly demonstrates the sonic character of the formation, (Fig. 14). The four parts of the SMRF can be seen most readily in Figure 14b.

The three parts of the upper member are recognized by their distinctive delta t's. The basal member is visible as a zone with an anomalously long delta t, representing the low sonic velocity of the coal beds. Coal seams are usually visible on sonic logs as very low velocity anomalies. They may show up on the Induction log as very resistive units, but thin seams may not be resolved by the induction tool. The most diagnostic log feature of a coal seam is a sonic transit time of 400-460 microseconds/metre.

The basal member approximates 30m in thickness in various wells in the study area. On the Oldman River, Douglas assigned 177m to the lower part of the formation. In the syncline to the east, the basal member is 27m thick as measured in outcrop on the St. Mary River (Williams, 1951). This thickness was taken between the Blood Reserve sandstone and the highest coal seam in the SMRF, whereas Douglas' "Lower Part" contains sediments well above the highest coal. From Douglas' measured section, the highest coal seam is 84m above the base of the SMRF. It is interesting to note that there are two coal seams about 30m above a 10m thick sand that may be a Blood Reserve equivalent. This suggests the possibility of an equivalent basal member in outcrop on the Oldman River. (There is a possibility that part of the lower SMRF as measured by Douglas is repeated by faulting, as evidenced by a thick covered section just above these lower coals).

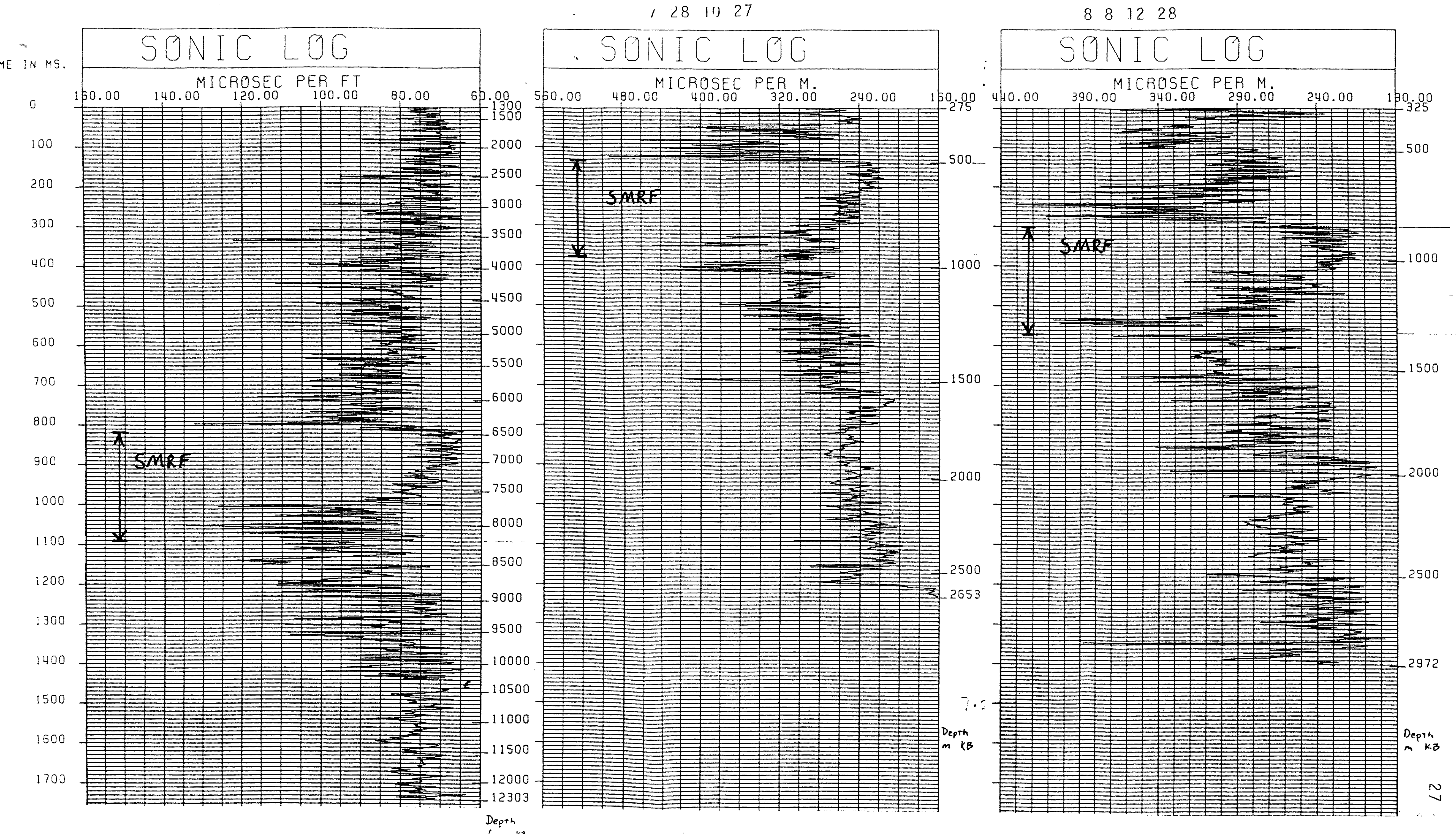


Figure 14. Sonic logs presented in a reduced time scale.

7 28 10 27

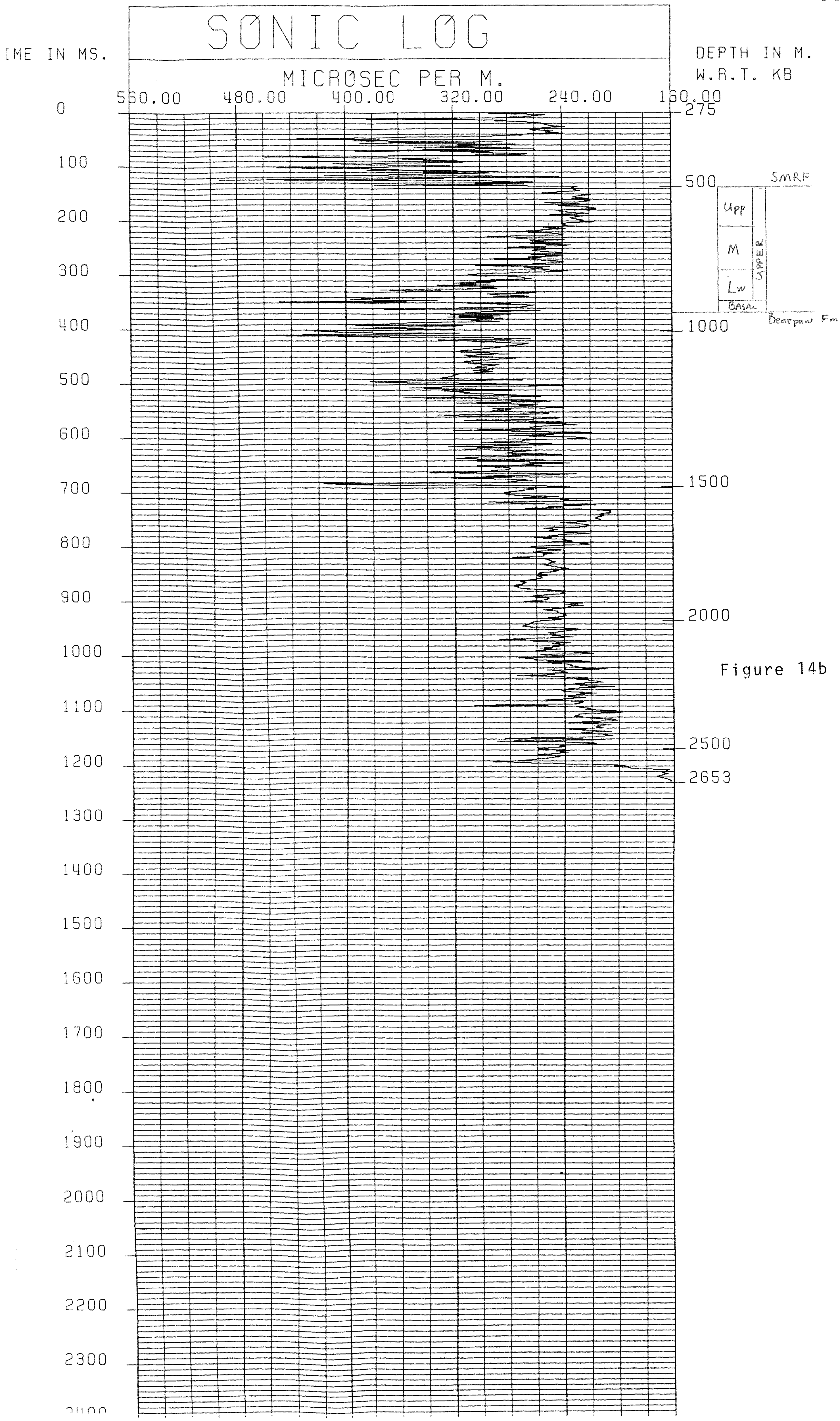


Figure 14b

Willow Creek Formation

The contact between the Willow Creek Formation and the SMRF is not visible in outcrop on the Oldman River. It appears on well logs that the contact is gradational and that the depositional conditions were similar. It appears that sandstone units become less numerous in the Willow Creek Formation, shale becoming the predominent lithology. The sandstones are less well indurated and less calcareous than the sandstones in the upper SMRF (Douglas, 1950).

5. SEDIMENTOLOGY

The measured section is a 95m thick segment of the "upper member" of the SMRF (Fig. 15). Its precise position within the formation cannot be determined, as the contact with the overlying Willow Creek Formation was not observed. As mentioned above, it is surmised that this section is representative of the upper beds of the SMRF. The section is composed of interbedded grey sandstones and greenish grey mudstones or shales, with subordinate coquina beds and local ironstone concretions. The measured section contains 50 units (Fig. 15), which are generally defined by specific beds. However, in many cases where the contact between beds is gradational, two or more lithologies have been grouped in one unit (e.g. units 3, 4, 13, 14, 20, 25, 26, 44, 47, 49 and 50).

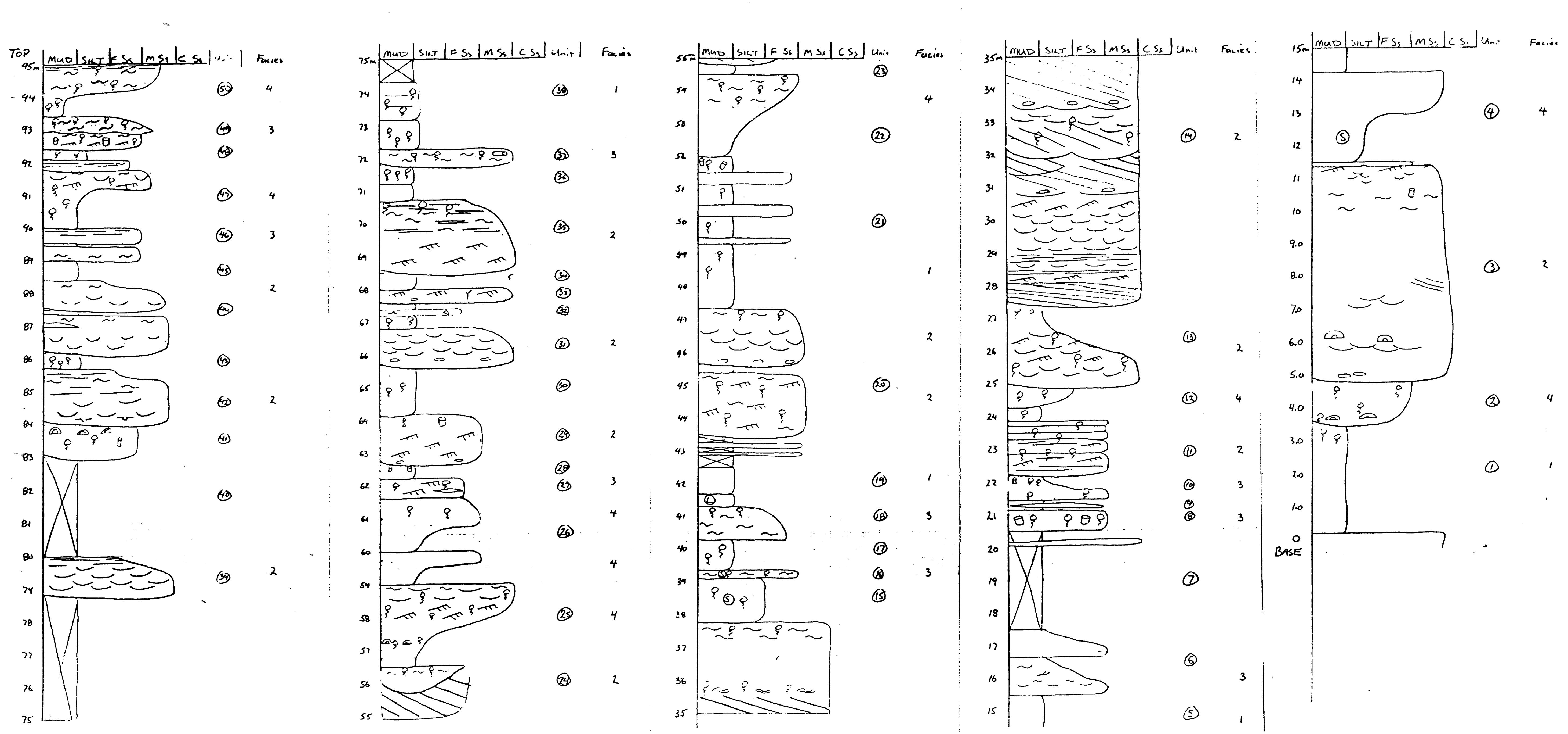
The sediments of the SMRF can be divided into two groups: 1) fine grained units and 2) coarse grained units. The fine members include mudstones, shales and rare siltstones, and the coarse members include very fine to coarse grained sandstones.

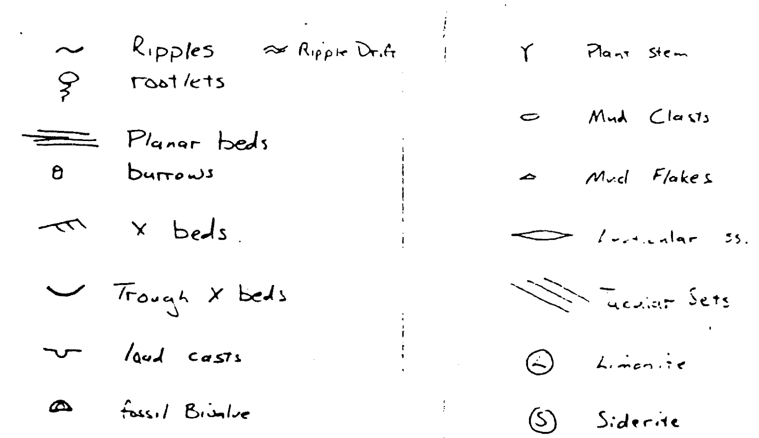
5.1 Fine-Grained Units

Approximately forty percent of the measured section is composed of mudstone and more fissile shale. These beds are dominantly greenish grey to grey, but very rare reddish mudstones were noted (unit 13 top part) and rare dark grey shales are present (units 15, 43). The greenish grey mudstones show colour zonation, usually lighter grey in the upper part, but occasionally alternating bands of light grey and grey (Fig. 16).

The mudstones and shales are fissile to blocky and micro-fractured which has resulted in poor exposure (Fig. 17). In outcrop, weathering has been extensive, with many zones being completely eroded and covered. The thickest fine member units are largely covered (units 7, 21, 38, 40). Including completely covered zones, the maximum thickness is 6.5m (unit 38), but the mudstones are variable in thickness and are as thin as 0.15m (unit 44). The average thickness overall is 1.27m, but of the units greater than 2.0m the average thickness is only 2.1m.

Figure 15 The measured section from the SMRF in outcrop on the Oldman River.


TOP
MUD SILT F Ss M Ss C Ss Unit Facies
BASE


Ripples
Ripple Drift
rootlets
Planar beds
burrows
X beds
Trough X beds
load casts
fossil Bivalve
Plant stem
Mud Clasts
Mud Flakes
Siderite

Many of the mudstone units are extensively rooted, but rootlets are difficult to observe because of the fissile and micro-fractured nature of the sediments. Apparently, root traces provided preferential sites for fractures which contributed to poor preservation.

Sideritic concretions are common in many of the mudstones (units 4 (lower part), 15, 17, 38), and at least one zone contained limonitic concretions (unit 19). These form the ironstones of the SMRF. Rare carbonaceous laminations were found in one unit near the top of the section (unit 47).

5.2 Coarse-Grained Units

As mentioned above, the coarse grained units contain a range of grain sizes. It is important to note that coarse sand sized grains are the coarsest particles present in the measured section, with the exception of rare mudstone intraclasts, which occur as lag deposits. Gravel deposits are not present.

The sandstone units are generally relatively thin with two exceptions. Unit 3 and unit 14 are composite sand units, 6.7m and 10.4m thick respectively. On closer examination, unit 14 is composed of seven separate units, the maximum being 2.5m thick. The average thickness of the remaining sand units is 1.0m, the maximum being 2.1m, unit 35, and the minimum being a 15cm bed within unit 21.

A very significant observation is that the sandstone units are almost exclusively flat topped showing no evidence of erosion (Fig. 16, 18). Other than unit 14, which is composed of multiple sets of stacked sandstone units, each of which scour the preceding members, only three sandstone units have other sandstone units scoured into them (unit 2, 41, 48). Each of these units have erosional bases that scour underlying mudstones. Although several fining-upward sequences were observed (units 3, 6, 10, 13, 14, 18, 20, 24, 29, 31, 35, 39, 42, 44), few of these grade to mudstone (unit 6, 10, 13).

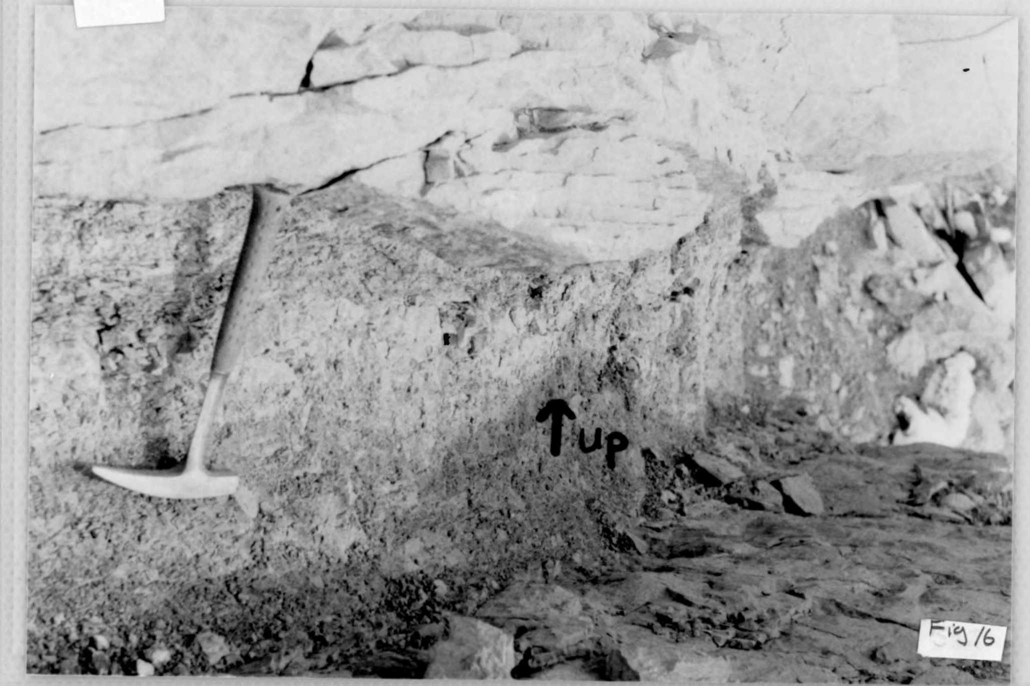
Several coarsening-upward sequences were observed (units 4, 12, 22, 25, 26, 47, 50) (Fig. 15). These sequences invariably start with mudstone at the base and grade upward to siltstone or fine to medium grained sandstone at the top. They usually have flat tops and are overlain by another mudstone unit.

In one case, unit 12, the sequence is eroded at the top by a subsequent sand unit. In this example the coarsest fraction is siltstone, suggesting a sandstone fraction has been removed. The coarsening-upward sequences usually have between 0.6m and 1.5m of mudstone in the lower part, and between 0.4m and 1.8m of sandstone in the upper part. The average overall thickness of these units is about 1.8m.

5.3 Fossils

One of the most striking features of the section is the almost ubiquitous occurrence of plant rootlets (Fig. 18). The rootlets are vertical, usually a few centimeters in length, to a maximum of 8-10 cm, very thin, less than a couple of millimeters in most cases, and reddish brown in colour. Rootlets are found in every sediment type but are particularly abundant in many sandstone units. This may not reflect the situation during the life of these plants, as it is likely that the rootlets are common in the fine member units but because of the fissile micro-fractured nature of the shales, they may not be as easily observed (Fig. 17). In most cases, the rootlets in sandstone units clearly penetrate down from bedding planes. This suggests these sands were deposited rapidly and subsequently subaerially exposed allowing the establishment of limited vegetation. It is interesting to note that individual rootlets are separated by a few centimeters suggesting the plant density was low. In addition to plant rootlets, plant debris was noted on a few bedding planes (Fig. 19,20). A trunk-like structure was observed, probably the fossil remains of a fairly large shrub or cluster of small tree trunks (Fig. 21).

Coquina beds were observed in four widely spaced sandstone units in the measured section. Fossil shells range from remarkably well preserved, complete articulated bivalves (Fig. 22) to comminuted shell fragments (Fig. 23 and upper part of Fig. 22). These bivalve shells have been identified as freshwater bivalves, Unio sp. (Douglas, 1950). The shells occur invariably as lag deposits at or near the base of sandstone units. Many of these shells were apparently transported over very short distances while others may have been carried as bedload over considerable distances.



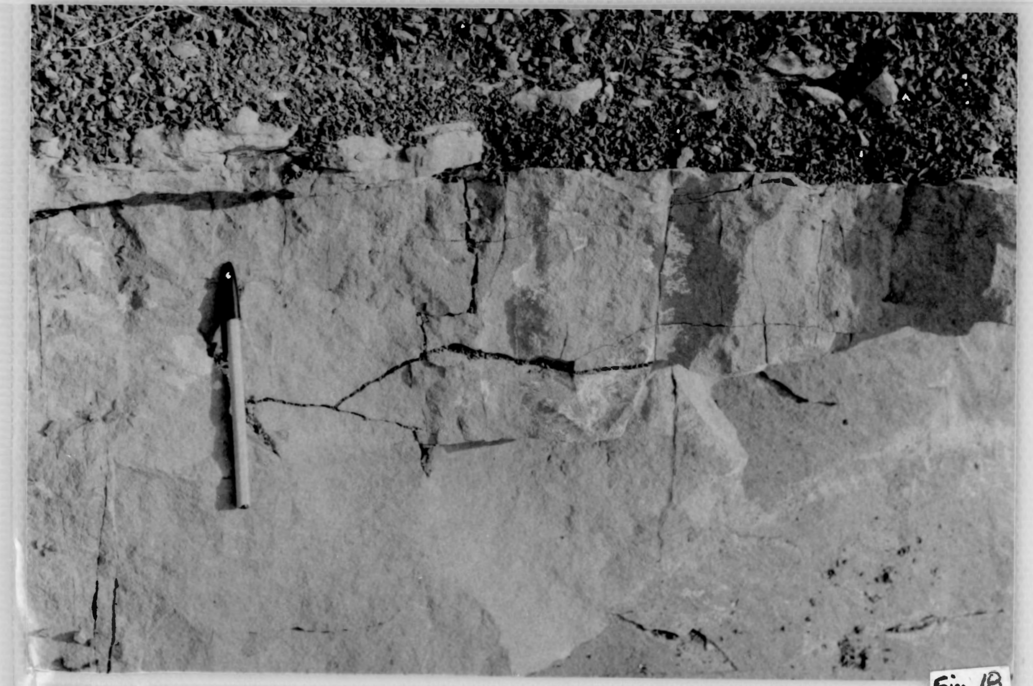


Figure 16. A mudstone bed

Figure 17. Fissile micro-fractured mudstones and shales.

Figure 18. Plant rootlets.

Figure 19. Plant fragments on bedding planes.

Figure 20. Plant fragments and surface trails indicated by the arrow.

Figure 21. A fossil shrub trunk.

Fig 22

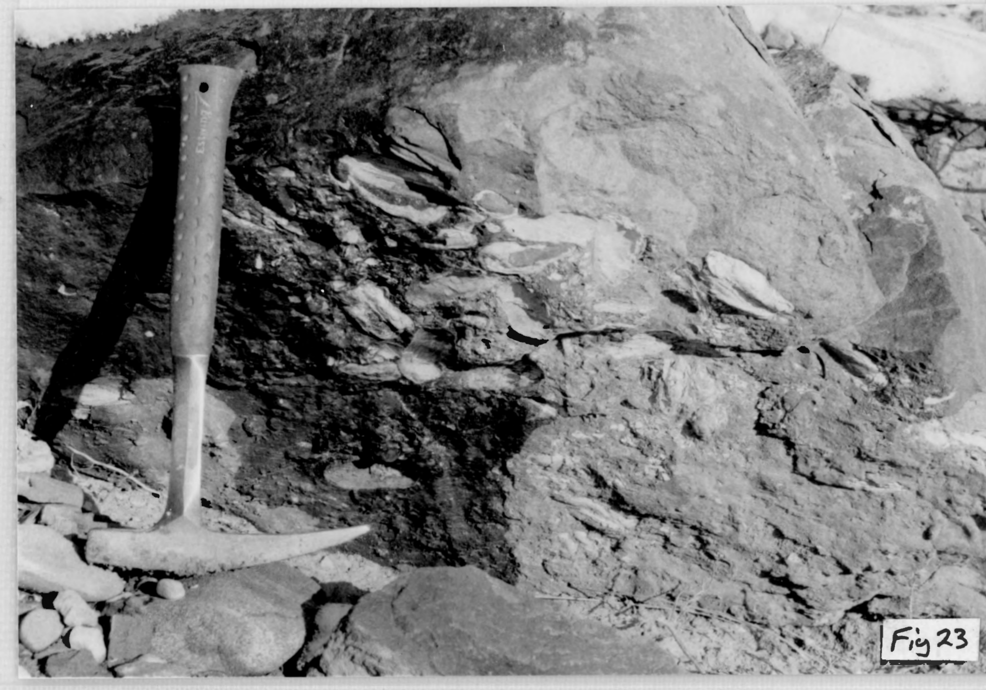


Fig 23

Fig 24

Figure 22. A well preserved articulated bivalve fossil.

Figure 23. Comminuted shell fragments.

Figure 24. Vertical burrows.

Figure 25. Soft sediment deformation.

Figure 26. Flute casts.

The only trace fossils observed were burrows and surface trails present in both a vertical and horizontal orientation. Surface trails are clearly visible on the base of some bedding planes (arrow Fig. 20). What at first glance appear to be stalk-like casts are more likely vertical burrows (Fig. 24).

5.4 Sedimentary Facies

Based primarily on lithology and primary sedimentary structures, four facies are recognized in the measured section (Fig. 15).

1) Mudstone facies, greenish grey to grey mudstone/shale, locally rooted, local lenses of silt and very fine-grained sandstone, rare burrows, few sideritic concretions, rare limonitic concretions.

2) Trough cross-bedded sandstone facies, variable grain size from fine to coarse sand, large scale trough cross-beds, tabular sets of cross-beds, local horizontal planar sets, local lag deposits with mud clasts and/or shell debris at or near the base, erosively based, fining upward sequence, often with ripple crossbeds at top.

3) Rippled sandstone facies, very fine to fine-grained, ripple cross-laminations and micro troughs, upward fining, locally muddy, commonly rooted, sharp contact at base.

4) Coarsening upward facies, very fine to fine-grained, ripple cross-laminated, local small scale trough cross-beds, often gradationally based, locally sharp based, local fossil shells, local mud drape, rooted.

Table 3 illustrates the relative abundance of the four sedimentary facies as well as providing the number of units within each facies and statistical information. The mudstone facies, facies 1, is the most abundant facies over the entire measured section, accounting for just over 40 percent of the section. It can be seen that the three sandstone facies together account for the remaining 60 percent of the section and that all three facies are well represented in terms of occurrence, but that facies 3 accounts for only 5.8m, or about 6 percent of the section.

Facies	Thickness	n	Average	Maximum	Minimum
1	total 40.6m	32	1.3m	6.5m	0.15m
2	37.5m[1]	14	1.5	2.5	0.9
3	5.75m	8	0.7	1.2	0.3
4	total 14.2m	9	1.7	2.8	1.0
	98.05[2]	63[2]			

1. Composite sandstones, units 3 and 14 not included in calculations (17.1m).
2. Some fine member units were included in facies 4 as well as facies 1.

Table 3 Relative abundance and thicknesses of the four sedimentary facies.

5.5 Previous Workers

The measured sections of Lerand (1982[a]), Zaitlin (1983) and the author contain very similar observations, differing only slightly in detail and interpretation.

Douglas (1950) recognized two sandstone lithofacies in the Upper Part of the SMRF: 1) grey, well-indurated, massive to thinly bedded, fine to medium-grained, locally cross-bedded, and greenish grey weathering; and 2) grey, massively bedded, medium to coarsed-grained, large scale cross-bedding, poorly indurated, weathering to light grey. Other lithologies include various types of shales, usually greenish or grey, carbonaceous, silty or calcareous, rarely bentonitic, and dark grey, argillaceous limestones, which weather dark brown.

Rahmani and Schmidt (1975) recognized four sandstone facies: 1) medium to coarse-grained, scours and load casts on lower surface, rip-up clasts, and a gradational upper contact; 2) fine to medium-grained, trough cross-stratified, occasionally tabular cross-stratified, medium to light grey, often calcareous to sideritic, common load casts, plant debris, leaves, twigs, coal streaks, rootlets and vertical burrows, usually gradational, occasional erosional contacts; 3) very fine to medium-grained, occasionally calcareous to sideritic, contains plant remains and twigs, plane-parallel to wavy stratified; 4) very fine-grained, calcareous to sideritic, plant remains, leaves, twigs are abundant, rootlets, burrows, ripple cross-stratified with small-scale trough cross-stratification. A fifth facies was also recognized, 5) mainly shale, siltstone and minor very fine-grained sandstone, with carbonate nodules and calcareous and sideritic lenses. The shales are dark grey and greenish, often carbonaceous, with twigs, leaves and rootlets.

Lerand (1982[a]) recognized two general sandstone facies: 1) thin beds 1-1.5m thick, resistant, fine- to very fine-grained, well cemented, usually with sharp lower contacts and gradational upper contacts, with wavy partings, small scale cross-stratification, cross-laminations and thin silty-argillaceous lenses, rootlets; 2) a similar sandstone, 10m thick, with small-scale and large-scale trough cross-stratification, planar beds, some climbing ripples and rootlets.

In addition, Lerand observed: 3) a fine-grained recessive mudstone facies, with greenish grey very fine sand, silt and clay and carbonaceous shale; and, 4) very calcareous, brown-weathering ironstone, locally rooted, with rare burrows and bivalve shells.

Zaitlin (1983) recognized three distinct sandstone facies: 1) a fining upward, coarse to fine-grained, trough-cross-bedded to trough-cross-laminated to ripple-cross-laminated sandstone, with a loaded, erosional or sharp base; 2) sharp based, massive sandstones, with rip-up clasts near the base, with low angle planar to ripple, climbing ripple and wavy beds; 3) thin, sharp based, trough cross-bedded fining upward sandstone, with siltstone and shale interbeds.

Zaitlin also noted: 4) massive and laminated, locally bentonitic mudstones; 5) ironstones, with shellhash and burrows; and, 6) limestones.

6. INTERPRETATION

6.1 Techniques

In this chapter, the four sedimentary facies are analyzed in three steps. The first step is an examination of the sedimentary structures observed and an interpretation of the physical processes that produced the bedforms that created them. Step two is an analysis of the facies associations observed in the measured section. With this information quantified, a local summary sequence, representative of the observed associations can be constructed. This facilitates further refinement of the initial interpretation. The third step is a review of the significance of the four sedimentary facies identified with respect to depositional systems, and a comparison of the local summary sequence with suitable existing facies models.

6.2.1 Sedimentary Structures and Bedforms

Primary sedimentary structures are observed in the sandstone members. A variety of sedimentary structures occur in the measured section. These range from small to large structures, representing a wide spectrum of flow conditions, from quiet water to high-energy, high-velocity currents.

The largest structures are trough cross-beds characteristic of many sandstone units (e.g. units 3, 14, 35). Such structures are formed by migrating dunes. Sandstone units with large-scale trough cross-beds at the base may contain lag deposits which include lithoclasts and shell fragments.

Tabular sets of cross-beds, up to 1m in thickness, are limited mainly to the thickest sandstone units (unit 3 and 14), but occur in one relatively thin sandstone (unit 24). These structures are the product of migrating sandwaves and occur in association with large-scale trough cross-beds and planar sets.

Planar bedding is not common in this outcrop of the SMRF. Examples are limited to unit 14, where they are relatively common, and units 35 and 47.

Plane bedding structures observed in unit 14 are always in association with large-scale trough cross-beds. In unit 35, the plane bedding occurs with a smaller scale trough cross-bedding. This association indicates these beds represent upper flow regime plane beds deposited during high velocity flow conditions. In unit 47, planar beds are associated with wavy lamination and rare ripples suggesting lower phase deposition.

A variety of small-scale sedimentary structures observed are attributed to current ripples. Small-scale trough cross-bedding and ripple cross-laminae are common in many sandstone units. Ripple drift laminations were observed in units 14 and 25. Although these structures are found in many parts of the sandstone units, they are most common near the tops.

6.2.2 Penecontemporaneous Deformation Structures

There is a scarcity of penecontemporaneous deformation structures observed in the measured section. One particularly odd sedimentary structure (Fig. 25), was probably created by soft-sediment deformation. Unfortunately, the orientation of the photograph does not adequately illustrate the feature. The photograph was taken looking upward toward a lower bedding surface from which the feature protrudes downward, rather like a bulb. The bulbous structure may have been created when a rock fragment or shale ball was dropped from a channel bank and sank into the soft-sediment of the channel floor. If this interpretation is correct, this feature represents the only good evidence (albeit indirect), that a relatively steep channel margin existed. It is not difficult to imagine such a fragment being eroded from the cut bank of a meandering river channel.

Unit 24, a 1.6m thick sandstone, contained the only observed examples of convolute bedding.

6.3 Sole Markings

Good examples of flute casts were observed on one of the lower bedding planes of unit 14 (Fig. 26). These provided one of the few locations for paleocurrent readings. Flute casts represent small scours in freshly deposited mud, preserved as molds on the sole of sandstone beds.

Although a rigorous attempt to record several paleocurrent directions was not undertaken, readings were recorded from within unit 14. Readings from a suite of flute casts produced a paleocurrent direction of 160° AZ (Fig. 26). A few metres higher in the section, but within the same sandstone unit, primary current lineation was observed. This orientation gave a paleocurrent direction of 180° AZ. There is at least 5m of sediment separating these two readings and at least three distinct, erosively based sandstone sets. However, the comparable results of the two paleocurrent indicators suggests an almost unimodal channel direction over a considerable length of time.

6.4 Physical Processes

The three sandstone facies are characterized by a variety of sedimentary structures. In the previous section these structures were attributed to different bedforms, each of which are representative of different physical processes. The observed association of bedforms was produced with a range of flow velocities. Bedforms are produced as soon as sediment transport begins (Blatt, Middleton, and Murray, 1972). Bedforms include flat-beds, ripples, dunes and sandwaves, each produced under different flow regimes.

Facies 2, the trough cross-bed sand facies, includes large-scale trough cross-beds, tabular sets of cross-beds and local horizontal planar sets. These structures are produced by dunes and sandwaves, representative of the upper part of the lower flow regime (Blatt, Middleton and Murray, 1972), and flat-beds created during upper flow regime conditions. Primary current lineations observed in unit 14 also indicate upper flow regime.

Facies 3, the rippled sand facies, is characterized by ripple cross-laminae and micro troughs which are attributed to current ripples formed in the lower flow regime. Some examples of climbing ripple-drift were noted indicating relatively high rates of sediment aggradation. Facies 4, the coarsening upward facies, contains similar sedimentary structures to those observed in the rippled sand facies and a similar flow regime is envisioned.

The sandstone facies, which are bed load deposits, are fundamentally different from the mudstone facies which was deposited from suspension. The contacts between the trough cross-bed sandstone facies and the fine member mudstone facies are sharp. This lack of gradation is significant in that it demonstrates that although waning flow did occur, where suspended sediment was deposited, it was quickly removed by subsequent increases in current velocity.

6.5 Facies Associations

The inter-relationships of the four sedimentary facies provides insight that facilitates a better understanding of the depositional environment. A brief analysis of the facies associations is present in table 4. Figure 27 is a graphic representation of the data in the table. From this diagram the dominant facies relationships can be readily determined. The three coarse member facies are all associated with the mudstone facies, but their association to each other is much less significant. The information from this analysis is combined with information from Chapter 5 to construct a local summary sequence (Fig. 28). Figure 28 illustrates the facies associations observed in outcrop, the relative abundance of each facies, and the average thickness of the various units.

FACIES	(1)	(2)	(3)	(4)	TOTAL
(1) Mudstone facies		9	8	2	19
(2) Trough cross-bedded sand facies	10			3	13
(3) Rippled sand facies	6	1		2	9
(4) Coarsening upward facies	4	2	1		7
	20	12	9	7	48

Table 4 (a) Matrix showing number of times any one facies passes upward into any other (after Harms, Southard, Spearing, Walker, 1975).

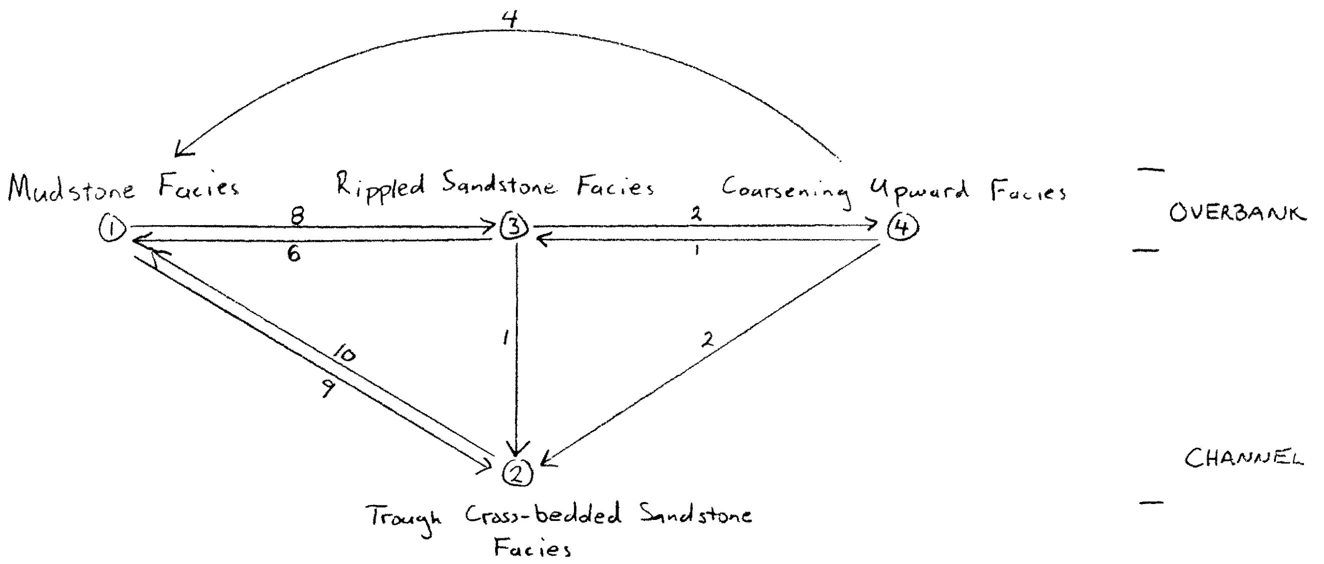


Figure 27. Facies association diagram. Arrows originating at one facies point to the overlying facies. The numbers associated with the lines indicate the number of times one facies passes upward to another.(adapted from Harms,1975).

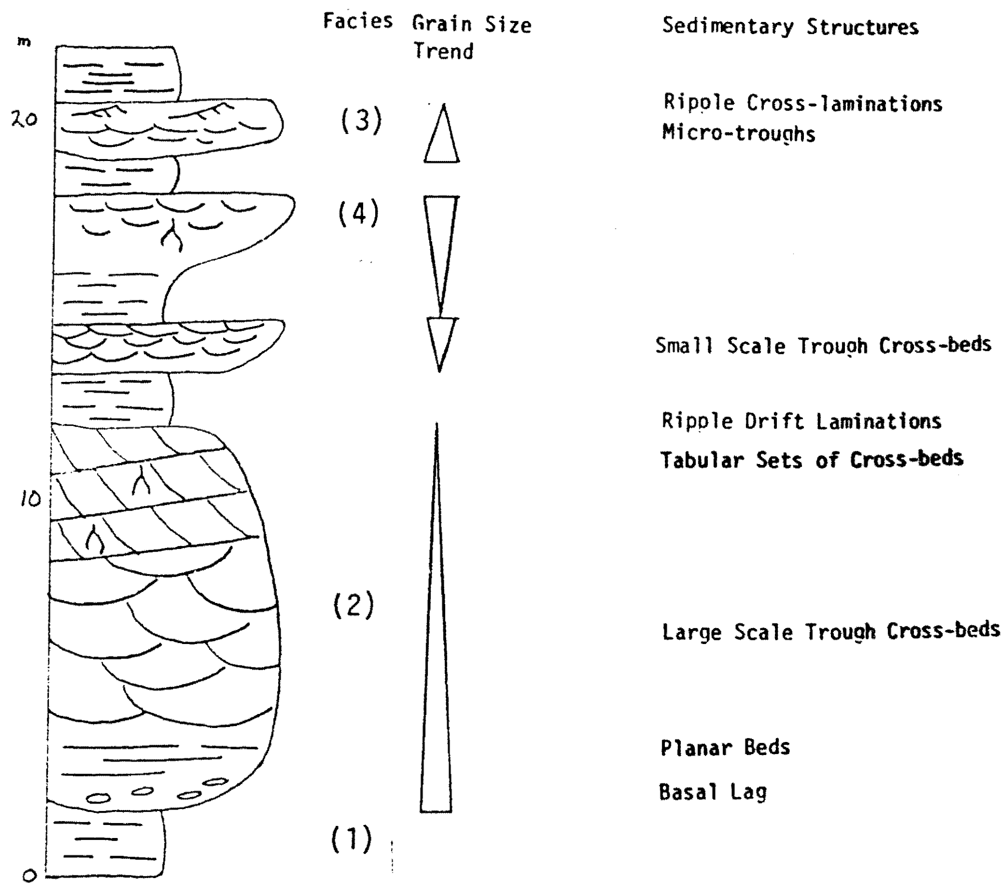


Figure 28. The local summary sequence. The grain size trend is illustrated by the arrows which point in the direction of decreasing grain size.

6.6 Sedimentary Environments

The SMRF has been well established in the literature as a terrestrial deposit (Wall and Rosene, 1977) and the features observed in outcrop along the Oldman River support this interpretation. Carbonaceous debris, plant fragments, rootlets and freshwater bivalves are diagnostic of a terrestrial setting. In the absence of any marine fossils, the suggestion of unimodal paleocurrent direction, and apparent channel sequences, the sedimentary structures preserved suggest a fluvial system. Bed load transport played a major role in the deposition of the coarse members, whereas the mudstone facies was deposited from suspension. This observation alone might suggest two distinct depositional environments, 1) the channel and 2) the floodplain. However, this sort of division is arbitrary, and premature at this point. The fine member mudstone facies which may represent overbank deposits could be vertical accretion deposits of inter-channel bars or clay plugs within abandoned channels.

Table 5 lists many of the major characteristics of braided and meandering systems. Although many features listed are ambiguous, it is hoped that when taken in total, one system may be preferred to the other for a depositional model for the SMRF. It must be stressed that the characteristics listed here are a distillation of many observations and do not apply specifically to any particular case. It should also be noted that these criteria are more representative of ideal end-members.

In proposing a depositional setting for the SMRF, it is useful to briefly review the major alluvial environments. Figure 29 illustrates the transitional relationship of the three major alluvial systems; 1) alluvial fans, 2) braided rivers, and 3) meandering rivers. The important points illustrated are the reduction in gradient, decreasing grain size and improved sorting in a distal direction from the fan. This classification is very general and a spectrum of transitional systems exist between end-members. A further breakdown of braided systems into pebbly braided, and sandy low-sinuosity rivers, (Collinson, 1978[a]), is desirable in that it helps avoid the implication of coarse grained proximal sediments for all braided systems. Sandy low-sinuosity rivers include many types which range from those gradational with pebbly braided rivers to those which are gently meandering (Collinson, 1978[a]). It is therefore difficult, in many cases, to assign a particular sedimentary sequence, such as

Braided	Meandering	SMRF
gravel-sand 90% minor silt-mud 10% conglomerates common dominated by bedload often red colour	sand-mud 50/50 rare conglomerates except intraformational clasts dominated by suspended load often grey, brown	sand-mud 60/40 intraclasts grey colour
oxidizing environment fossils rare lack carbonaceous material	reducing environment associated coal seams fossils common abundant carbonaceous material	slightly reducing environment local fossils common carbonaceous debris
unstable channel banks no clearly defined overbank	competent bank material well defined overbank	
fining upward poorly developed sedimentary sequence haphazard	well established fining upward sands grade upward to mud bed sets decrease in thickness upward	fining upward poorly developed mudstones lack gradational contacts
sediment choked bar morphology variable discharge diagnostic abandoned channel sequence, double erosion surface above/below shales	vertical accretion dominates clay plugs more consistent discharge but still subject to wide fluctuations	coarse grained overbank deposits
high gradient reduced vegetation	low gradient well vegetated	 rooted

Table 5 Common characteristics of fluvial systems (after Selley, 1976, Miall, 1977).

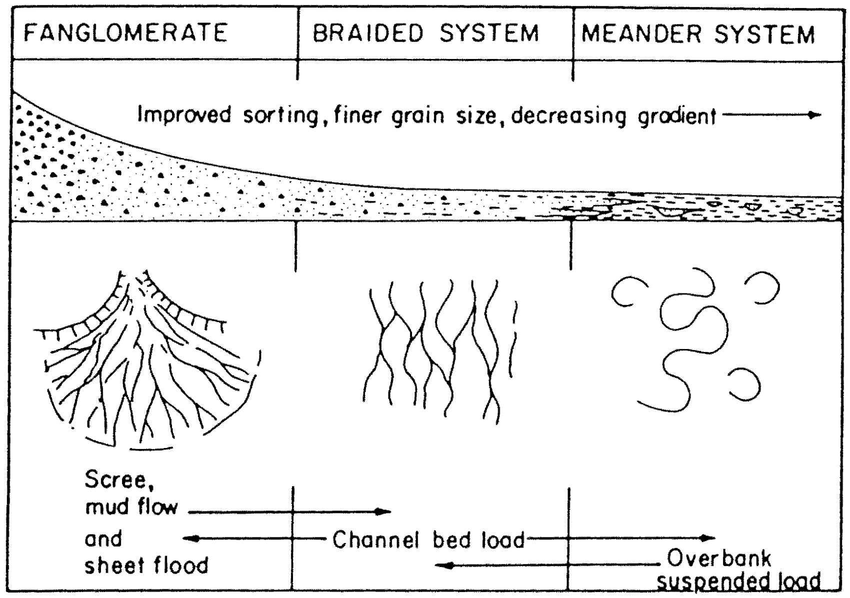


Figure 29. Major alluvial systems (from Selley,1976).

that observed in the SMRF, to a specific fluvial system. No absolute criteria exist for distinguishing the deposits of distal braided and meandering rivers, (Rust, 1978) due in part to the transitional nature of these types, but also due to the similar physical processes that occur in both.

Sandy low-sinuosity rivers may be characterized by well defined, relatively straight channels that are transitional between braided and meandering rivers (Fig. 30) (Coleman, 1969). Like braided rivers, these systems are characterized by steep gradients and variable discharge rates, but like meandering systems, straight channel types have lateral bars analogous to point-bars, stable channel banks and a generally fine-grained bed load fraction (Coleman, 1969). These channels are often sediment choked with shoals developing between lateral bars, corresponding to a "... semi-braided reach ..." (Coleman, 1969). The channel bars, particularly mid-channel types, are unstable and shift frequently (Coleman, 1969). This suggests that straight channel 'braided' systems in the ancient record may not contain preserved mid-channel bar deposits. Straight channel types in the Brahmaputra River system do not tend to migrate with time due to the relatively stable banks (Coleman, 1969). This is not necessarily the case in other parts of the system where channel banks contain common collapse features (Coleman, 1969). Sandy low-sinuosity channels may exhibit lateral continuity where the channel has migrated through time. Distal sandy braided, (e.g. sandy low-sinuosity) deposits commonly fine upward and contain a significant mud fraction (Rust, 1978).

The local summary sequence (Fig. 28) is strikingly similar to the point-bar sequence of meandering river systems, and indeed, several previous workers have assigned the upper SMRF to such a system (Rahmani and Schmidt, 1975, Lerand, 1982). A comparison with a local summary sequence from a similar section, slightly lower stratigraphically, shows a close resemblance, with a few significant modifications (Fig. 31).

There are problems with the meandering river system interpretation, one of which is the lack of channel margins in outcrop. This deficiency was noted by Zaitlin (1983) and persists as a problem for the author. However, it is not surprising that, in the limited outcrop studied, channel margins were not observed, and if the channel banks were not particularly competent and easily eroded, lateral migration would predominate and channel margins would be much

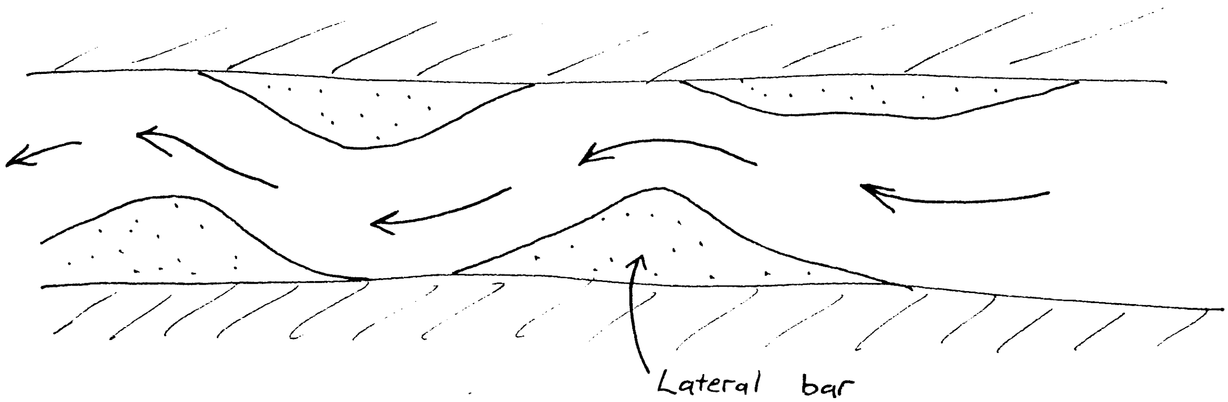


Figure 30. Straight channel system showing development of lateral bars (after Coleman,1969).

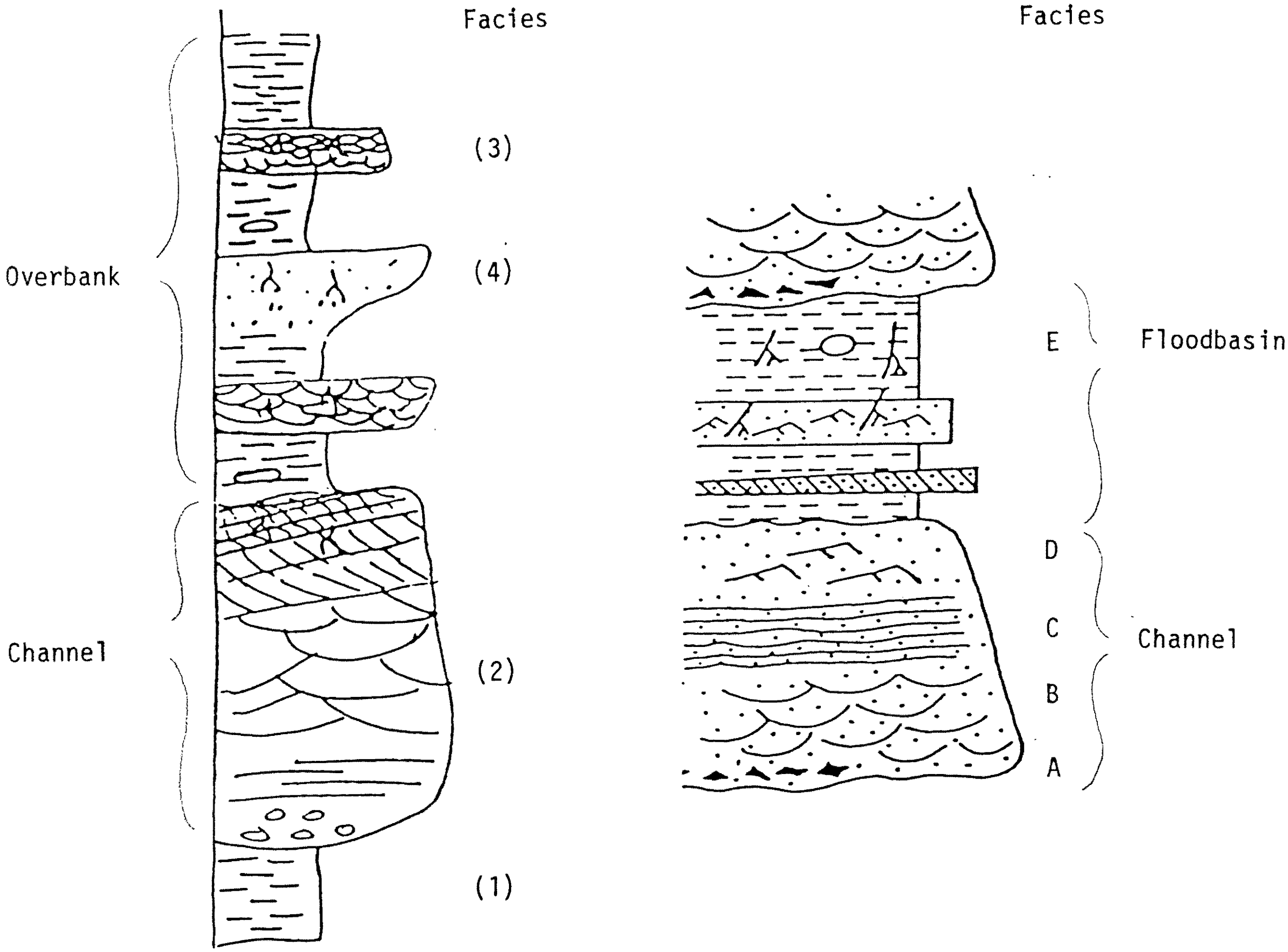


Figure 31. Comparison of the local summary sequence on the left with the summary sequence of Rahmani and Schmidt (1975) on the right.

less commonly seen. A second deficiency is the lack of gradational contacts passing upward from sandstone to mudstone. However, a chute modified point-bar sequence may not grade upward to mudstone, and such deposits are common to meandering systems with increasing discharge variability (Galloway, 1983). Well defined lateral accretion surfaces are not obvious in the outcrop. The tabular cross-bedded sets could represent lateral accretion, if they were deposited in a point bar, migrating channel floor, bedforms, or localized inter-channel bars.

Many of the coarse grained units, including examples of all three sandstone facies, are conspicuous by their relative thinness, and their association with the fine member mudstone facies. From table 3, in the previous chapter, it can be seen that excluding units 3 and 14 (composite sandstone units), the average thickness of all the sandstones is less than 2m. In fact, the maximum thickness for a single sandstone (2.5m) is found within unit 14, and probably represents a single channel in a series of stacked channels that comprises unit 14. The seven individual channel sequences within unit 14 (Fig. 15), range from 0.8m to 2.5m and average 1.6m over a total unit thickness of 11.2m. As each sequence is erosively based, it may be assumed that the channel depth, as represented by the thickness of these sediments, may have been in the order of 2-3m although the thickness removed by erosion is not known. This is not the case for many of the coarse member sediments found outside units 3 and 14. Although these units are erosively based, they are usually overlain by mudstones, rarely by other erosively based sandstones, and therefore their depositional thickness is preserved.

Coarse members less than 1-2m may not be channel deposits especially when channel margins are not present (Collinson, 1978[b]). This would suggest that many of the sandstone units present in the measured section may represent overbank deposition on levees or as crevasse splays. When the association of the rippled sand and coarsening upward facies with the mudstone facies is reviewed, (Fig. 27) it is apparent that these sediments represent overbank deposits.

Crevasse splays commonly exhibit a coarsening upwards sequence which occurs as coarser sand material is deposited over the finer silts and clays of the floodplain. The coarsest material will be dropped from the flow shortly after the current has breached the channel. The finer sediments will be dropped from suspension with waning flow at some distance from the channel and may show graded bedding, and fine upwards. If the splay progrades into a standing body of water, such as an interchannel lake, a facies analogous to a Gilbert style delta may be observed (Selley, 1978). However, a situation analogous to a turbidity current deposit is also possible (Walker, 1979). Crevasse splays occur in association with both braided and meandering river systems. On the braided section of the Brahmaputra River, crevasse splays are similar to those in meandering river systems, but are much more common (Coleman, 1969). Crevasse splays typically contain small-scale trough cross-bedding, climbing ripple lamination, and horizontal planar bedding (Collinson, 1978[a]). All of these features were observed in the thin sandstone units of the measured section. Crevasse splay deposits may have erosional bases if they are proximal to the channel (Collinson, 1978[a]), or they may be flat based, showing no sign of erosion in the more distal part of the splay (Walker, 1979). Crevasse splays may merge into an almost continuous sheet (Collinson, 1978[a]), and in flood-prone systems, splays may become extensive, covering several square kilometers (Galloway, 1983).

It is now established with reasonable certainty that the SMRF, as visible in outcrop on the Oldman River, contains both channel and floodplain sequences. The mudstone facies is interpreted as overbank deposits from suspension. Many of the sandstone units assigned to the rippled sandstone and coarsening upward facies, are interpreted as crevasse splays based on thickness, less than 2m, the absence of channel margins, the association with the overbank mudstone facies, common sharp upper contacts and common slightly erosive, undulating lower contacts. Discharge rates fluctuated widely, as evidenced by coarse member overbank deposits (e.g. crevasse splays). It is also apparent that well developed channels remained relatively stationary for extended periods of time, as evidenced by the composite channel sequence, unit 14. The fluvial system that deposited the SMRF was apparently transitional between a braided and meandering system. This view is supported by the fine- to medium-grained sandstones, the relative abundance of overbank mudstones, and the moderately well organized sequences. Some attributes of a braided (low sinuosity) system are the relatively shallow channel depths, the lack of gradationally based mudstones, and the occurrence of mudstones with erosional bases and tops.

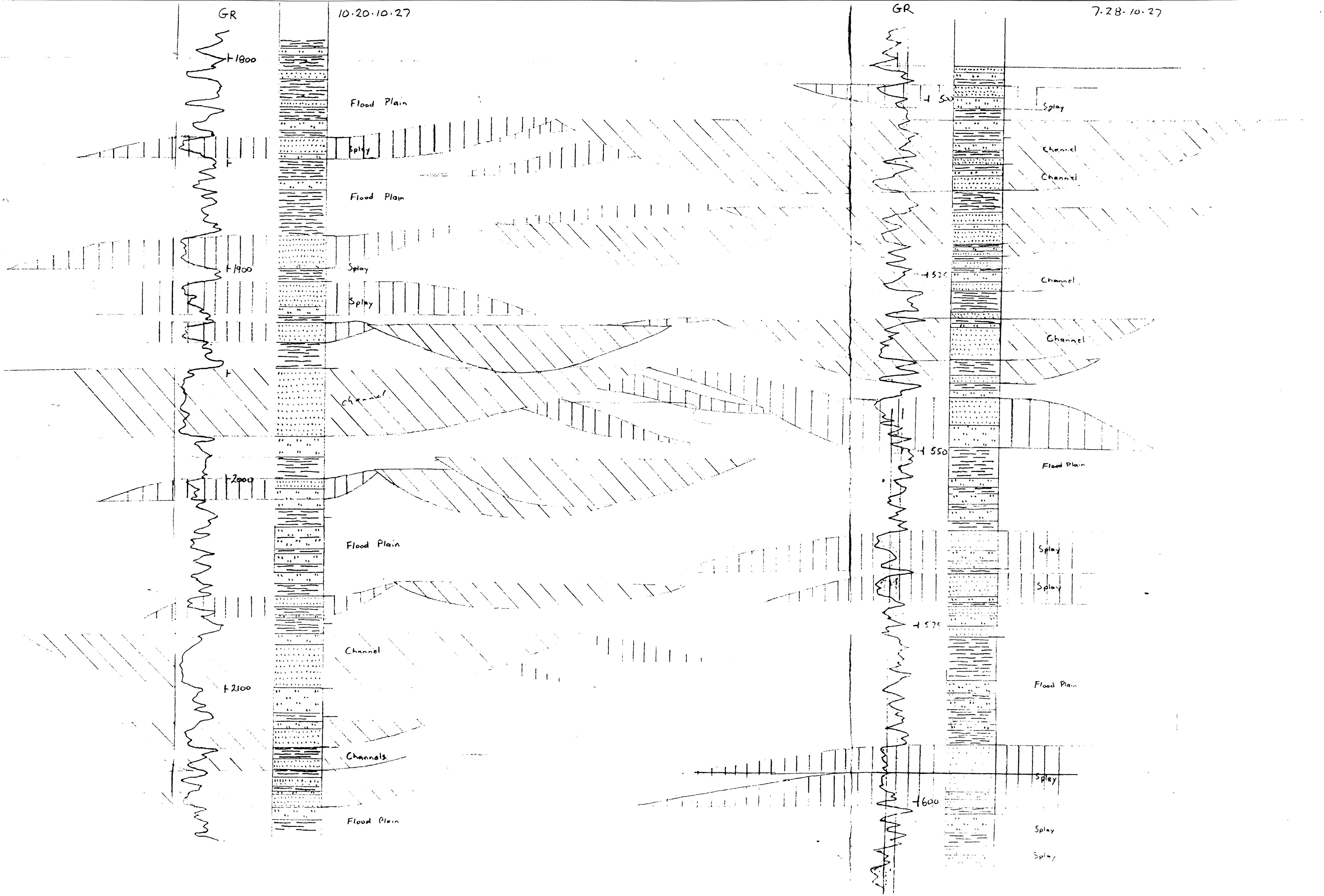
This interpretation, fits the observed log character in nearby wells. Figure 32 clearly demonstrates many of the features expected including both fining-upward and coarsening-upward sequences, a significant fine member component, and a lack of lateral continuity. In fact, the log character is more indicative of a meandering system which is not surprising as the wells are more distal than the measured section. Although many ancient examples of braided river systems contain stacked coarsening-upward units, (Klein, 1980), as visible on the logs, the lack of lateral continuity suggest they are not braided river deposits, which typically develop laterally extensive sheet-sands.

The broad subgrouping of braided rivers into proximal pebbly systems and distal sandy low-sinuosity systems (Collinson, 1978[a]), is not very specific in that a range of river types exist between these two end-members. Braided river systems have been grouped into five general types; 1) proximal gravel rivers (Scott type), 2) transitional rivers (Donjek type), 3) shallow sandy braided rivers (Platte type), 4) sand dominated (South Saskatchewan type), and 5) ephemeral sandy streams (Bijou Creek type), (Miall, 1978).

Straight channels contain a sedimentary sequence similar to a modified Donjek-type braided system (Miall, 1977). Such a system may resemble a South Saskatchewan-type braided river, (Fig. 33) but mid-channel bars may be less common. A comparison of the local summary sequence with a vertical profile model of a Donjek-type river (Fig. 33) clearly shows many similarities. If the model is modified to remove the crudely bedded gravel facies, the similarity is more striking. This model shows striking similarity to the Battery Point sequence (Walker and Cant, 1979) (Fig. 33). However, there are significant differences between these two models and the local summary sequence, notably, the small amount of mudstone or shale, the lack of coarsening upward sequences, and the lack of thin rippled sandstone units within the fine grained units. A comparison of the local summary sequence with the Old Red Sandstone at Mitcheldean (Allen, 1964), a braided sequence with a significant fine member component, shows some of the observed features which are missing from the modified Donjek model (Fig. 33). It is interesting to note that the sequence at Mitcheldean does not fit any of the five braided river types mentioned above. It is apparent that at least one more category can be added to this classification, a straight-channel sandy low-sinuosity type.

Figure 32. Detailed gamma log correlation between two wells 2 km apart. Note that individual beds do not correlate particularly well and that sandstone units have been inferred between the two wells.

- Fining upward sequences
- Coarsening upward sequences
- Sandstone
- Siltstone
- Shale


GR
10·20·10·27
1800
Flood Plain
Splay
Flood Plain
1900
Splay
Splay
Channel
2000
Flood Plain
Channel
2100
Channels
Flood Plain
GR
7·28·10·27
Splay
Channel
Channel
Channel
Channel
550
Flood Plain
Splay
Splay
Flood Plain
Splay
600
Splay
Splay

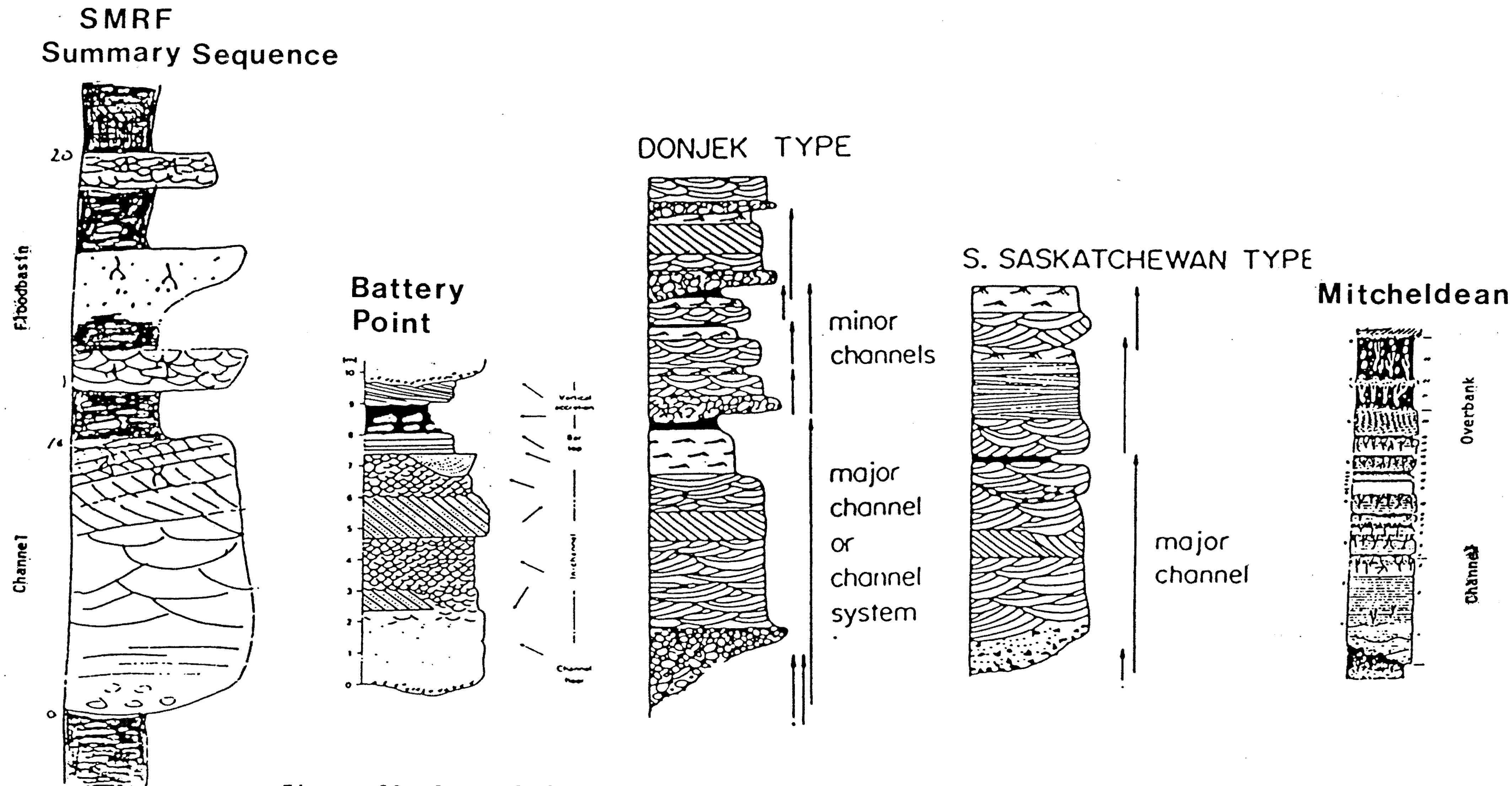


Figure 33. Several fluvial system models compared to the local summary sequence of the SMRF.

In proposing a straight-channel, low-sinuosity system for the SMRF, the presence of a significant amount of overbank fine material is a key factor. The association of relatively thin sandstone units within the mudstone facies was one factor in their classification as floodplain deposits, e.g. crevasse splays. There are, however, other factors that support the interpretation of the mudstone facies as overbank deposits.

It is apparent, for the most part, that the greenish grey colour of the mudstones is indicative of a reducing environment. Although some mudstones were apparently oxidized (e.g. top of unit 13), this is the exception rather than the rule. The occurrence of carbonaceous laminae, although very thin and not common, indicates slightly reducing conditions. Rootlets are present in the mudstones and "... grey beds are more likely to be disturbed by rootlets and to preserve organic matter as either comminuted debris or coal." (Collinson, 1978[a]). The lack of coal seams may be a function of insufficient quantities of organic matter rather than improper conditions for preservation. In addition, siderite concretions are common to many of the mudstone units. "siderite nodules ... are commonly associated with grey fine members ..." (Collinson, 1978[a]). In short, at least slightly reducing conditions commonly associated with meandering river systems were present during deposition of the SMRF. This provided further evidence that the depositional environment of the SMRF was transitional to a meandering river system.

7. CONCLUSION

The objective of this study was to interpret the sedimentary environment of the SMRF. It is clear the sediments of the SMRF are fluvial in origin, as has been well established in the literature. However, a specific depositional system has not been so well established. Some previous workers have assigned the SMRF to a meandering river system (Rahmani and Schmidt, 1975, Lerand, 1982). At least one assigns the formation to a braided river system modified by sheetflood deposits (Zaitlin, 1983).

From this study several points have been made about the fine member and coarse member facies, and their associations. It has been determined that well established channels existed in the SMRF and a significant portion of the sediments represent overbank deposits. In particular, many of the coarse grained units, less than 2m thick, are not attributed to channels. This is in an agreement with the interpretation of these units as crevasse splay deposits (Lerand, 1982).

The lack of definite channel margins, the relatively shallow channels (2-3m), and the lack of gradationally based mudstones are cited as possible problems with assigning the SMRF to a meandering river system. However, relatively small scale meandering rivers may well have shallow channels and channel margins in many cases are not commonly seen. A possible composite point-bar sequence (unit 14), may represent a lateral bar in a low-sinuosity river. Many other attributes of the SMRF which are common to meandering rivers (Table 5) are also commonly associated with distal, sandy low-sinuosity river systems. Tabular sets of cross-beds, although not diagnostic of low-sinuosity rivers, are more commonly found in them, being associated with various types of in-channel bars.

This study was the first attempt to integrate outcrop and subsurface data. The log character of the SMRF showed an abundance of coarsening upward sequences in addition to well defined fining upward sequences. The coarsening upward sequences are interpreted as crevasse splay deposits. Individual sandstone beds are not laterally extensive. Fining upward channel sequences visible on logs appear to be grouped together suggesting channels may have persisted in a general area for long periods of time. The log character clearly demonstrates that a braided fluvial system is not likely. However, a straight-channel, low-sinuosity system is possible.

In the 'basal member', the presence of coal (although only in thin seams), brackish water fauna (Douglas, 1950, Young and Reinson, 1975), and the proximity to marginal marine sandstone seqences, suggest that this part of the SMRF may have been deposited on a delta plain. However, the 'basal member' is relatively thin, about 30m, and the much thicker 'upper member' lacks coal, suggesting either a decrease in vegetation or a change to an environment unsuitable for preserving enough organic matter to produce coal seams. Either case suggests that the sediments of the 'upper member' were deposited under more oxidizing conditions in a well drained environment. However, the presence of disseminated carbonaceous debris, the greenish/grey colour of the sediments, and the occurrence of siderite concretions in the mudstones suggest that the environment could not have been highly oxidizing. These characteristics suggest that the SMRF, in the area of the measured section, may represent the upstream facies equivalent of the deltaic environment of the 'basal member'. This would place the upper SMRF in the inland extension of a deltaic environment. It is often difficult to choose between a continental floodplain and an upper delta plain (Gersib and McCabe, 1981).

In looking back at the tectonic setting of the SMRF there are three points to consider, 1) the provenance area and its spatial relationship to the SMRF; 2) subsidence of the foreland basin; and 3) regression of the Cretaceous epeiric sea. The present distance from the provenance area to the study area, about 150 km, is not great. In the late Cretaceous, the mountains of the western Cordillera probably had high relief, perhaps higher than the present Rockies. As the SMRF was being deposited, tectonism was recommencing and the epeiric seas were regressing rapidly. The tectonic activity would have resulted in more sediment discharge into the foreland basin, and at the same time increased subsidence due to crustal loading. All these factors suggest that gradients could have been relatively steep, discharge rates high, and fluvial systems characterized by bedload transport.

All the evidence, taken in entirety, supports a new interpretation of the SMRF as a sandy low-sinuosity river possibly characterized by straight channels and containing coarse-grained overbank deposits.

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