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Meandering River Eddy Accretions: Sedimentology, Morphology, Architectural Geometry, and Depositional Processes

By

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Abstract

Very little is known about the sedimentology of eddy accretions (elsewhere termed concave bench deposits). These deposits occur where parallel bedrock valley walls confine a channel meander belt, preventing formation of oxbow cutoffs. In such confined settings, eddy accretions form along both margins of the floodplain, where deep scour holes are eroded by bankfull river flows impacting valley sides at right angles. In unconfined meanders, eddy accretions form where meander belt channels impinge upon valley walls. Commonly in confined settings, each eddy accretion deposit occupies 25 percent of the floodplain surface and the lower portion of a second eddy accretion deposit underlies the point bar. Typically, confined meanders with eddy accretions have a ratio of floodplain width to channel width of between 6:1 and 9:1.

Cross-valley lithostratigraphic profiles from vibracores illustrate the 2-dimensional architecture and sedimentology of eddy accretions. Geophysical bottom profiles of river channels and one river current velocity profile were used to study the geomorphic and depositional processes.

Results from two confined sand bed meandering rivers in British Columbia and Alberta, Canada, indicate that eddy accretion deposits are twice as thick as adjacent point bars (17m to 6m, and 9m to 5m, respectively). Eddy accretion deposits often form on both sides of confined floodplains that are laterally bounded by resistant bedrock, clay or glacial till. Downvalley-dipping inclined stratification is thought to dominate the internal sedimentary structure of eddy accretions.

In some cases the sedimentology of eddy accretions may seem to consist of two fining upward sequences dominated by clean medium grained sand. A coarse sand channel lag with pebbles and silt rip-ups forms the base of the deposit, above which sand fines upward. A thick silt layer located mid-sequence may be present above a lower fining upward trend on silty rivers, and may separate the upper and lower fining upward trends. Unconformably overlaying the mid-sequence silt layer, a second coarse sand channel lag with pebbles is present, over which sand fines upward into over-bank silts.

This apparent double fining upward sequence may be misinterpreted as the product of two superimposed point bars in ancient rocks.

Eddy accretions are previously unrecognized as potentially thick aquifers and major fairways for fluid movement in incised river valley-fills associated with marine transgressions following a sealevel low stand. In deeply-buried ancient rock sequences, valley margins with thick eddy accretion sandstones should be considered as preferred exploration targets by the oil and gas industry.

Acknowledgments

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Table of contents

List of figures

List of tables

1. CHAPTER ONE INTRODUCTION

1.1 Introduction

One of the few remaining unstudied sedimentary deposits within meandering river systems are eddy accretions. Eddy accretions were first identified in the Mississippi River (Carey1969) and later in other meandering rivers (Lewin 1978, Hickin 1979, Page and Nanson 1982, and Page 1983). Several researchers have studied the floodplain ridge and swale pattern associated with reverse eddies, terming them concave benches (Woodyer 1975). The term eddy accretions will be used throughout the remainder of this report rather than the later term concave benches. Acquisition of sedimentological data in earlier studies was limited to the upper few metres by trenching and augering (Woodyer 1975, Taylor and Woodyer 1978, Woodyer, Taylor and Crook 1979, Page 1983). The sediment grain size in concave benches was determined to be silt and clay; however, the deeper subsurface sediments were not investigated. Consequently, no previous study of deeper eddy accretion sediments or geometry exists.

Despite their widespread occurrence, eddy accretion sedimentology and details of their depositional processes have remained largely unstudied (Page and Nanson 1982). They are of interest to sedimentologists interpreting modern and ancient fluvial deposits as possible reservoirs for fluids, to geomorphologists examining the processes which form contemporary floodplains, to hydaulicians interpreting and modeling the character of channel migration in relation to channel bend curvature, to planners of pipelines and buried cables to avoid deep scours at river crossings, and to aquatic biologists for over-wintering fish habitat.

Eddy accretion deposits commonly form along the flanks of confined meandering river valleys where parallel resistant valley walls are close together and prevent oxbow cutoffs from forming, or where meander belts form against a resistant valley wall, as observed in the Mississippi and Red rivers, U.S.A. On reaches of the Kootenay, Clearwater, Beaver, and Fort Nelson Rivers, eddy accretion morphology constitutes 25 to 30 percent of the confined floodplain area. Deep scour holes form at bankfull discharge, where channel flow impacts the valley wall at right angles causing flow separation and a reverse flow eddy on the upvalley channel side (Carey 1969). This powerful back eddy releases as much energy as several meander wave lengths (Carey 1969). In confined meanders, eddy accretions migrate downvalley simultaneously with adjacent mid-valley point bars forming new floodplain. Eddy accretion scroll bar patterns are reverse to point bar scrolls (Figure 1.1), that is, looking downvalley eddy accretion scrolls are concave whereas point bar scroll bars are convex in pattern.

1.2 The Scientific Problem

It has been widely and often correctly assumed that floodplains of actively migrating meandering rivers are formed from laterally accreted and relatively coarse grained (sand) point bars (Allen 1965b), but not all laterally accreting facies are point bar in origin (Nanson and Page 1983). A largely ignored meandering river process is that of eddy accretion formation and their associated deposits (Nanson and Page 1983). Consequently, the present understanding of meandering river deposits is not complete. This is because eddy accretion sediments are difficult to study as they are water-saturated and therefore cannot be deeply trenched due to bank collapse.

However, recent innovations in vibracoreing technology have allowed deeper penetration into saturated sediment (Smith 1984,1992, and in press). These innovations allow the entire eddy accretion package to be cored and studied for the first time at low cost. Knowledge of the relationship between eddy accretions and adjacent point bars, and their architectural cross-valley geometry has not been studied. Little field data exists on the depositional processes of eddy accretions. Page and Nanson (1982) provide a descriptive depositional model, but it remains untested and does not include data on the channel morphology, hydraulics or sedimentology.

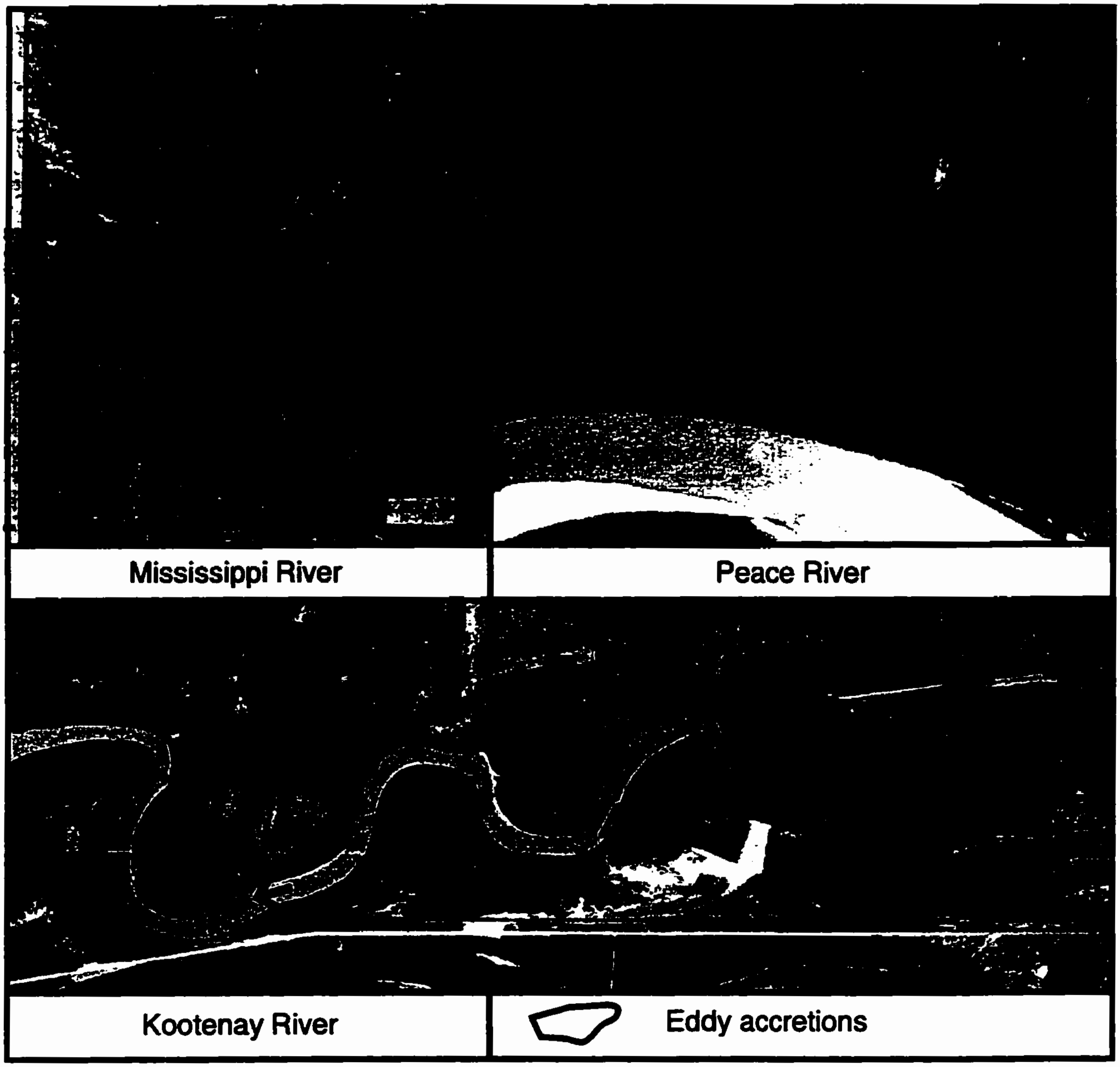


Figure 1-1. Eddy accretions on the Mississippi, Peace and the Kootenay rivers. Looking down-valley scroll bars that are convex delineate point bars, whereas concave scroll patterns delineate eddy accretions.(Clockwise from top left; After Carey 1969; Alberta Energy Mines and Resources, 1:40 000, Roll #5812, Photo #109 1950; British Columbia Surveys and mapping Branch, 1:40 000, Roll #BC77036, photo #006 1977)

1.3 Pilot Study

In October, 1995, D.G. Smith and I conducted a preliminary field investigation of eddy accretion deposits on the Kootenay River near Wasa, British Columbia. Eddy accretion channel depth measurements and vibracores indicated that the channel and deposits were much deeper than adjacent point bars. Also, contrary to previous research, the sediment grain size was found to be medium sand (the literature suggests silt, clay, and organics). Subsequent examination of aerial photographs identified eddy accretions on other confined meandering rivers (Beaver and Clearwater Rivers, Alberta), and along the margins of unconfined meandering rivers (Peace River, Alberta and Liard River, N.W.T.), as potential field sites.

1.4 Objectives

The main research objectives were to better understand the geometry, depositional processes, and sedimentology of eddy accretion deposits. This was achieved through the following procedures:

1) detailing the vertical profile of eddy accretion sediments through lithostratigraphic logs from vibracores;
2) determining the cross-valley geometry of eddy accretions and adjacent point bars through cross-sectional lithostratigraphic profiles using vibracores;
3) inferring depositional processes of eddy accretions by geophysical bottom profiling and current metering;
4) comparing eddy accretion variability between the Kootenay River in a mountain valley (Rocky Mountain Trench) and the Beaver River in the plains of eastern Alberta.

1.5 Previous Research on Meandering Rivers

Several major depositional environments and associated facies have been identified in meandering river systems. These include channel bed lags, point bars, overbank deposits, oxbow lake fills, chute channel fills and eddy accretions. From research of depositional environments, a vertical lithofacies sequence has been developed (Allen 1965a). As well, the three dimensional architectural geometry of meandering river sediments has also been suggested (Jackson 1976, Leeder 1974, Jordan and Prior 1992, Piet 1992). Although the meandering river model is well established, its basis is somewhat dated (Walker and Cant, 1984) and components may be incomplete or wrong (Smith pers. com. 1997, for example crevasse splays in the model). Although much work has been conducted on the meandering river model, refinement continues with increased study of meandering river sedimentology, sediment geometry and depositional processes (Jordan and Prior 1992, Piet 1992).

1.5.1 Point Bar

1.5.1.1 Depositional Processes

Meandering river channels are maintained by erosion of outer cutbanks at meander loops and deposition of point bars on the inner parts of loops. The main depositional environment is the point bar which builds laterally and downstream across floodplains (Fisk 1947, Leopold et al 1964, Sundborg 1956).

The channel floor usually contains a thin 'lag' (0-30cm) of material often consisting of coarse sand, pebbles or gravel with waterlogged wood fragments, and consolidated mud balls or chips eroded locally from cutbanks that are transported only at bankfull discharge or greater. Above the lag, sand is transported as bedload during average flows in a series of sinuous crested dunes ranging in height from 30 to 100cm. Their structure may be preserved as trough cross stratification. In shallow parts of the flow, higher up the point bar sequence (upper 25%), ripples are the most common bedform. Generally the preserved deposit will pass from trough cross-stratified coarse sands to rippled sands upward. Isolated horizontal stratification occurs in pockets at the top of the deposit due to shallow but high velocity flow conditions and may be found interbedded with trough cross-beds or ripples (Walker and Cant, 1984).

Preservation of these features depends on lateral migration of the channel over time. Channel floor dunes may be deposited onto the lower part of the point bar, aiding in the lateral accretion and burial of channel lags (Walker and Cant, 1984). Above the point bar sequence overbank deposits of fine grained sand and silt form a series of ridges and swales, referred to as scroll bars. These ridges may, at times of flood, redirect the flow and erode a chute channel across the floodplain (Walker and Cant, 1984).

1.5.1.2 Sedimentology

Fisk (1947), Sundborg (1956), Leopold and Wolman (1957, 1960) and Jackson (1975, 1976, 1978) were the first to describe point bar genesis, mechanical processes and sedimentation. Their work established the basic principals of point bar development and the concept of helicoidal flow in meander bends.

The fining upward model for point bar sediments was developed through the work of Allen (1965a, 1965b, 1970a, 1970b), Bernard et al. (1970), and Bridge (1975). This theoretical model shows that at bankfull discharge, when helicoidal flow is developed, current velocities and water depth decrease up the point bar slope. This decrease in velocity produces an upward decrease in mean sediment grain size. This research produced a point bar facies sequence consisting of a basal coarse channel lag with mud clasts, pebbles, and woody material, followed by a fining upward sequence of lateral accretion fine sand, and vertical accretion overbank sediments of sand, silt, and clay (Figure 1-2).

Although not well understood, inclined heterolithic stratification (I H S), consisting of alternating sand and mud layers in a vertical section, are an important refinement to the point bar facies model (Thomas et al. 1987). First described by Allen in 1963 as epsilon cross-stratification, recent research has attempted to increase understanding of I H S deposits in the modern and ancient (Calverley 1984; Woods 1985; Piet 1992; Molnar 1994).

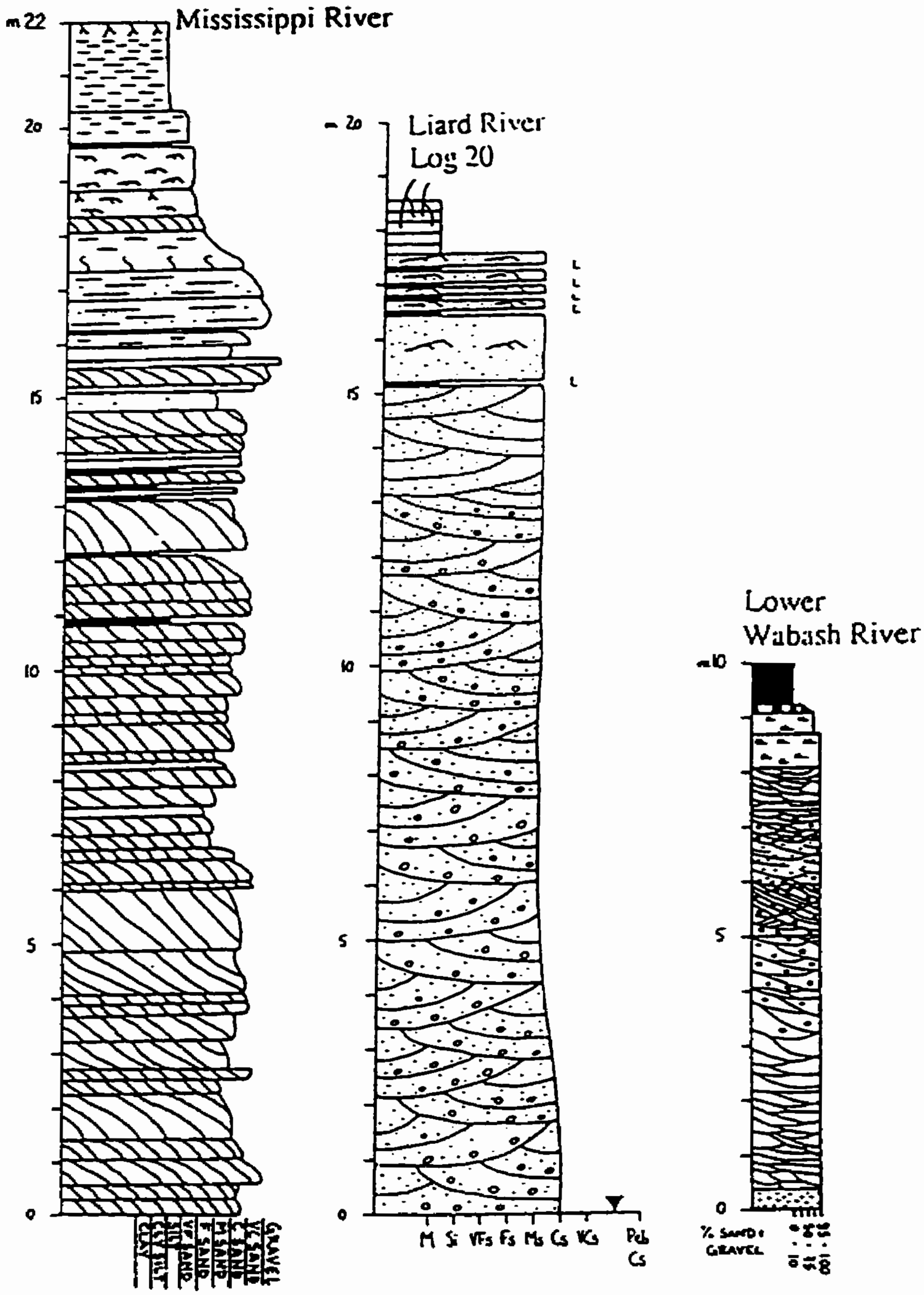


Figure 1-2. Three lithostratigraphic logs of point bar successions. Cores, from left to right, are from the upper Mississippi, the lower Liard and the lower Wabash Rivers. (From Piet 1992).

1.5.2 Eddy Accretions

1.5.2.1 Terminology: Eddy Accretions and Concave-Bank Benches

There has been some confusion in the literature over the terms concave bank benches and eddy accretions. Eddy accretions and concave benches appear similar in aerial photographs, are deposited by similar river processes, and therefore have been discussed as being the same feature (Hickin 1979; Page and Nanson 1982; Nanson and Page 1983; Page 1983). However, they are quite different. Carey (1969) was the first to identify the process of eddy accretion deposition upvalley of a river impingement (abrupt 90° turn) and identified nine features common in all Mississippi River eddy accretions. In rebuttal to Carey (1969), Woodyer (1970) suggests that the river channel turn responsible for eddy accretions formation should not be restricted to 90° because similar concave benches form on 180° turns on the Barwon River in Australia.

Woodyer (1975) studied channel bars, termed concave-bank benches, found along the Barwon River, Australia, and claimed they were similar to the eddy accretions described by Carey (1969); confusion in the literature over the terminology began with this paper. Concave-bank benches found on the Barwon River (Woodyer 1975), are missing six of the nine features that all Mississippi eddy accretions have in common (Carey 1969). The missing features are: (1) the abrupt angle, (2) a powerful pressure eddy (reverse flow), (3) a suction eddy (normal flow), (4) downvalley migration of meanders, and (5) the greatest river depth in the abrupt angle channel. Tributary streams flowing between the eddy accretion and point bar scrolls (6) were also missing but are not an important feature. Due to the differences between Carey's (1969) eddy accretions and Woodyer's (1975) concave-bank benches, it seems that they are related but somewhat different river features. The lack of a 90° turn does not allow the pressure eddy, suction or deep scour to form in concave-bank bench channels. Channel features missing in concave-bank bench channels are all important features in the eddy accretion channels described by Carey (1969) and in this study.

Woodyer (1975) claimed that cutbank erosion and channel migration is not necessary for eddy accretion formation. In contrast to the Mississippi River, the Barwon

River channels are stable and do not allow space for benches to accrete and form floodplain. They form only on 180° bends where flood-scour resulted in expansion of the present channel. Woodyer (1975) speculated that these benches were developed during more moderate flows, in flow separations within the flood-widened channels. Sediments forming concave-bank benches are usually fine-grained silts and clays, and are thought to reflect low energy depositional environments of the original separation zone. A major paradox exists for the concave bench deposits. How can they deposit and still exist as stable channels?

Carey reported Mississippi River channel migration rates of 2.4 km in 80 years (30m/yr) in eddy accretions. In contrast, the Barwon River study reach had not shifted in planform since 1848 (Woodyer 1975). Due to this stability, concave bank deposits or benches can only form in special circumstances where channel expansion favors the development of reverse flow and provides space for bench development. These conditions are associated with 180° bends in the two cases observed in the study reach (Woodyer 1975).

Confusion has been caused in the literature following the Woodyer (1975) paper and subsequent studies of concave-bank bench formation being applied to eddy accretion evolution (Hickin 1979; Page and Nanson 1982; Nanson and Page 1983; Page 1983). Due to the differences in the definitions of eddy accretions (Carey 1969) and concave-bank benches (Woodyer 1975), I propose that they are related, but different features. To determine the differences, I also propose that a subsurface study of concave bench deposits be a next step in meandering river research.

1.5.2.2 Depositional Processes

Carey (1963) determined that meandering river channels change direction in two distinct ways. When flowing through their own alluvial sediments a meandering channel makes sweeping gentle curves as it wanders; this is called a regular bend. When a meandering river channel encounters a resistant non-alluvial material, such as a resistant valley wall or cohesive sediment (clay), it changes direction with an abrupt angle (of approximately 90°). Carey (1963) was the first to recognize the difference between the regular bend and the abrupt angle. In his 1963 literature study, dealing with river hydraulics or the associated branches of hydraulic geometry and stream morphology, no recognition of the fact that streams turn or change direction by the use of these two distinct and different mechanisms was revealed. Carey (1969) likened the processes involved in an abrupt angle on the Mississippi River to a jet impinging on a wall and dividing, part of the flow enters a counter circulation away from the main flow, carrying some of the shear line vortices with it. Carey (1969) estimated that the total energy consumed by an abrupt angle, the energy expended by impingement on the valley wall, plus the energy expended by an enormous pressure eddy, is probably equal to the energy required to overcome flow resistance of several kilometres of normal meandering river channel.

Carey (1963) noted that the Red River in Louisiana, a natural alluvial river, impinges on the erosion-resistant valley wall on one side or the other. These impingements introduce violent hydraulic anomalies into the flow. The Mississippi River, for example, impinges on the valley wall at 17 locations between, Cairo, Illinois, and Baton Rouge, Louisiana, a river distance of 460km. The Red River impinges on its valley walls at 11 locations between Shreveport and the confluence with the Mississippi, a distance of 173km (Carey 1963).

The eddy accretion at Port Hudson on the Mississippi River (Figure 1-3), is so active that over 80 years the accretion migrated 2.4 km downvalley (Carey 1969). Carey (1969) also noted the abrupt angle associated with eddy accretions caused rapid caving and recession of the cutbank and encourages the opposite eddy to accrete a low island in its separation zone instead of a solid accretion to the floodplain. Later, these islands and associated perched channels will become incorporated into the floodplain.

Carey notes that as the entire eddy accretion channel configuration migrates downvalley, the eddy may form either a concave accretion on the upstream shore (the perched channel accretion surface as discussed later), or a concave island (separation zone island as discussed later) within its separation zone, depending upon temporary local conditions. The migration rate of such an island is less than that of the adjacent point bar

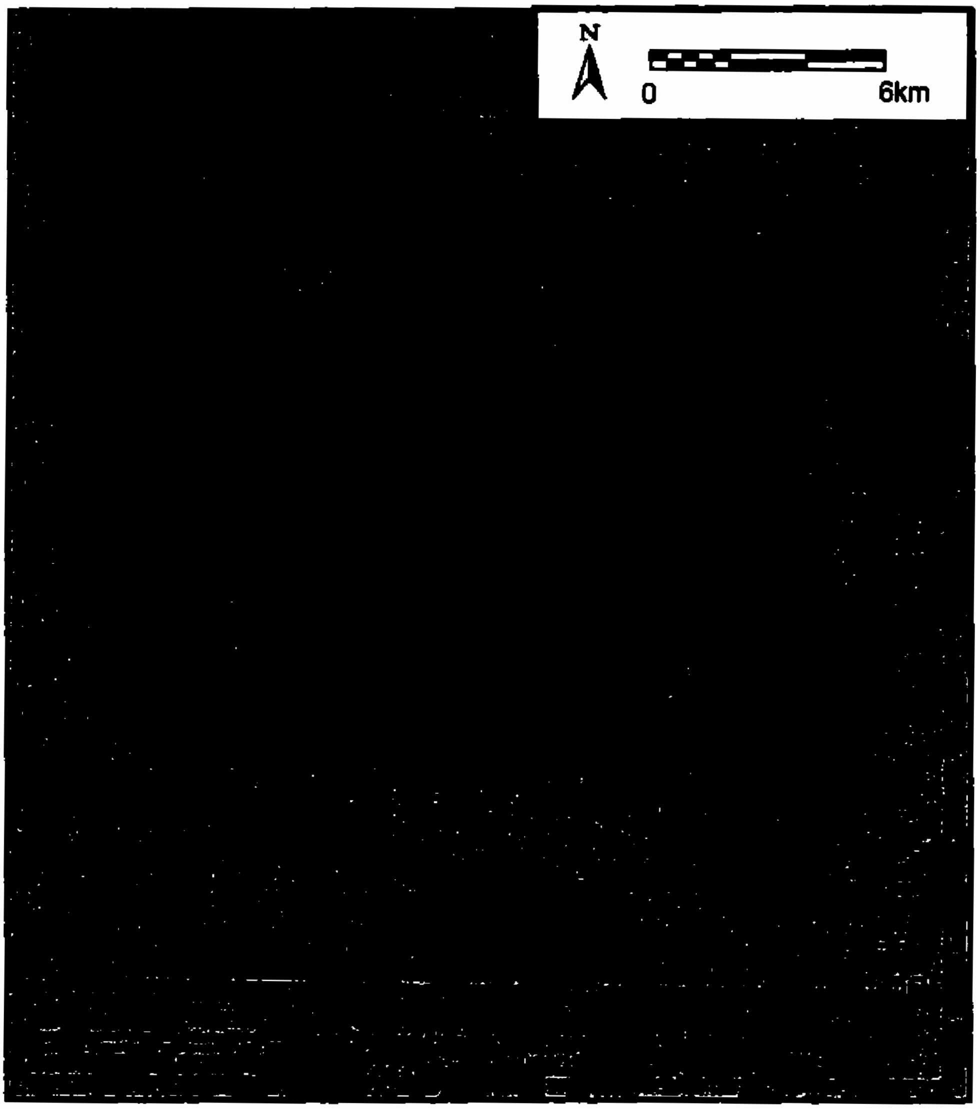


Figure 1-3. An eddy accretion on the Mississippi River at Port Hudson. Ridges that concave downvalley and flank the valley sides delineate eddy accretion deposits.

and all eddy accretion islands are doomed to be left behind to join the floodplain (Carey 1969). The island merges rapidly with the floodplain and remaining open water areas are soon filled in to produce solid, new land. Occasionally, an arcuate-shaped residual lake is left as evidence of the floodplain origin. The identifying characteristic of such features are topographic patterns concave to the active eddy accretion river channel. This is contrary to what is found in point bars, where topographic patterns are convex with respect to the river flow direction.

Carey (1969) states that all eddy accretion channels have the following features in common:

1) An abrupt-angle change of channel direction due to impingement on an erosion-resistant valley wall with the central angle generally greater than 90°.
2) A powerful pressure eddy (reverse flow) upstream of the impingement (Figure 1-4).
3) A suction eddy (normal flow) just upstream of the impingement (Figure 1-4).
4) Contours and other topographic features are concave with respect to the active river channel flow direction within the valley (downvalley).
5) Cutbank erosion as the system migrates downvalley.
6) High silt and clay content at the surface, higher than any other alluvial deposit other than "back-swamp" clays. It appears that a substantial part of the organic matter carried by the river lodges in these eddy deposits.
7) Greatest river depth occurring at abrupt angles. On the Mississippi, below the Old River, these depths range up to 60m.
8) Lower elevation than point bars or natural levees; such deposits remain low and swampy indefinitely.
9) Small streams commonly flow from the valley side down along the depression between the point bar and eddy accretion scrolls.

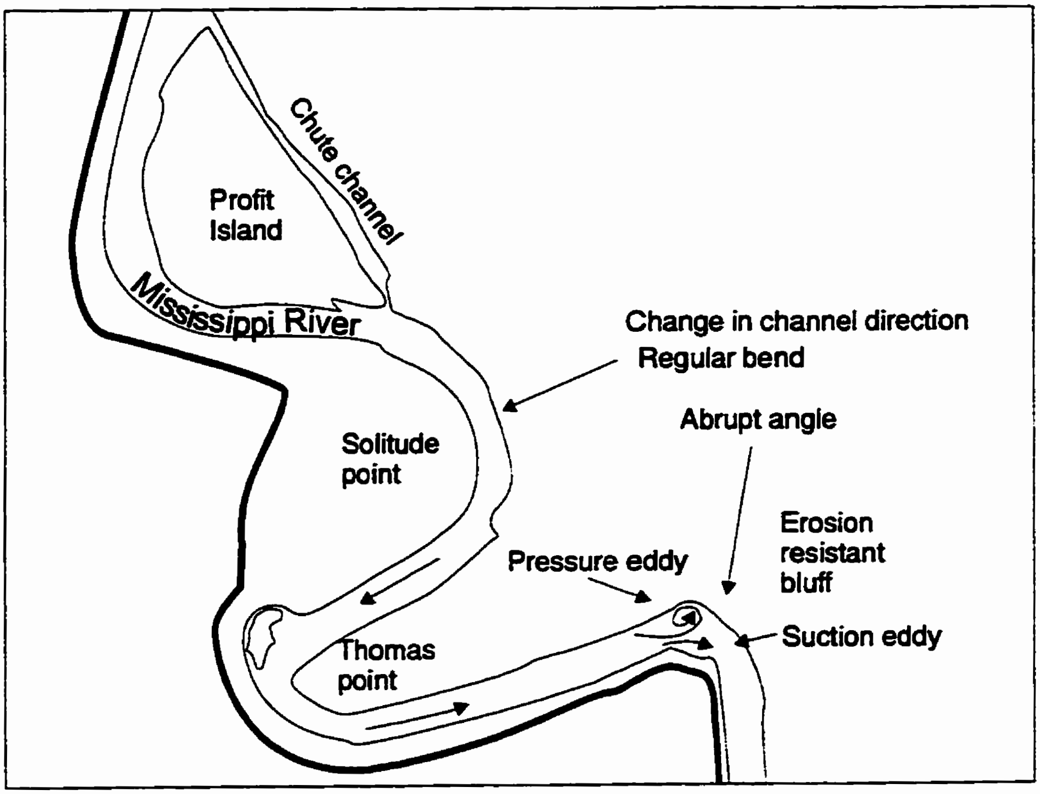


Figure 1-4. The Mississippi River showing an abrupt angle and regular bend. Note the location of the pressure eddy (reverse flow) and the suction eddy (normal flow). (After Carey 1969)

Woodyer (1975) suggested that concave-bank benches found along the Barwon River, Australia, were similar to eddy accretions. In contrast to the Mississippi River eddy accretions, the Barwon channel is stable. Concave-bank benches form only on "hairpin bends" (180°) where channel expansion occurs. These benches consist of muddy sediments deposited adjacent to the outside channel bank and are deposited in a gentle reverse flow upstream of the apex of the bend. Woodyer (1975) noted that the pattern of deposition suggests an association between turbulence, at the interface between upstream and downstream flow. He determined the rate of aggradation on concave-benches to be very rapid, 48-64 mm per year, even though the channel has been stable for 130 years.

Woodyer, Taylor, and Crook (1979) identified three different in-channel bench forms including concave-bank benches and stated that normally only fine suspended sediments are drawn into the reverse flow over the concave-benches in spite of marked macroturbulence along the interface between the main stream and the reverse flow.

In Canada, eddy accretions are common in Pleistocene river valleys occupied by contemporary under-fit streams and these deposits may contribute significantly to floodplain formation (Page and Nanson 1982). On the Fort Nelson River in northeastern British Columbia, an estimated 30 % of the floodplain is composed of eddy accretion deposits (Figure 1-5; Page and Nanson 1982).

Page and Nanson (1982) predicted that on confined meandering rivers where concave benches are commonly associated with rapid channel migration, appreciable amounts of fine sand and mud can be deposited by within-channel lateral deposition of eddy accretions. Eddy accretions develop against the upstream limb of the concave bank of abruptly curving meander bends, and were thought to be formed of mainly fine suspended load (Page and Nanson 1982). They thought that erosion of the upstream limb of the convex bank widened the channel, producing a zone of expanded flow which facilitates flow separation near the upstream limb of the opposite concave bank. A platform of sand in the form of a longitudinal-shaped bar is deposited into this zone, followed by further aggradation of fine sand, mud and organic matter. Even when fully

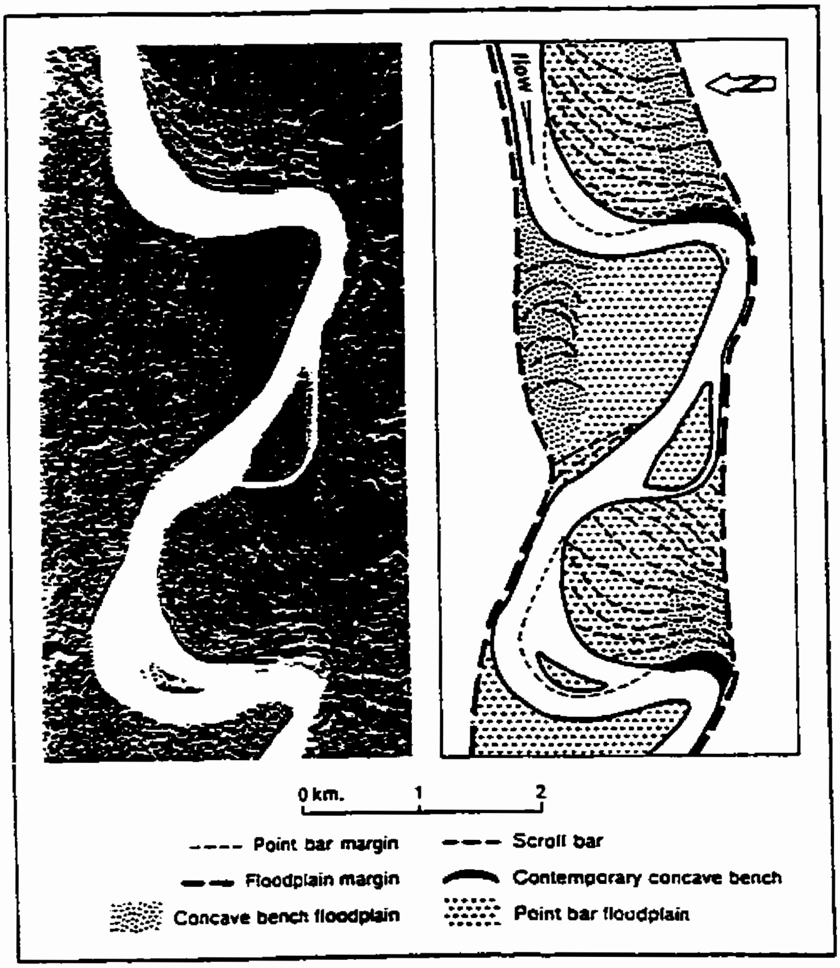


Figure 1-5 Confined meanders of the Fort Nelson River, British Columbia. On this reach 30% of the floodplain area results from eddy accretion deposition. (from Page and Nanson 1982).

formed, at high flow the concave bench remains isolated from the rest of the floodplain by a secondary channel around the margin of the original concave bank of the main channel. According to Page and Nanson (1982), with continued downvalley migration of the meander bend, another concave bench is formed and this process continues until eventually new floodplain surfaces are locally created by the lateral accretion of these benches.

Hickin (1979) used the term concave-bank bench as introduced by Woodyer (1975) to describe within channel features on the Squamish River in coastal British Columbia. He described the form, sediments, and possible origin of two concave-bank benches in this gravel-bed stream. He found the concave-bank benches in the Squamish River contain only fine-grained sand and silt and claimed they are generally similar to features on the Barwon River, Australia. Hickin (1979) found one major difference between the two examples; the Squamish River benches consist of fine sand and silt, while the Barwon River bench is composed of silt and clay due to the difference in sediment supply or channel slope.

One concave-bank bench on the Squamish River was a mature feature and the other was actively being formed. Evidence from the latter indicates that the features, like those on the Barwon River, are deposited in the separation zones developed at the concave bank of very sharp bends (Hickin 1979). Sediment appears to be supplied from suspension in dissipation vortices advected into the separation zone. Hickin (1979) thought it likely that these types of features will develop in any channel where the bend curvature is such that flow separation occurs along the concave bank.

There is little data on eddy accretion or concave-bank bench channel shape. Hickin (1979) shows a bottom profile from the active channel forming the concave-bank bench. This profile shows flow separation, a deep scour in the main channel, and reverse flow in a perched channel (Figure 1.6). This bottom profile is very similar to those collected by the author on the Kootenay River, British Columbia, and the Beaver River, Alberta.

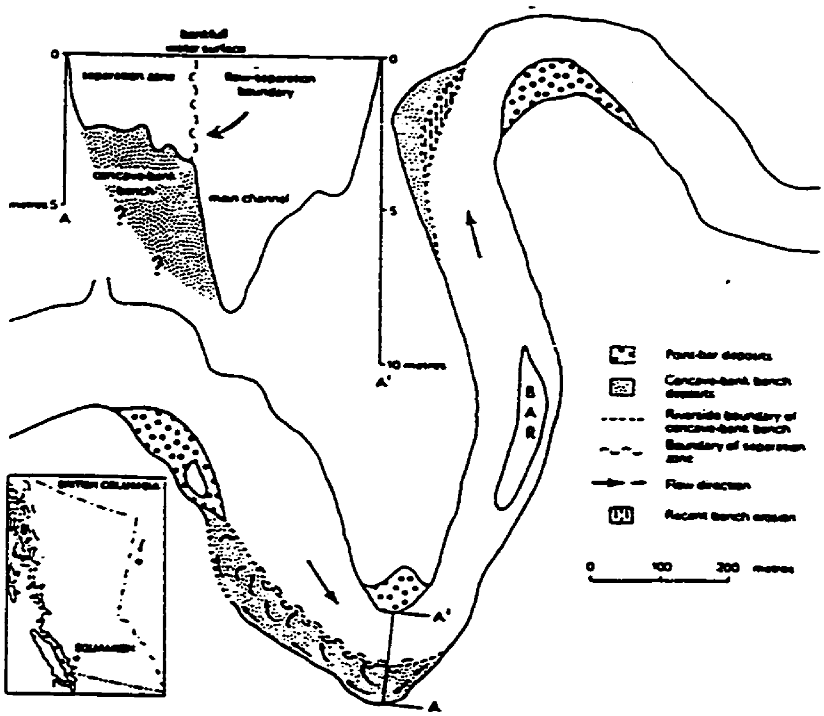


Figure 1-6. Map of two concave benches on the Squamish River, British Columbia. Bottom profile of the 8m deep scour in the main channel and the perched channel with reverse flow. (from Hickin 1979)

Page and Nanson (1982) examined the formation of concave-bank benches on a reach of the Murrumbidgee River, New South Wales, Australia, where sequential development is readily apparent. They identified eddy accretion evolution from aerial photographs and field surveys of the Murrumbridgee River, Australia. They produced a general model from concave-bank benches (separation zone islands) at different stages of development. The model involves sequential phases of convex bank retreat and flow expansion, basal bar-bench nucleus, and mature bench formation (Figure 1-7). This model is based on aerial photographs and has had little field verification. The matter of eddy accretion evolution and deposition is still open to interpretation and debate.

1.5.2.3 Sedimentology

Carey (1969) identified the surface of eddy accretions as having higher silt and clay content than any other alluvial deposit other than "back-swamp" clays. He also noticed that a substantial part of the organic matter carried by a river lodges in these eddy deposits. Also on the Mississippi, Farrell (1987) found laminated fine grained sand at the eddy accretion ridge margin, and alternating sand and clay layers that are replaced by laminated rooted clays upsection in the swale. Saucier (1994) noted that at the surface, eddy accretion deposits in the Mississippi near Baton Rouge consist of extremely loose clayey silt and fine sand that are strikingly different from upstream and downstream point bar deposits. At the surface, a shallow lake or swampy depression occurs rather than typical point bar topography (Saucier 1994).

Hickin (1979) also noted that concave-bank bench surface sediments are formed mainly by deposition of the fine sand, and concluded that only fine suspended sediments are normally drawn into the reverse flow over the concave-benches in spite of marked macroturbulence along the interface between the main stream and reverse flow. He noted the major difference between the Barwon River and Squamish River benches is that the Squamish River benches consist of fine sand and silt, while the Barwon River bench is composed of silt and clay due to the difference in sediment supply.

Page and Nanson (1982) examined the sedimentology of a concave-bank bench on the Barwon River through auger holes sunk to just below the water table (up to 5.5m

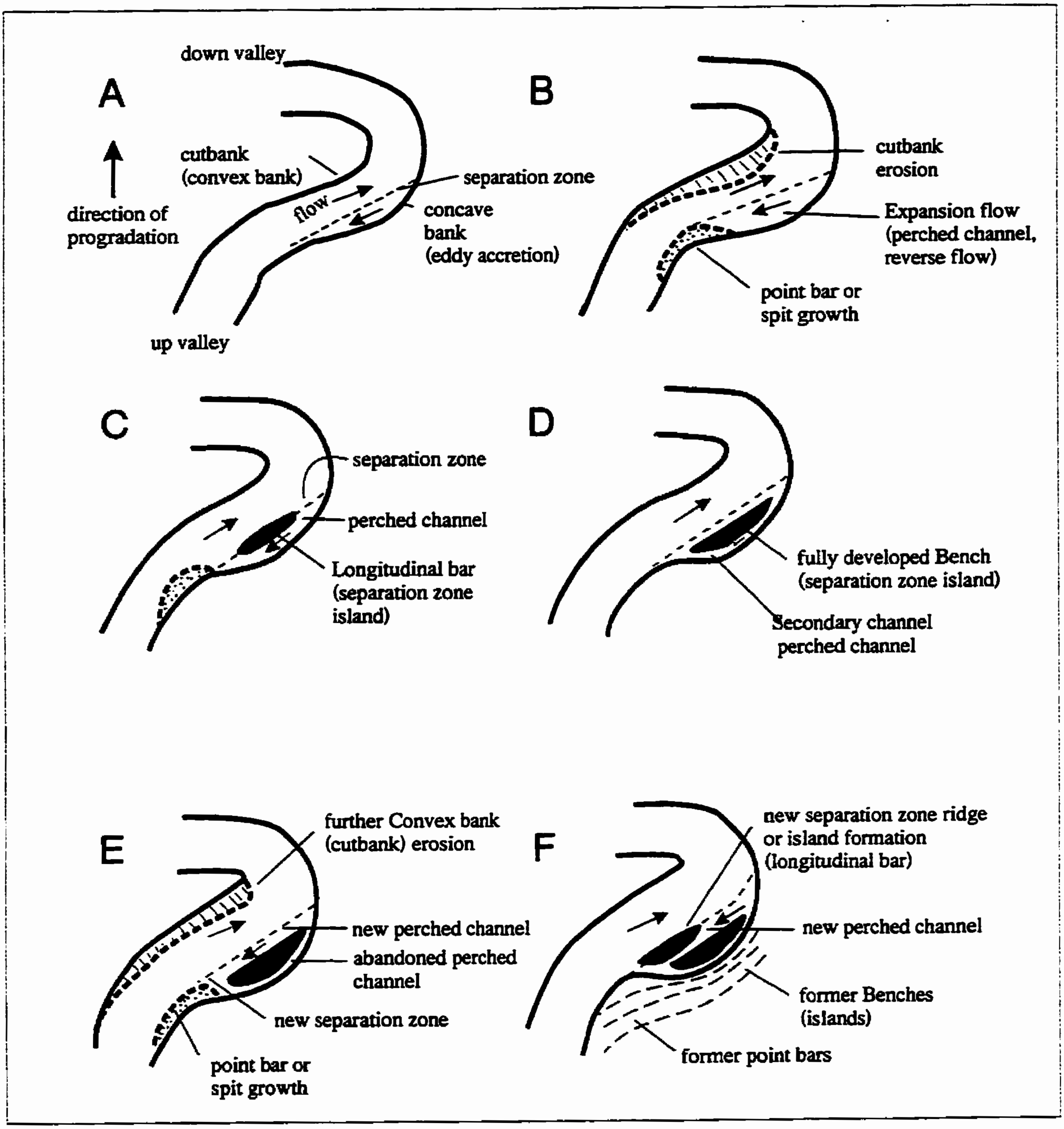


Figure 1-7. Generalized model of concave-bank bench evolution.
(After Page and Nanson 1982)

depth). They found that well sorted medium sand forms the lower deposit and 4m of silt and clay interbeded with organic detritus immediately overlie the sand on the upstream limb (Figure 1.8).

In river valleys where eddy accretions occur on both sides, as demonstrated by a large number of Pleistocene meltwater spillway valleys containing confined meandering streams in western Canada (Page and Nanson 1982), the downstream limb of each point bar grades into an eddy accretion upstream of each eddy accretion. Page and Nanson (1982) suggest that the downvalley sweep of the meander train results in a mid-valley swath of coarse sediment trailing the migratory point bar, grading into a swath of largely fine-grained organic-rich eddy accretion deposits adjoining each valley wall (Figure 1-5).

Nanson and Page (1983) were the first to estimate the geometry of juxtaposed eddy accretion and point bar deposits (Figure 1-9). This sequence was interpretive, particularly in respect to the detailed architecture of the contiguous eddy accretion deposits in a migrating channel. The measured sedimentology and geometry of eddy accretions and adjacent point bars is shown in chapter 4.

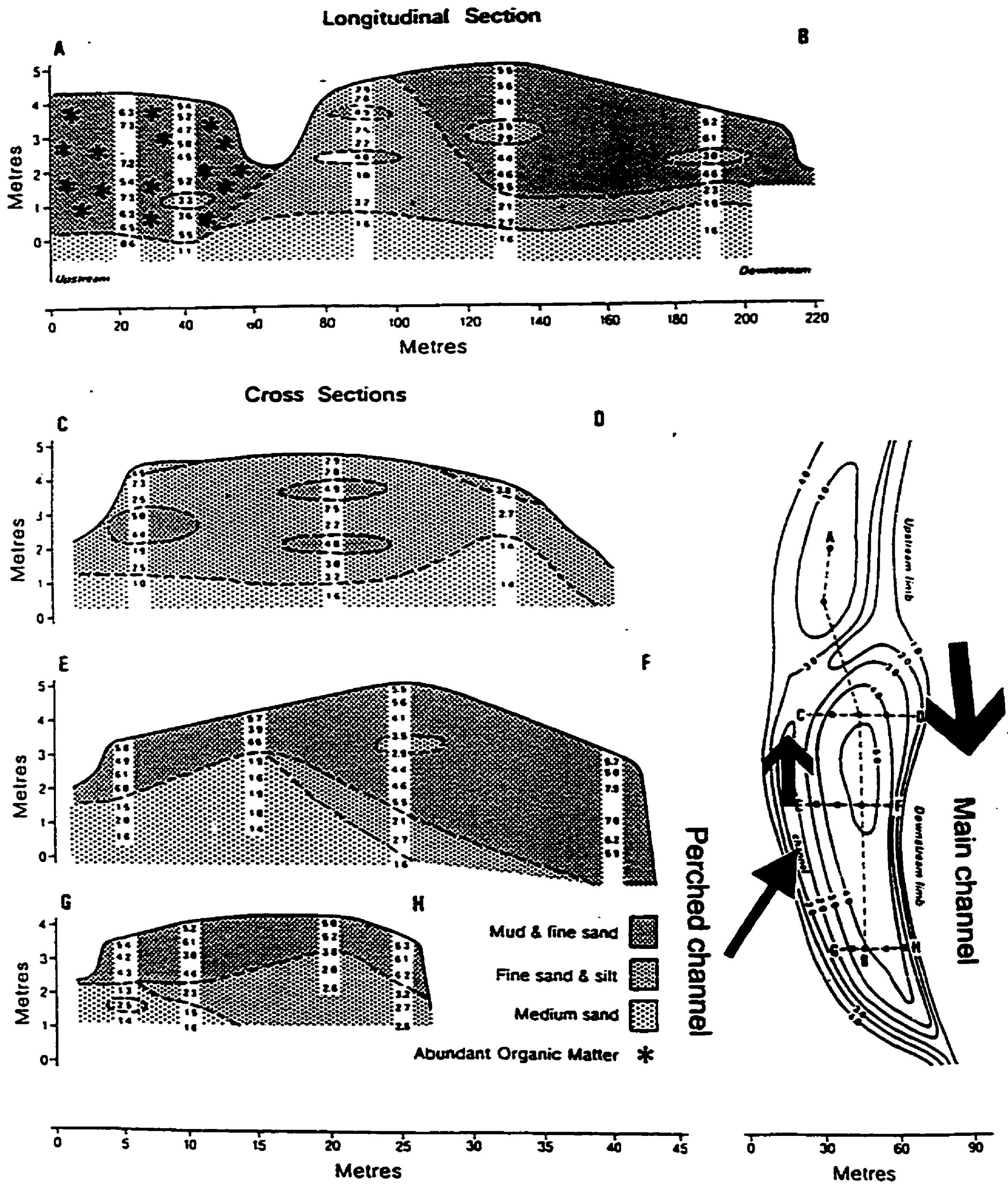


Figure 1-8. Sediment composition of concave-bank bench on the Murrumbidgee River, Australia. (from Page and Nanson 1982)

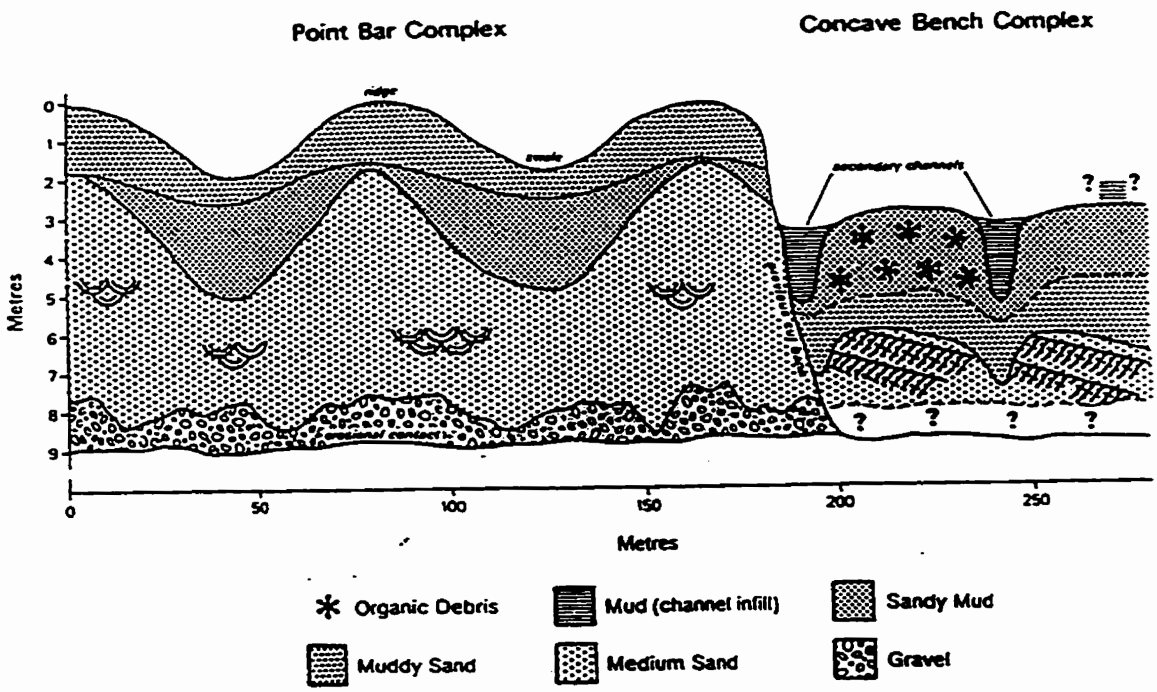


Figure 1-9. Schematic drawing of the hypothesized architecture of point bar and adjacent concave-bank bench facies on the Murrumbidgee River. This was the first figure to try to show the sediment geometry. Section is perpendicular to scroll pattern. (From Nanson and Page 1983)

2. CHAPTER TWO REGIONAL SETTING

2.1 Introduction

Two rivers containing eddy accretion deposits were studied for this thesis, the Kootenay River, British Columbia, and the Beaver River, Alberta. The Kootenay is a tributary of the Columbia River, which discharges into the Pacific Ocean; the Beaver is a tributary of the Churchill River, which discharges into Hudson Bay (Figure 2-1).

2.2 Kootenay River, British Columbia

The upper Kootenay River flows south within the Rocky Mountains between the Park Mountain Ranges to the east and the Kootenay Mountain Ranges to the west. The Kootenay River enters the Rocky Mountain Trench at Canal Flats where it turns south and flows into Lake Koocanusa which extends across the Canada-U.S. border into Montana. After entering Montana, the Kootenay arcs north and flows back into British Columbia into Kootenay Lake at Creston, B.C. The Kootenay River exits Kootenay Lake at Nelson and flows to Castlegar where it enters the Columbia River which empties into the Pacific Ocean at Astoria, Oregon.

The Kootenay River study area is located approximately 3 km south of the town of Wasa, B.C. Here, the Kootenay River floodplain is 1km wide and is confined on both sides by bedrock or glacier till with eddy accretion deposits on both sides of the floodplain.

2.2.1 Regional Physiology

The study reach of the Kootenay River lies in the Rocky Mountain Trench, which is an extensive, arcuate-shaped, composite, faulted valley that extends along the Cordillera for 2500 km, from east-central Alaska to northwestern Montana. On a regional scale this composite fault is parallel with the tectonic strike of the Canadian segment of the Cordillera (B.C. Hydro and Power Authority 1978). The Rocky Mountain Trench is bounded to the west by Precambrian metasedimentary rocks of the Purcell Mountains, formed during the early Cretaceous Colombian Orogeny, and to the east by

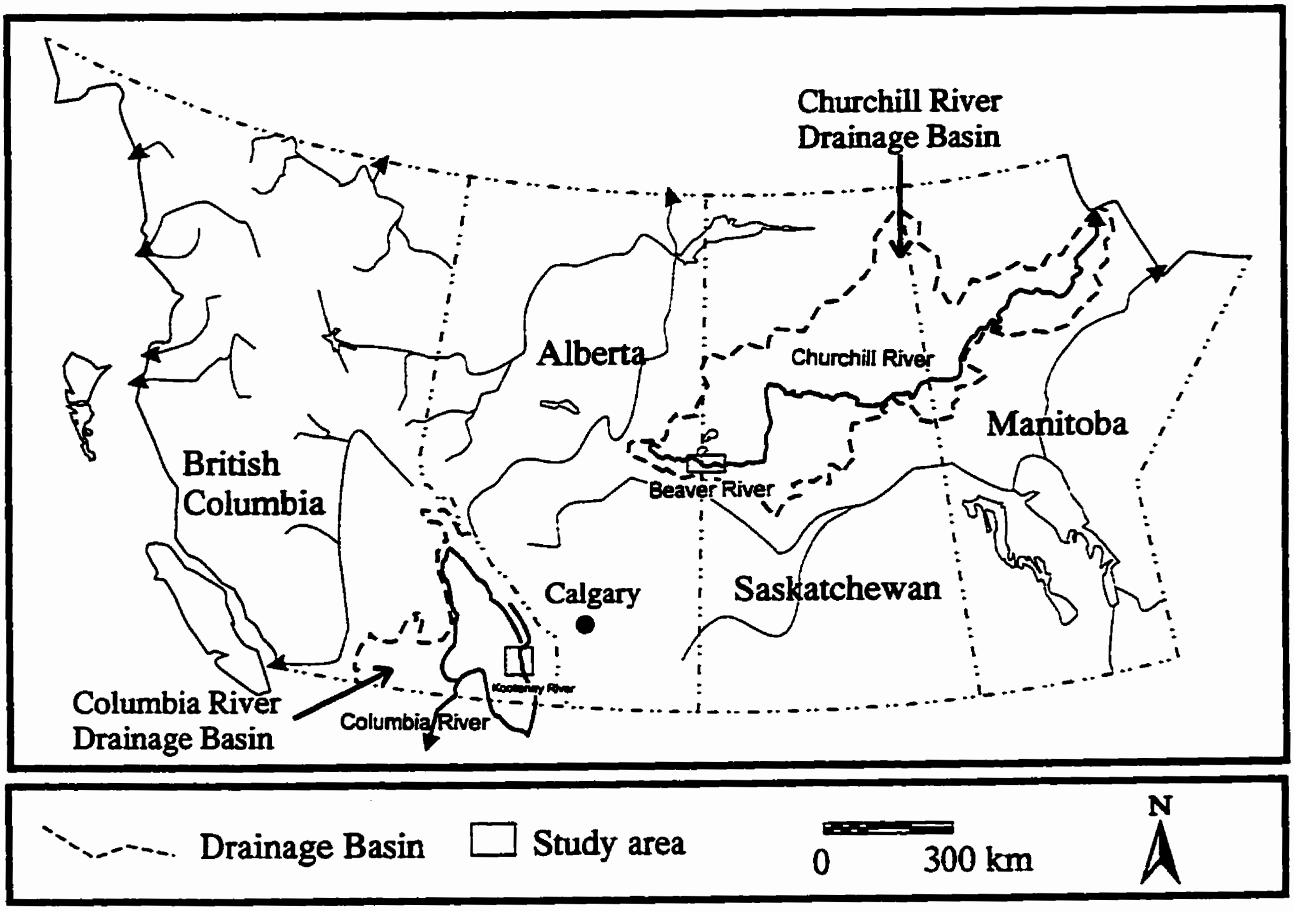


Figure 2-1. Locations of study areas on the Kootenay River, British Columbia, and Beaver River, Alberta. Also shown are the drainage basins of the Columbia River, into which the Kootenay River flows, and the Churchill River into which the Beaver River flows.

Precambrian to mid-paleozoic sedimentary rocks of the Rocky Mountains, formed during the Late Cretaceous-Tertiary Larimide Orogeny (B.C. Hydro and Power Authority 1978).

2.2.2 Quaternary Geology

The southern Rocky Mountain Trench was a major outlet valley of the British Columbian Cordilleran Ice Sheet during the Quaternary. Overlying the floor of the trench in southeastern British Columbia glacial, glaciofluvial, and glaciolacustrine sediments were deposited during the Fraser Glaciation (Late Wisconsinan), and fluvial and lacustrine sediments deposited during the preceding interglaciation (Clague 1975a).

Deposits of three stades and two nonglacial intervals are recognized (Clague 1975a). Interglacial sediments which contain wood dated at 26 800 ±1000 B.P. underlie drift of the early stade (Clague 1975a). During the interval between the early and middle stades, the Rocky Mountain Trench in southeastern British Columbia was probably completely deglaciated, and sediments were deposited in one or more lakes on the floor of the Trench. In contrast, glacier recession between the middle and late stades was of short duration and extent. Glaciolacustrine sediments were deposited only along the margins of the Rocky Mountain Trench, and residual ice may have remained in the center of the valley. Final recession of the trunk glacier occurred prior to 10 000 B.P. with no major halts and without significant stagnation of the terminus (Clague 1975a).

The Rocky Mountain Trench acted as a major channel for melt water during the retreat of the Cordilleran glacier from southern British Columbia. Wasting ice located in the Trench and flanking Rocky and Purcell Mountains contributed to meltwater which flowed south past 49° latitude (Clague 1975b).

Deposits and landforms of the southern Rocky Mountain Trench record late glacial events. The flat valley floor is largely ground mantled with moraine and drumlins parallel to the Trench. This till plain is traversed by meltwater channels, many of which are underlain by outwash. Large glacial outwash plains and kame terraces occur along the margins of the trench (Clague 1975b).

2.2.3 Hydrology

The area of the Kootenay River drainage basin is 7120 km^2 measured from the Skookumchuck gauging station 12 km upstream of the study area (Figure 2-2). The average monthly discharge hydrograph for the Kootenay River shows the maximum monthly discharge, caused by spring snow melt, occurs in June (Figure 2-3). The Lussier River enters the Kootenay River downstream of the gauging station, it is a small river with few years of data, and therefore will not be considered.

2.3 Beaver River, Alberta

The Beaver River study area is located on the Alberta-Saskatchewan border near the town of Cold Lake, Alberta. The river flows east from Beaver Lake in east-central Alberta to join the Churchill River in west-central Saskatchewan. The Churchill River continues east through many small lakes into Manitoba where it turns northeast and discharges into Hudson Bay, at the town of Churchill, Manitoba.

The study area is located 5km south of the hamlet of Cherry Grove near Cold Lake, Alberta. It occupies a deep glacial meltwater channel cut into bedrock, gravel and till (Fenton and Andriashek 1983). The meandering river has rare oxbow lakes because it is confined by the valley walls. Aerial photographs show eddy accretions on every meander throughout most of the valley.

2.3.1 Regional Physiology

The regional physiography of the Cold Lake area is quite flat, dominated by low undulating hills with many lakes. The Lea Park Formation underlies the Cold Lake area with marine dark gray shale, glauconitic and silty marine shale with iron stone concretions (Fenton and Andriashek 1983). These rocks likely form the Beaver valley walls.

2.3.2 Quaternary Geology

During the last glaciation, the interior plains were covered by the Laurentide ice sheet. In the Cold Lake area ice flowed from the northeast to the southwest and deglaciation occurred at 11,500 BP (Dyke and Prest 1987). The Cold Lake area is

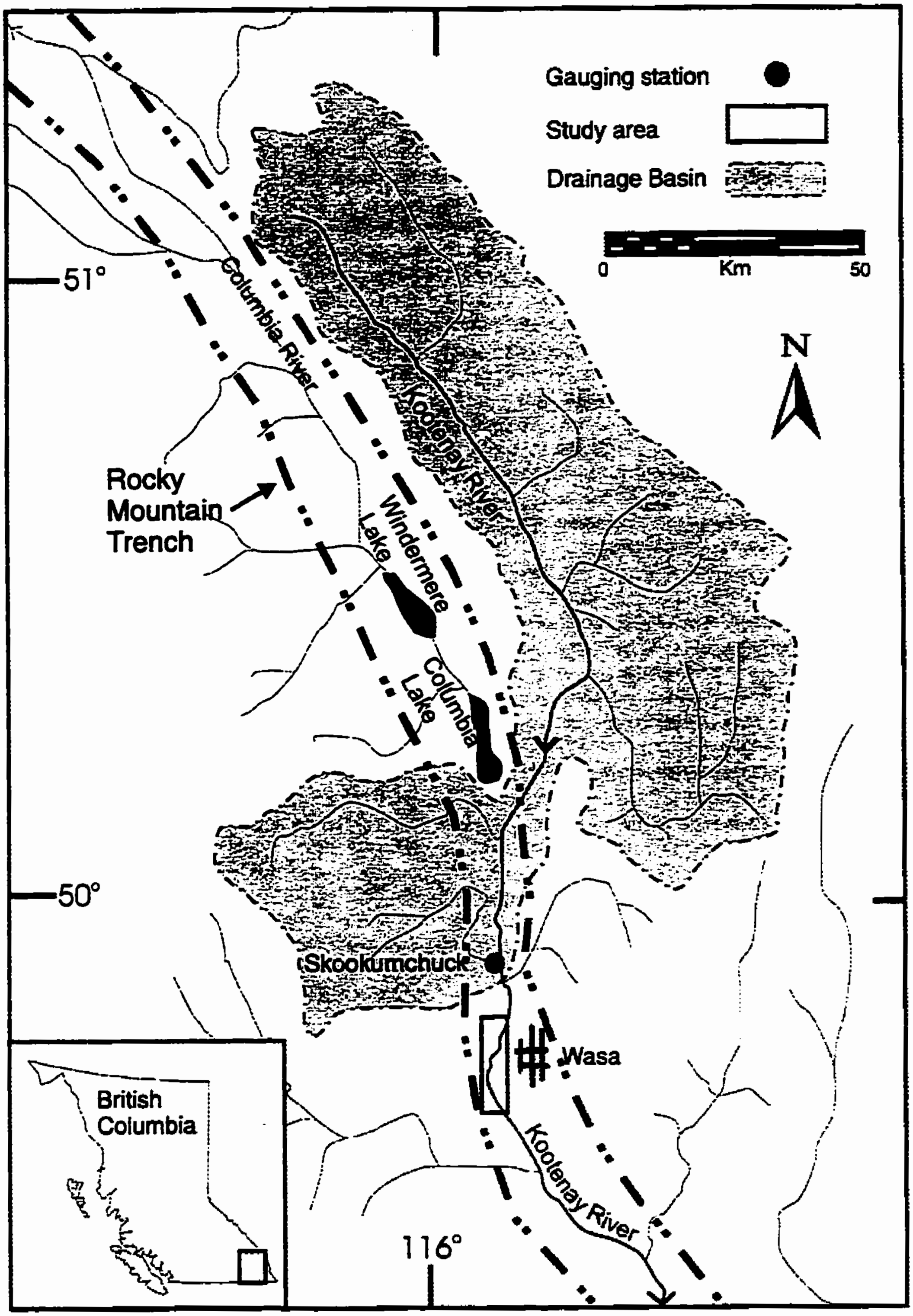


Figure 2-2. Kootenay River drainage basin and gauging station location.

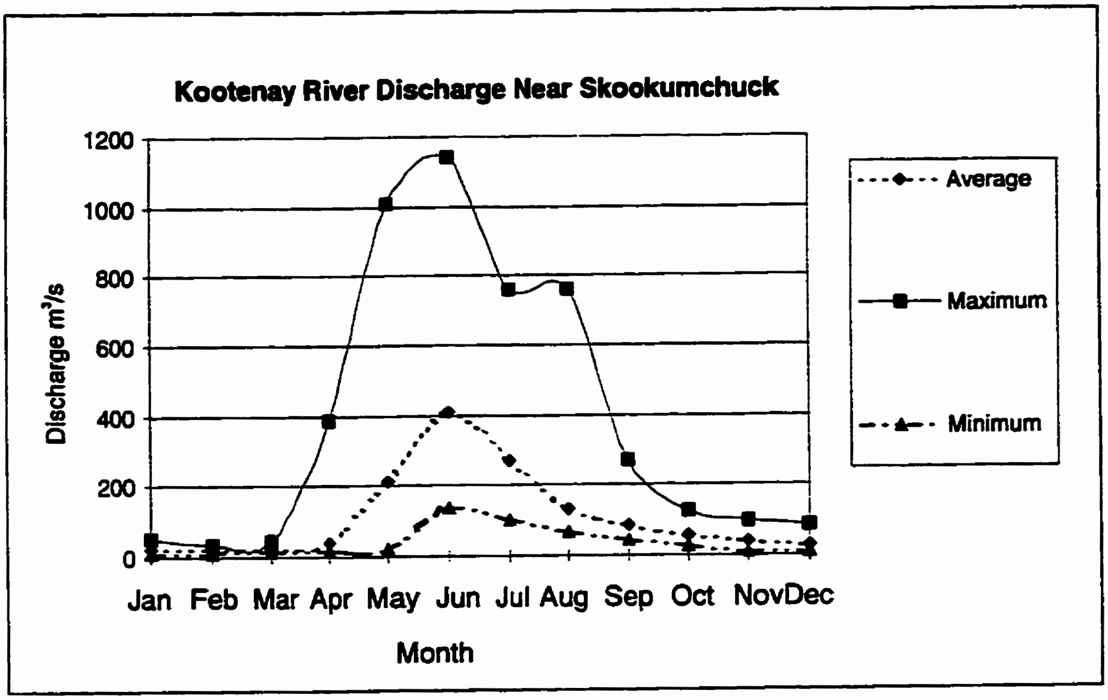


Figure 2-3. Average, maximun, and minimum monthly mean discharge of the Kootenay River near Skookumchuck (1950-1994; Water Survey of Canada 1994).

covered by moraine and glaciofluvial gravel with numerous meltwater channels running north-south and east-west in the area (Fenton and Andiashek 1983).

2.3.3 Hydrology

The effective area of the Beaver River drainage basin is 11 600 km^2, with a gross area of 14 500 km^2, measured from the Cold Lake gauging station 20km upstream of the study area (Figure 2-4). The difference in effective and gross basin area is due to numerous small closed basins within the main Beaver River basin, due to the flat lying topography. The average monthly discharge hydrograph for the Beaver River shows the maximum monthly discharge, caused by spring snow melt, occurs in May (Figure 2-5). Large discharges may also occur in June in response to summer rainstorms.

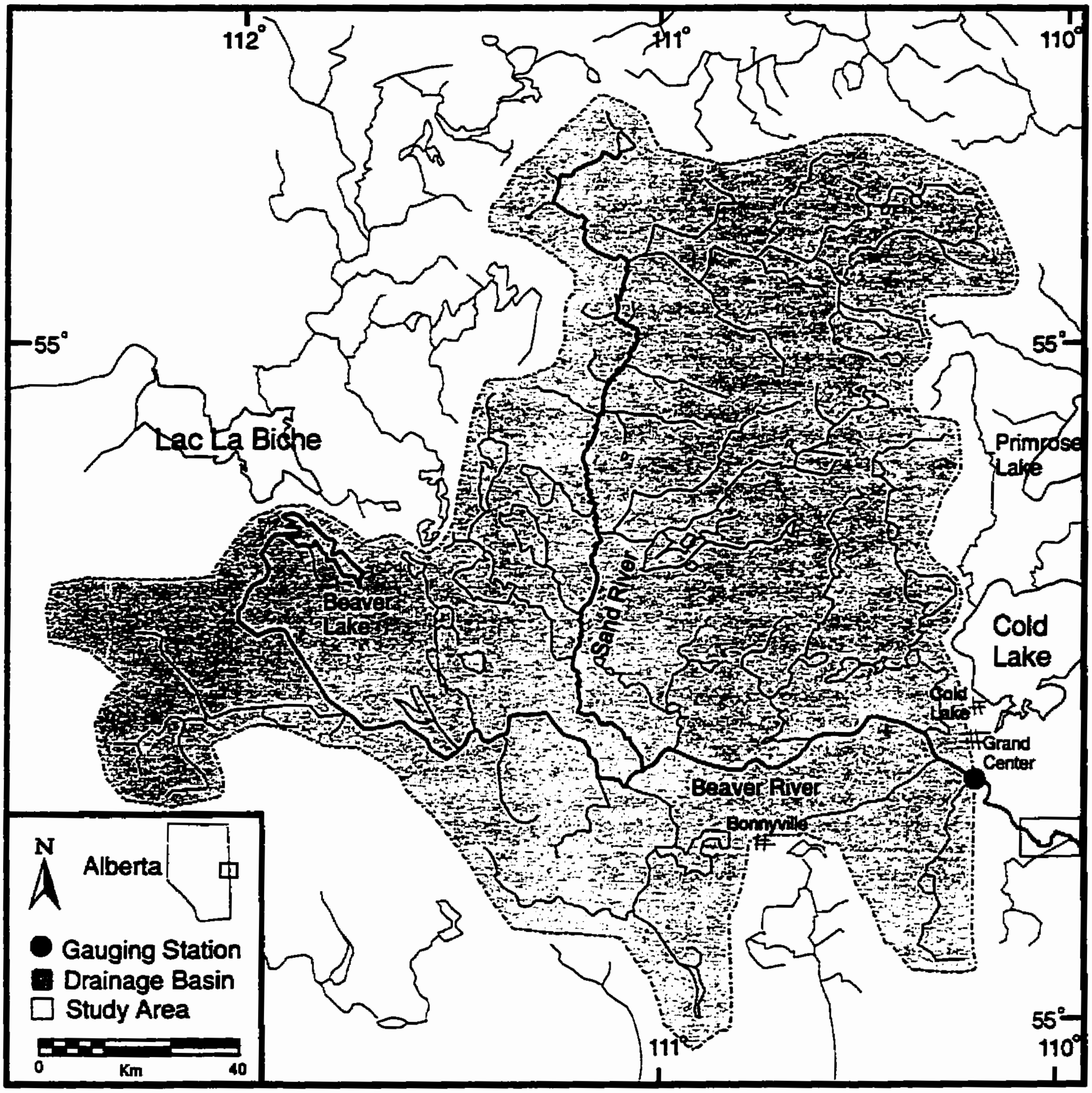


Figure 2-4. Beaver River drainage basin and gauging station location.

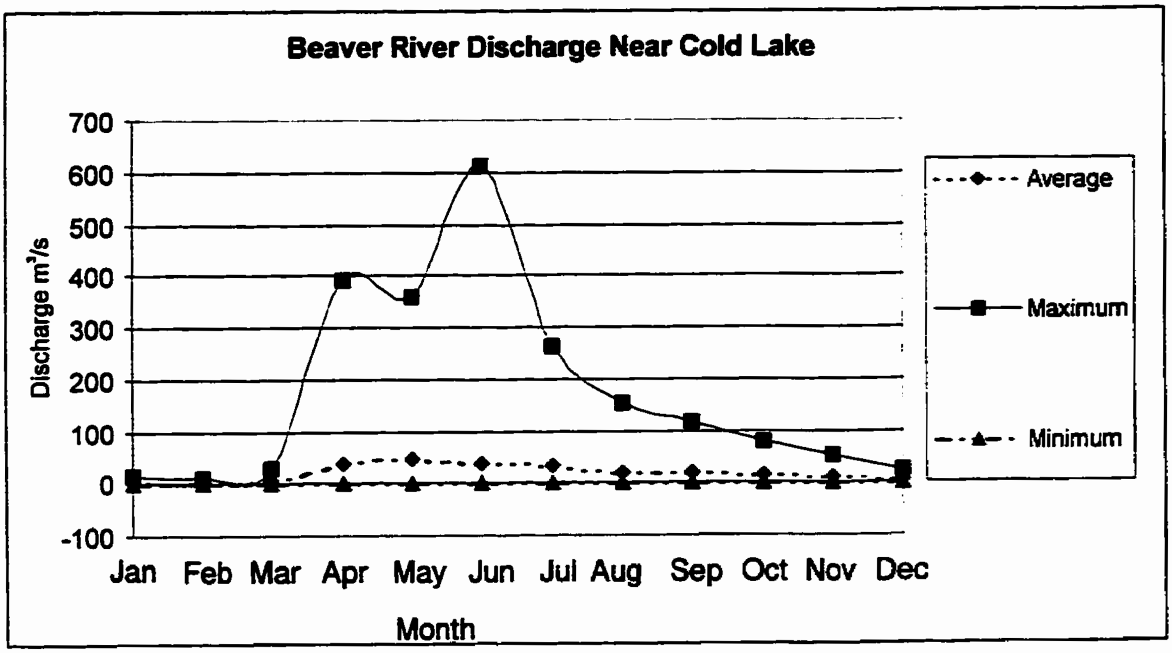


Figure 2-5. Average, maximum, and minimum monthly mean discharge of the Beaver River near Cold Lake (1955-1994; Water Survey of Canada 1994).

3. CHAPTER THREE RESEARCH METHODOLOGY

3.1 Field Methods

Six field methods were employed during the research program: vibracoring, lithostratigraphic logging, geophysical bottom profiling, flow velocity measurement, aerial photographic interpretation, and topographic and planform surveying. Aerial photographs were used prior to field work to identify potential field sites and potential core sites. Vibracoring, lithostratigraphic logging, cross-sectional bottom profiling of river channels and river velocity measurements were used to investigate the river geomorphic and depositional processes. Lithostratigraphic logs were analyzed to determine lithofacies and the related depositional processes. Cross-valley lithostratigraphic profiles from vibracores illustrate the architectural geometry of valleys containing eddy accretions.

3.1.1 Vibracoring

Construction of lithostratigraphic logs from vibracores was the principal field method. Vibracores were taken across the Kootenay and Beaver Rivers to determine subsurface cross-valley profiles. The vibracorer was used for this field research because it is portable, can obtain long continuous cores and is relatively inexpensive.

At the Kootenay River site, vibracores were taken at 200m intervals perpendicular to the axis of an eddy accretion deposit, starting at the west valley edge and proceeding across the valley along the channel levee. At the Beaver River site, coring followed a straight road across the floodplain which lies perpendicular to the axis of the eddy accretion deposit. In total 19 cores were taken from both rivers.

3.1.1.1 Vibracorer System

The vibracorer is a coring system that vibrates core pipe into unconsolidated saturated sediment (sand, silt, clay and peat). The vibracorer was designed by D.G. Smith at the University of Calgary in the 1980's. Weighing approximately 50 kg, the vibracorer consists of nine main parts: the gasoline-powered engine, flex-cable, vibrahead, core pipe, core coupler, core catcher, folding aluminum jaws ladder, ratchet hoist, and core troughs (Figure 3-1). To increase depth, a core casing, and a flushing pump system was used.

3.1.1.1.1 Gasoline-powered engine

A five horse power Briggs and Stratton gasoline engine mounted on a steel wheel-barrow-shaped platform supplies power for the vibration of the core pipe, through an attached flex-cable inside a rubber housing (Figure 3.1).

3.1.1.1.2 Flex-cable (Jack cable)

The flex-cable transfers power from the vibra-motor to the vibrahead. The flex-cable is a strong 8m long steel wire which spins inside a rubber hose-like housing (4 cm in diameter).

3.1.1.1.3 Vibrahead

The vibrahead is a steel device that creates vibration, translating it to the core pipe. Vibration is created by the off balance steel camshaft spinning inside the external casing. The vibrahead is permanently attached to the flex-cable and temporarily clamps to the core pipe by a round 15cm long clamp permanently bolted to the vibrahead. The core pipe slides into the clamp and is temporarily secured by two bolts (Figure 3.1).

3.1.1.1.4 Core pipe

The core pipe is standard thin-walled, 6m long and 7.6cm diameter, aluminum irrigation pipe that penetrates into and holds sediment.

3.1.1.1.5 Core coupler

Core couplers attach (couple) one pipe to another in a chain, allowing deeper penetration. Couplers consist of a 30cm long aluminum pipe with a slit cut in one side and flanges (3cm high) located on each side of the slit. A coupler is slightly larger in diameter than the core pipe, allowing the pipe to slide in and out easily. Four bolts, through the two flanges, clamp the coupler to each core pipe, thereby holding the pipes together.

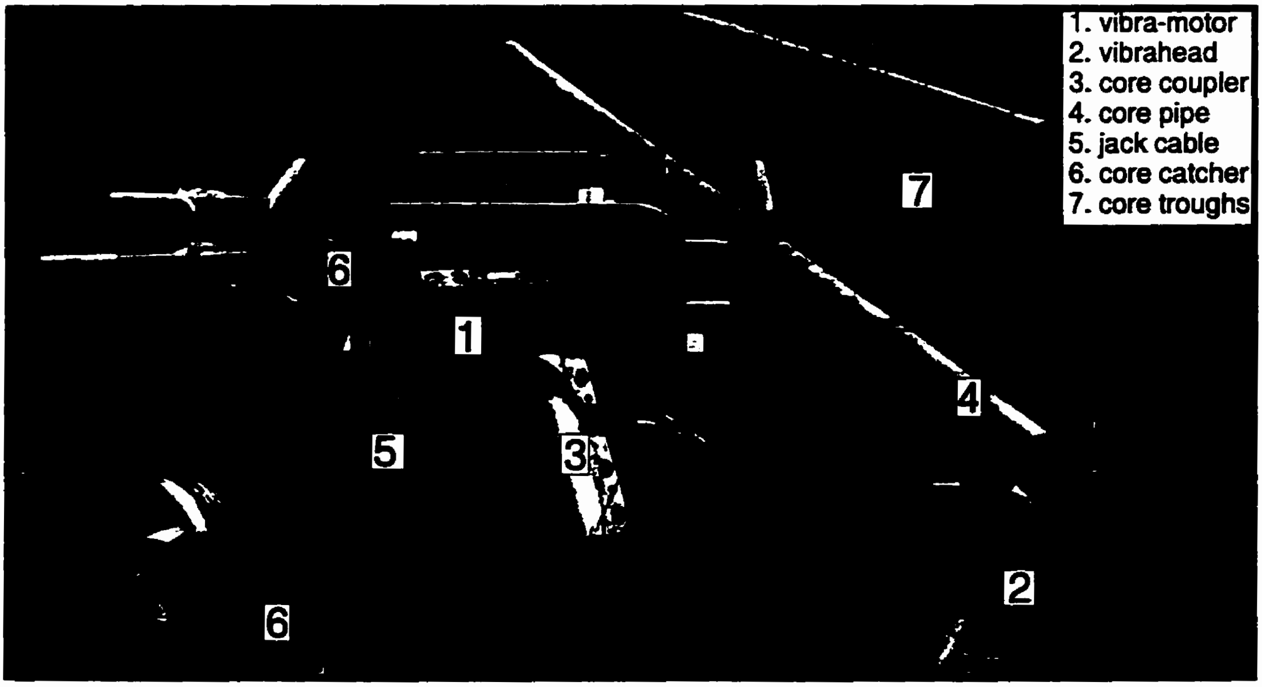


Figure 3-1. Vibracorer system consisting of nine main parts. Seven of the nine parts listed 1 to 7. Missing are the ratchet hoist, folding aluminum jaws ladder, and core casing.

3.1.1.1.6 Core catcher

The core catcher is a hardened steel device that, like a one-way valve, stops the sediment from sliding out of the core pipe during retrieval. It fits tightly over the end of the core pipe and is attached by four small screws. It consists of a steel outer ring, blunt on one end and sharp on the other, and a series of brass fingers. The brass fingers are riveted inside the outer ring so that they will be pushed back as the sediment enters the pipe and come together as the pipe is extracted, holding the sediment in place. After extraction, the core catcher must be taken off to retrieve the sediment core from within the core pipe.

3.1.1.1.7 Ratchet hoist and folding aluminum jaws ladder

The ratchet hoist is a standard 1 500kg winch that draws in a chain as the handle is cranked or ratcheted. The collapsible aluminum jaws ladder is a folding ladder that forms a 2m tall "A" shape when extended. The hoist is secured to the top of the ladder and tied to the pipe with a large rope in a prusik knot (a mountain climbing knot that only slips one way). As the ratchet is cranked, the pipe is slowly extracted from the ground.

3.1.1.1.8 Core troughs

Core troughs are 2m long black plastic (PVC) pipes that have been cut in half. Core troughs hold sediment cores for lithostratigraphic logging after removal from the core pipe.

3.1.1.1.9 Core casing

Core casings are 15cm diameter standard thin-walled aluminum irrigation pipes that are used to increase depth of penetration of vibracores in deep deposits. Core casing pipes are vibrated into sediment in the same manner as the core pipe. Once maximum penetration depth is reached, the core casing is flushed out with water, creating a casing that the 7.5cm core pipe may be inserted into. The 6m and 3m long core casing pipes may be coupled together to obtain a 9m deep casing.

3.1.1.1.10 Flushing pump system

The flushing pump system is a set of hoses connected to a small high flow gasoline powered water pump. The flushing system is used to flush sediment from the core casing after the casing has been penetrated into the ground.

3.1.1.2 Vibracoring Techniques

The vibracorer is a coring system that liquefies sediment through the vibration of a core pipe, allowing the pipe to penetrate sediment (Figure 3-2). A 5 hp motor drives the vibrahead, attached to the top of the pipe, through a flex-cable inside a rubber hose-like housing. A core catcher, attached to the bottom of the core pipe, holds the sediment in the pipe during extraction. To start coring, the pipe is hoisted vertically by hand and placed into a hole augured to the water table. After the vibra-motor is started additional pressure may be added to the pipe by applying downward pressure through a rope tied to the pipe by a prusik knot. A core coupler is used to attach one pipe to another to increase the depth of penetration.

If the core pipe stops penetrating, but a deeper depth is required, the core pipe is extracted, the core is removed and the pipe is reinserted into the same hole. This technique continues until no additional penetration occurs.

To extract the core pipe from the ground, the vibrahead is removed, and a rope is tied to the pipe using a prusik knot. A ratchet chain hoist is then attached to the rope, and a collapsible aluminum jaws ladder is used as a pulling platform. Once the pipe is extracted, the sediment core must be removed from the core pipe for viewing. The core catcher is first removed, and the vibrahead re-attached. Then, the pipe is placed on an angle by attaching one end to the ladder. Lastly, the vibra-motor is started and the sediment core is slowly vibrated out of the pipe onto the plastic troughs.

When sediment is deeper than the maximum depth achieved by the 7.5cm diameter core pipe and the reinserting technique, a core casing is used to obtain a longer core. The 15cm core casing pipe is vibrated into the sediment, over the hole left by the extracted 7.5cm core pipe. After the core casing is vibrated into place, it is flushed clean with water, pumped by the flushing system (Figure 3-3). By coupling a 6m and a 3m

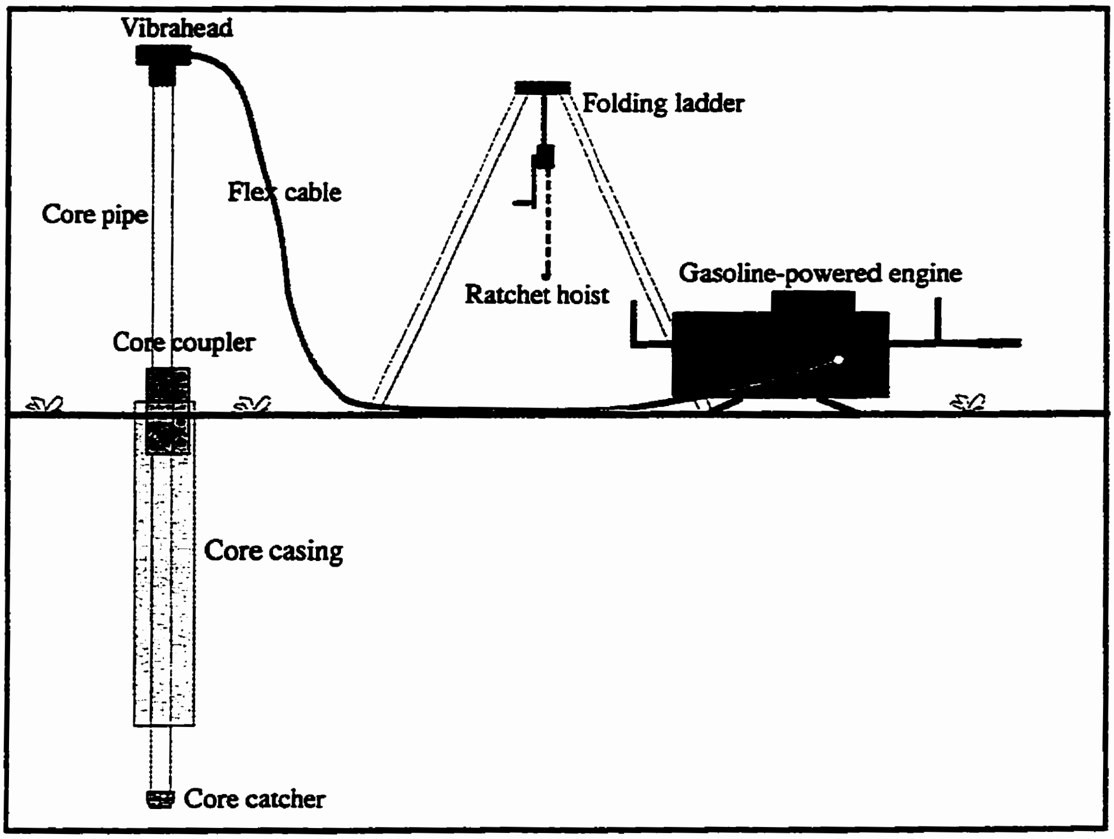


Figure 3-2. Schematic diagram of vibracorer system showing all components connected during penetration.

Figure 3-3. Vibracoring in the field. (A) The system with the core pipe placed into the augured hole ready for penetration. (B) 15cm diameter vibracore casing, for deep coring, being flushed with water after it was vibrated into the ground. The long black pipe carries water to flush the casing and is attached to a high flow water pump. After flushing the casing, a 7.5cm diameter pipe was inserted to obtain the deepest penetration depth.

pipe a casing depth of nine meters may be attained. The 7.5cm pipes can then be inserted into the casing and coring may continue until no additional depth will result. Using this process a maximum depth of 17 m was reached in the Kootenay River deposits.

3.1.2 Lithostratigraphic Logging

Lithostratigraphic logging was conducted immediately following core extraction. Graphical and descriptive lithostratigraphic logs were constructed in the field from every vibracore. Sand grain sizes were determined by visually comparing sediment with an Amstrat (American/Canadian Stratigraphic) grain size chart using a 16 power handlens. The silt-clay fraction was classified using qualitative tests such as consistency, feel, and grittiness between teeth. The abundance of shells, woody debris and fibrous organics were also noted. The integrity of this method of measuring grain size has been successfully tested against laboratory sieving (Folk 1974) with field results accurate to 90% (Caverley 1984, Piet 1992).

3.1.3 Geophysical Bottom Profiling

Channel cross-sectional geometry and depths were determined by geophysical bottom profiling. A Raytheon DE-719E depth sounder was employed from a Zodiac type boat. On the Kootenay River, two eddy accretion channels and one point bar were profiled at bankfull discharge. Six eddy accretion and corresponding point bar channels were profiled on the Beaver River below bankfull discharge (-1.7m). Most profiles were taken perpendicular to the channel edge to obtain a true cross-section.

3.1.4 Flow Velocity Measurement

One cross-sectional flow velocity profile was measured on a Kootenay River eddy accretion at bankfull discharge in order to record the channel forming velocities. A Gurley-Price current meter and a 13kg (30lb) torpedo weight were used from a Zodiac type inflatable boat pulled across the river by a cross river cable (Figure 3-4). The current meter was lowered and raised with a hand-powered winch on a bridge frame. A velocity profile was constructed following standard metering procedures (Water Survey of

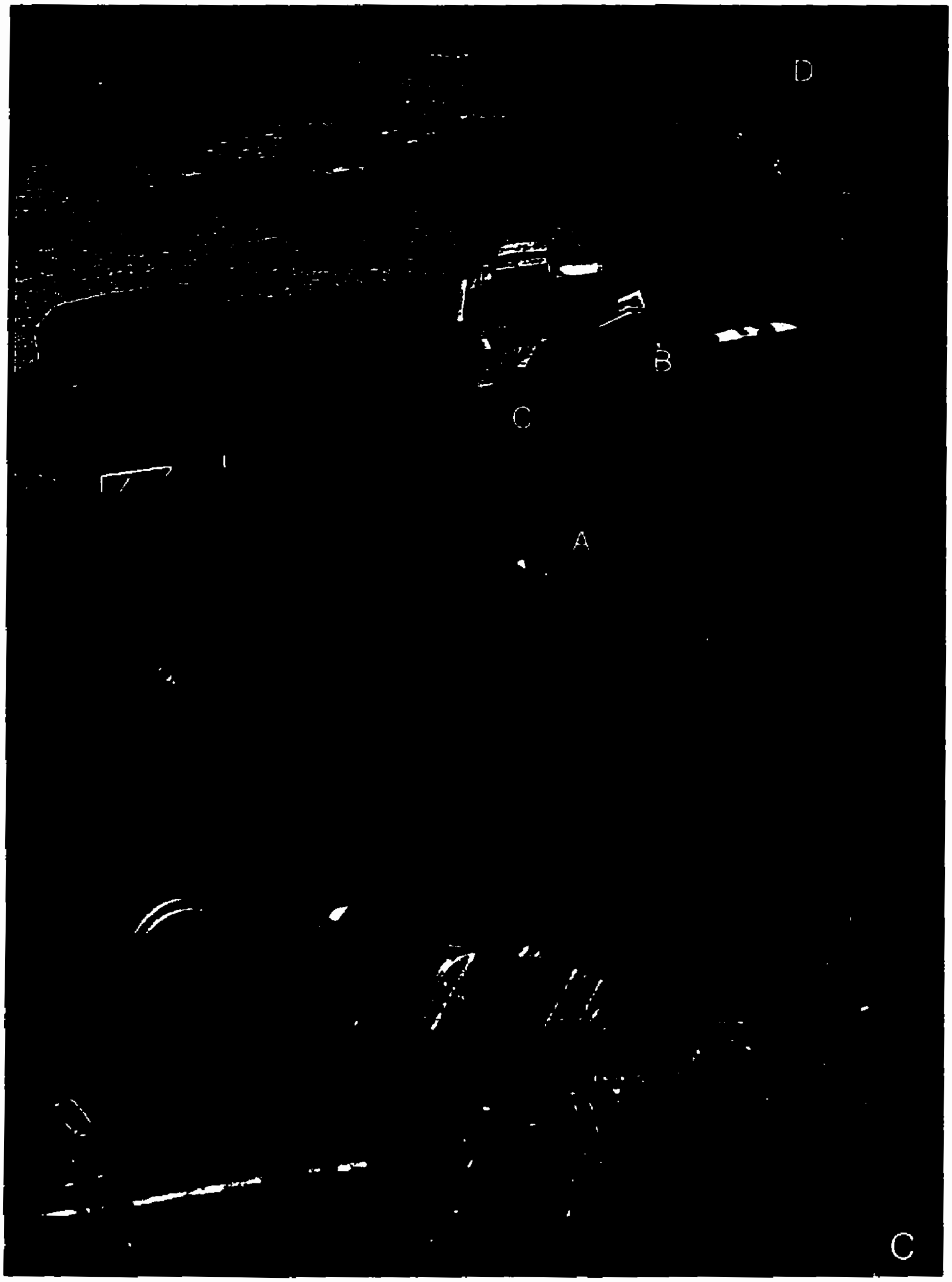


Figure 3-4. Current metering equipment. (A) Gurley-Price current meter, (B) ringer for counting current meter revolutions, (C) bridge frame hoist, and (D) cable strung across the channel from which the boat is secured. Not shown is a 13kg (30lb) torpedo weight attached below the current meter to keep the current meter vertical.

Canada pers. com.). Readings were taken at every 10% of channel depth for most of the 20 cross-channel sites, for a total of 177 point measurements.

3.1.5 Surveying

The floodplain surface consists of ridges and swales. Each core was zeroed at ground level and a datum of bankfull discharge was later surveyed to tie the cores together in a profile. A transit, stadia, and 50m tape were used to survey core locations to the datum. Channel widths were also measured with transit and stadia rod or 50m tape.

4. CHAPTER FOUR RESULTS

4.1 Sedimentology

The sedimentology results will be discussed in two sections: (1) lithofacies description and interpretation, and (2) lithofacies successions.

4.1.1 Lithofacies Description and Interpretation

Lithostratigraphic logs are presented using facies descriptions and interpretation of depositional environments. To increase the integrity of field observations, logs were recorded in the field without preconceptions of facies present. The field data were then redrafted and interpreted in the lab. Sediment grain size, structures, contact type (erosional, and gradational), thickness of beds, and organic material were recorded in the field. Lithostratigraphic logs were then subdivided into homogenous, workable units called facies. Next, the facies were classified into vertical successional sequences.

Depositional environments of facies were interpreted from their geographical location, position in relation to the channel profile, and through previous research (Allen 1965a; Walker and Cant 1984).

A total of 19 lithostratigraphic logs were recorded from vibracores on the Kootenay and Beaver rivers, 9 from the Kootenay cross-sectional profile and 10 from the Beaver. All lithostratigraphic logs and location maps will be presented here for referencing in the next section on facies descriptions. Each core location map will be followed by the corresponding lithostratigraphic logs (Figures 4-1 to 4-4). The Kootenay River logs are numbered east to west across the floodplain, K1 to K9 (Figure 4-1), while the Beaver River logs are numbered by the distance from the north valley wall (at 0) B20 to B250 (Figure 4-3). Cores were obtained and logged between May 27 and August 19, 1996. Floodplain surfaces consist of ridges and swales, therefore cores were zeroed at ground level. A datum of bankfull discharge was later surveyed to tie the cores together in cross-sectional profiles. The following table is a summary of seven facies including the description and interpretation (Table 4-1).

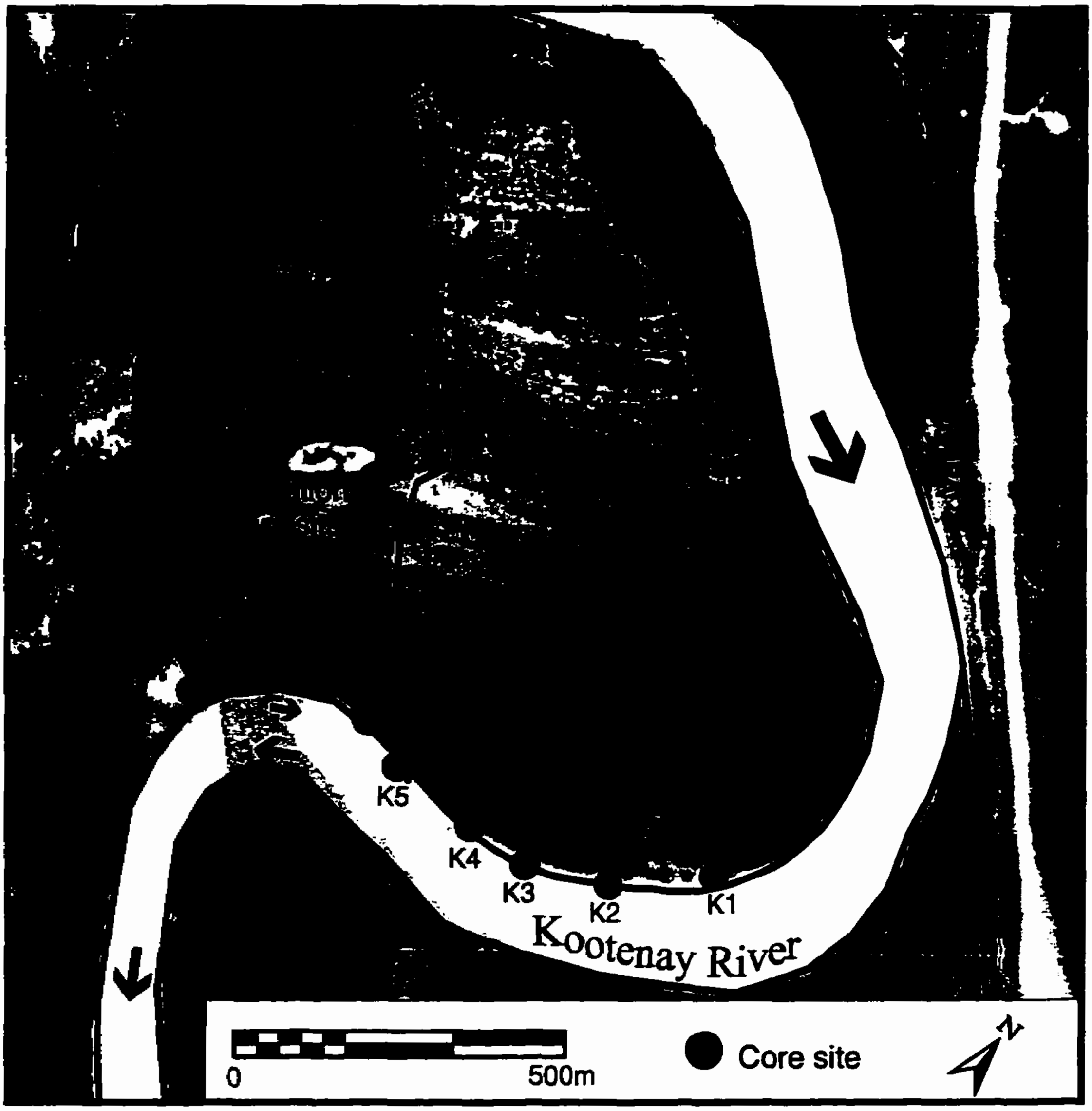


Figure 4-1. Locations of vibracores taken from the Kootenay River, British Columbia. Eddy accretion deposits are located on the west side of the valley and point bar deposits are located in the center of the valley (British Columbia Surveys and Mapping Branch, 1:40 000, Roll #BC77036, Photo #006 1977).

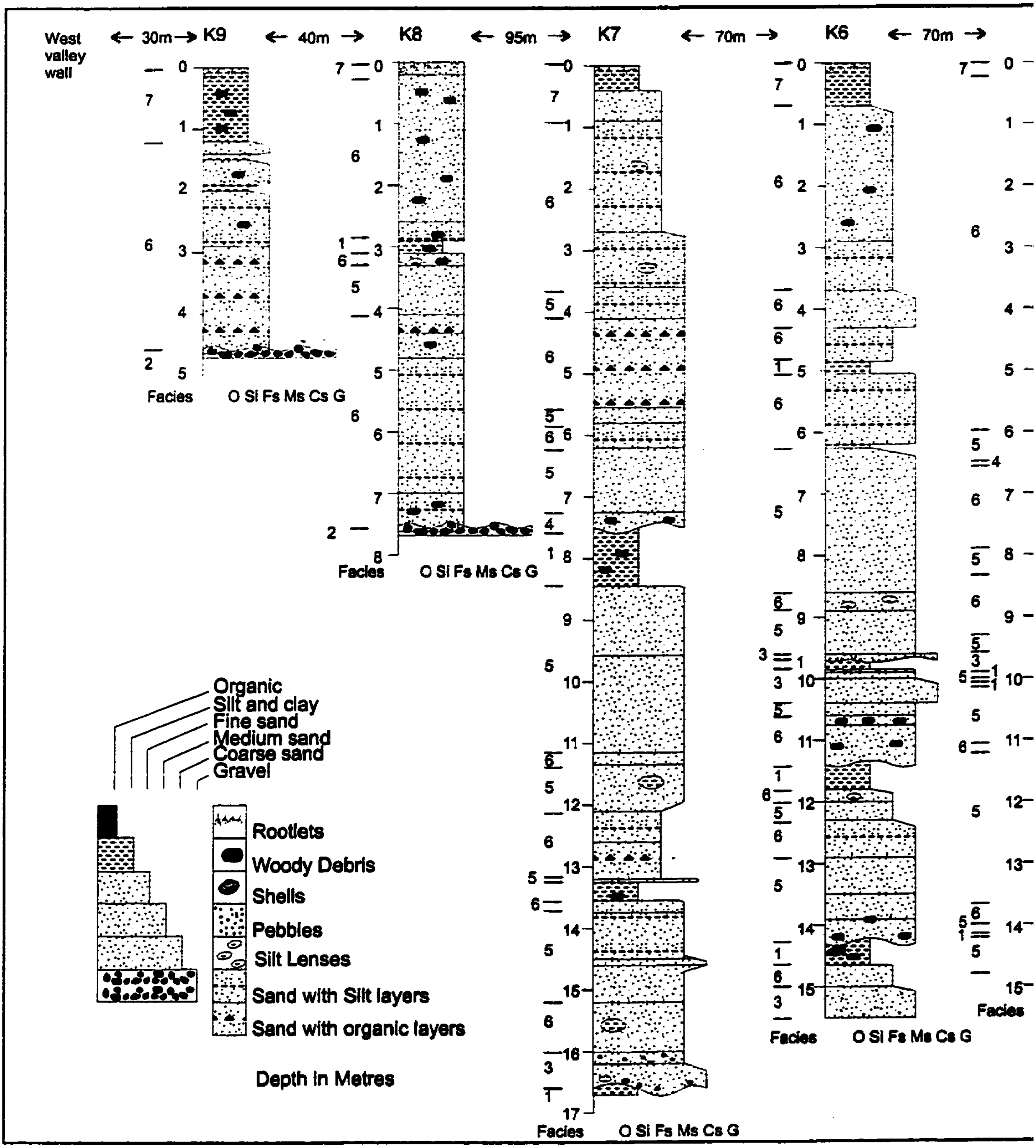
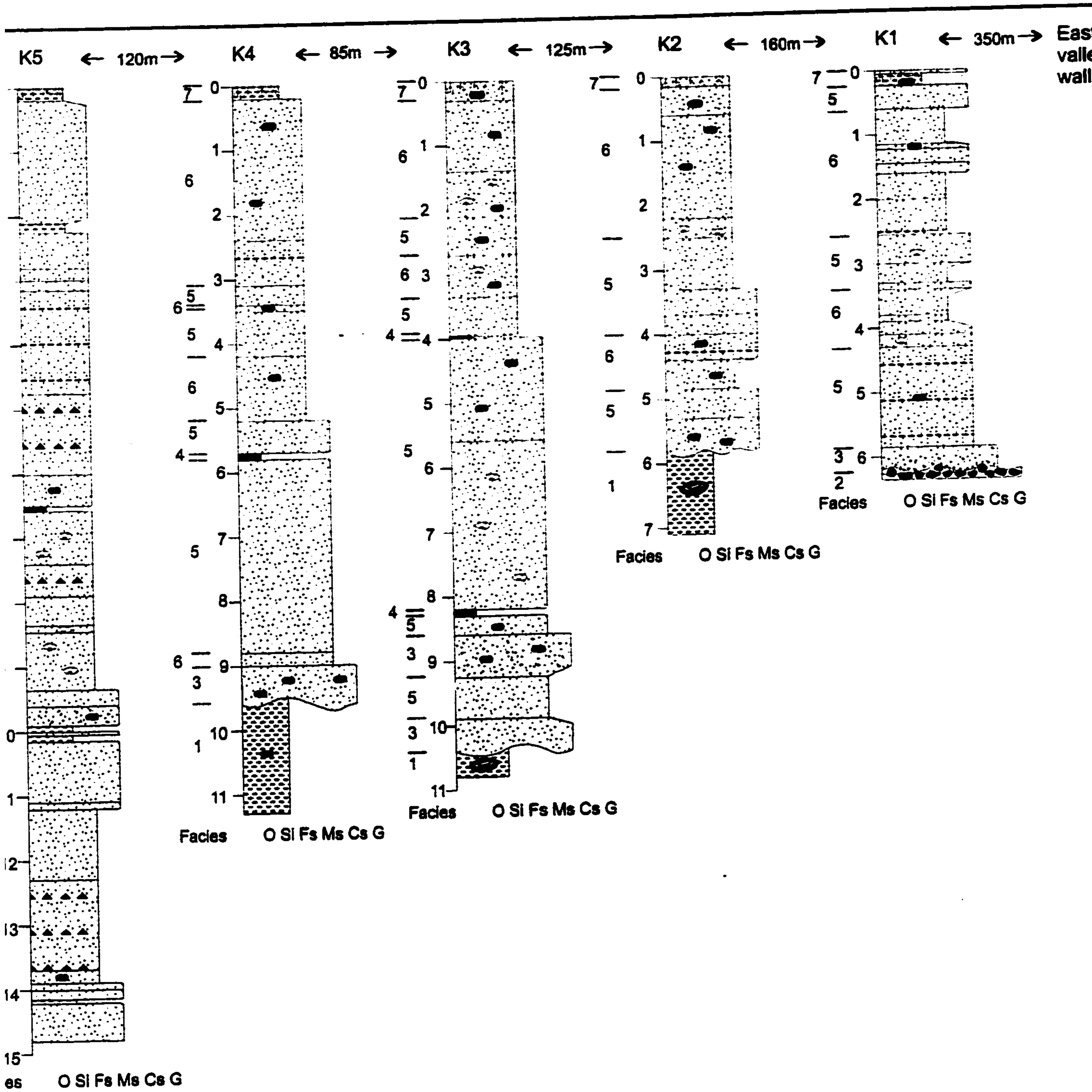


Figure 4-2. Lithostratigraphic logs (K1-K9) from vibracores, Kootenay River, British Columbia.



K5 ← 120m → K4 ← 85m → K3 ← 125m → K2 ← 160m → K1 ← 350m → East valley wall
Facies
O Si Fs Ms Cs G

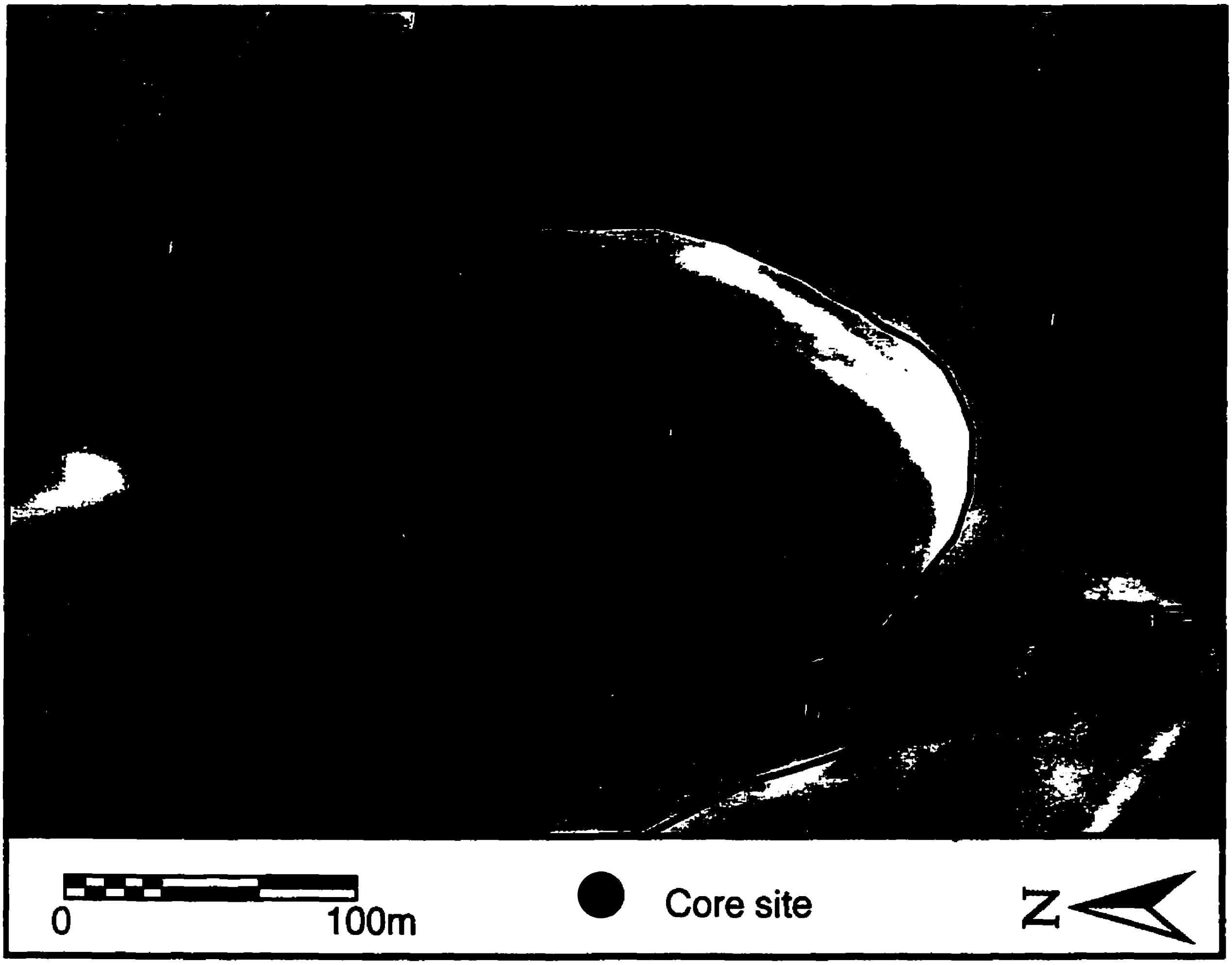


Figure 4-3. Locations of vibracores taken from the Beaver River, Alberta. Eddy accretion deposits are located on the north side of the valley and point bar deposits are located in the center of the valley (Alberta Energy Mines and Resources, 1:15 000, Roll #1633, Photo #316, 1977).

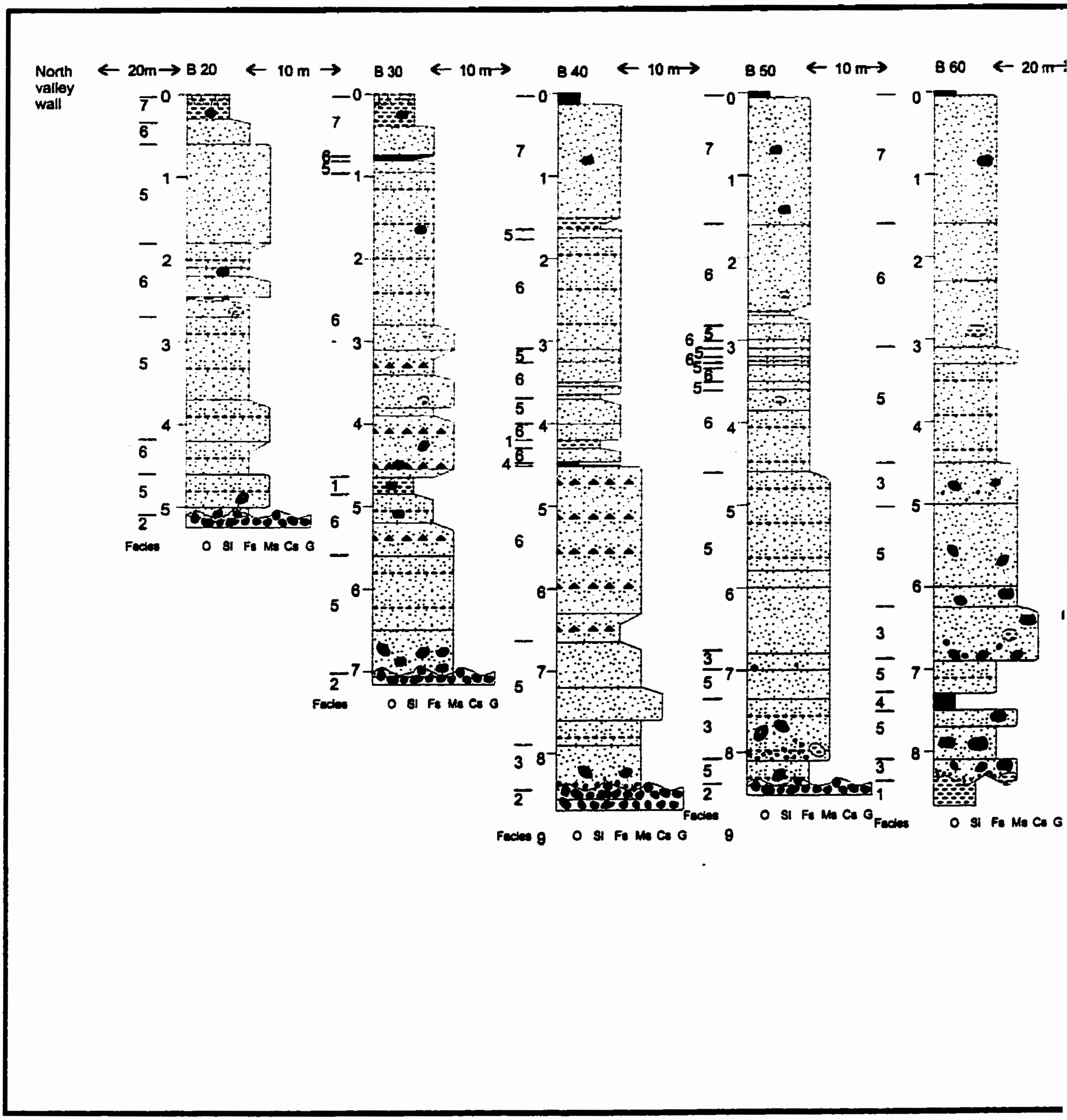


Figure 4-4. Lithostratigraphic logs from 10 vibracores, Beaver River, Alberta.

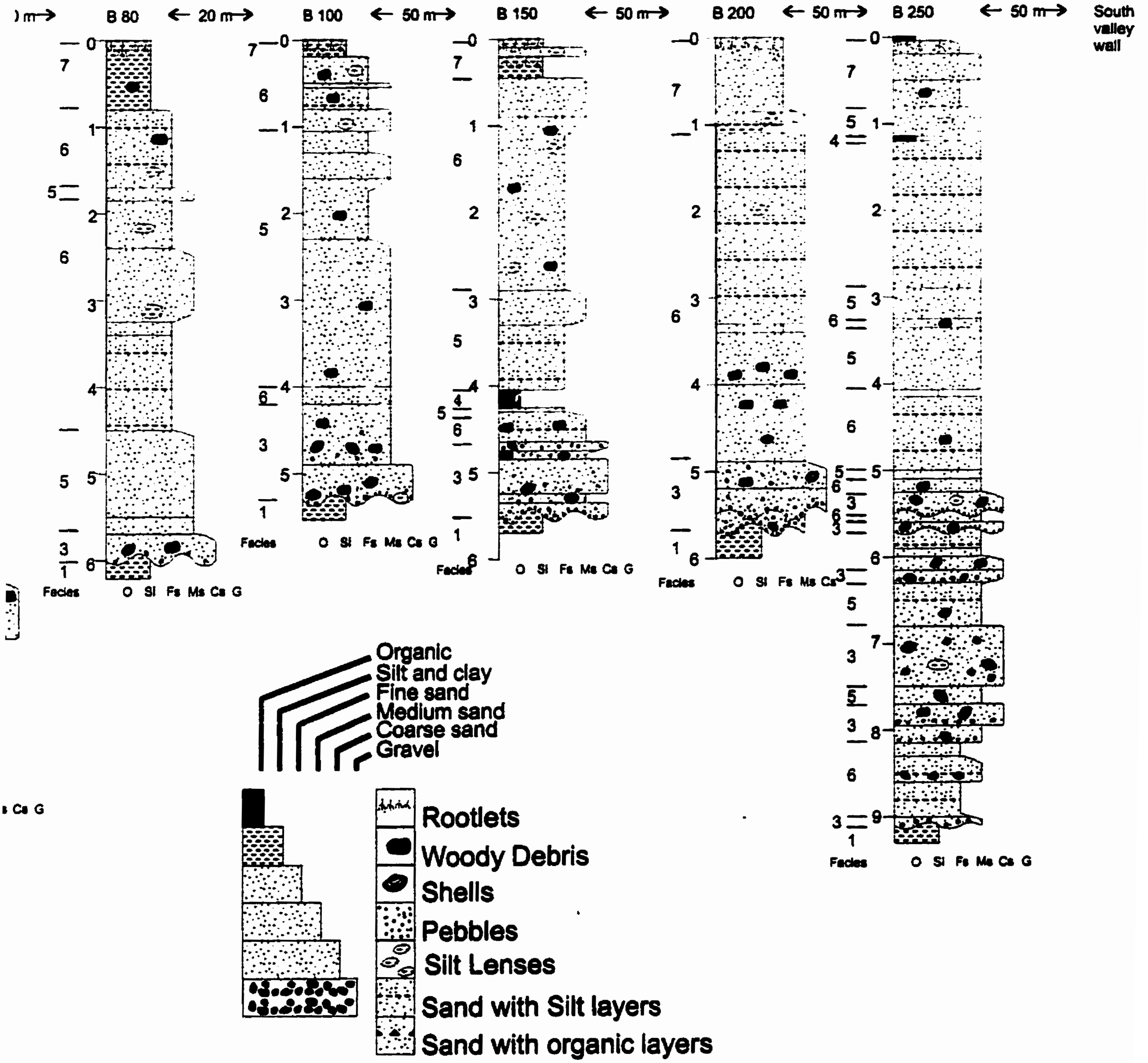

B 80
← 20 m →
B 100
← 50 m →
B 150
← 50 m →
B 200
← 50 m →
B 250
← 50 m →
South valley wall
Facies
O Si Fs Ms Cs G
Organic
Silt and clay
Fine sand
Medium sand
Coarse sand
Gravel
Rootlets
Woody Debris
Shells
Pebbles
Silt Lenses
Sand with Silt layers
Sand with organic layers

Table 4-1. Summary of seven facies, descriptions, and interpretation.

Facies	Description	Interpretation
1	Massive silt	Glacio-lacustrine or in-channel slack water deposition
2	Gravel	Glacio-fluvial or alluvial fan
3	Coarse sand with pebbles	Channel bed lag
4	Organic litter and wood	Lateral accretion
5	Clean sand	Lateral accretion
6	Sand with silt and/or organic litter layers	Lateral accretion
7	Silt and sand with rootlets	Overbank deposition

4.1.1.1 Facies 1 Massive silt

Facies 1 occurs in cores K2 to K7 on the Kootenay River and cores B30, B40, B60, B80, B100, B150, and B200 on the Beaver River. The thickness of this facies varies from 0.1m to 1.7m, with an average thickness of 0.35m. Its colour is shiny gray in the Kootenay and black in the Beaver, and usually contains minor shells and may contain minor-to-numerous organic material (Figure 4-5). Facies 1 most commonly occurs at the base of the cores (average thickness 0.4m) and is erosionally overlain by sand with pebbles (facies 3). Less commonly, facies 1 may be found at any level but usually occurs mid-sequence. Here, it underlies clean sand (facies 5) or sand with silt and/or organic litter layers (facies 6), and overlies sand with pebbles (facies 3) or facies 6 (sand with silt and/or organic litter layers). The mid-sequence facies 1, occurred 7 times in the Kootenay cores and 3 times in the Beaver, with an average thickness of 0.25m.

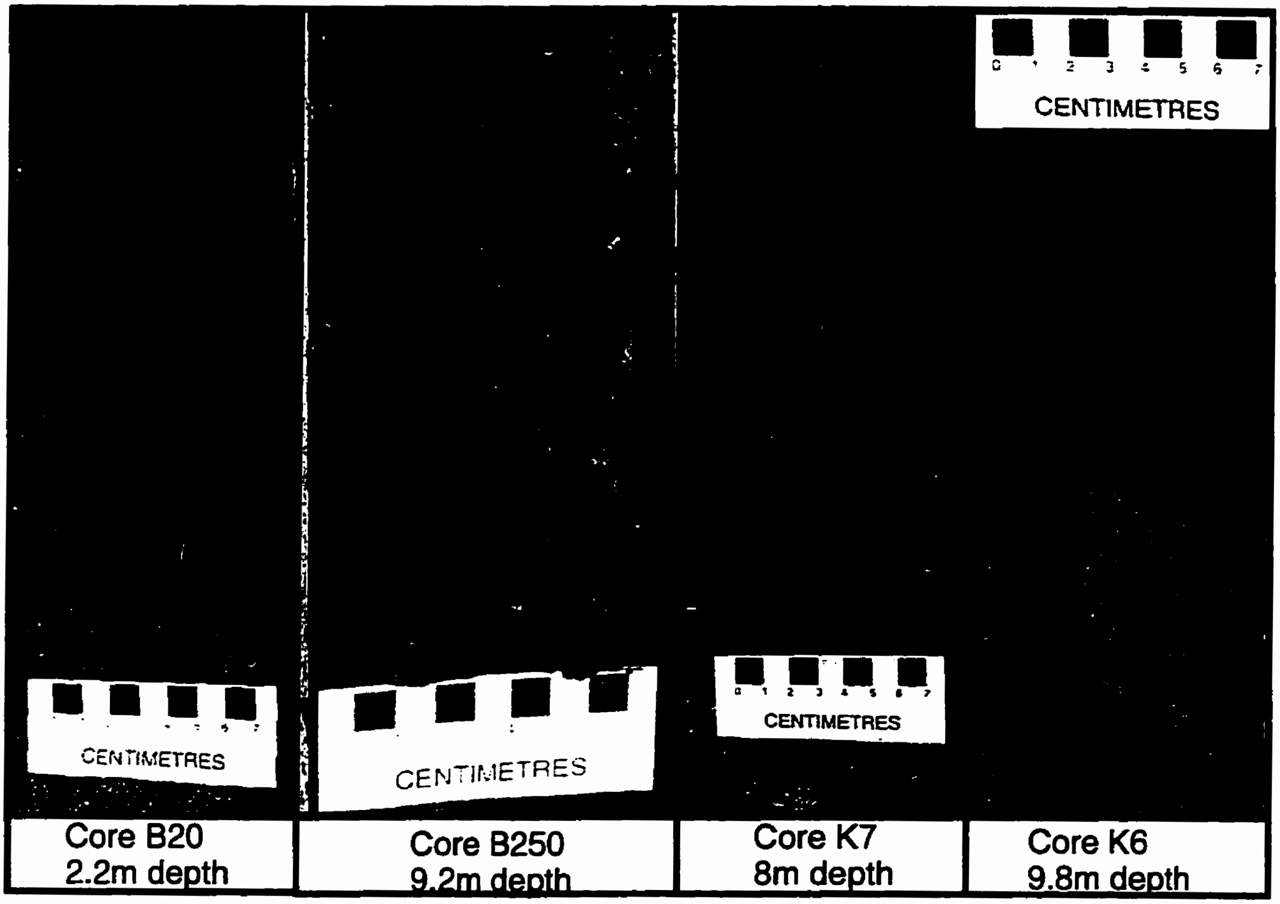


Figure 4-5. Examples of facies 1, massive silt, from the Beaver and Kootenay rivers.

Facies 1 is interpreted two ways depending on the location in the core. If located as a basal deposit it is interpreted as glaco-lacustrine, due to its location under the modern fluvial system and consistency with a lacustrine deposit. The Kootenay River flows through the Rocky Mountain Trench in which many glacial lakes resided during late Wisconsin deglaciation (Clague 1975b, Sawicki and Smith 1991). The dates and extents of the lake are still unknown. The Beaver River flows in a glacial melt-water spillway channel formed during deglaciation (Fenton and Andriashek 1983).

The mid-sequence silt layers are interpreted as slack water rain-out sediment deposited at low stage, onto the eddy accretion perched channel bed. This process of deposition will be discussed in the depositional processes section in Chapter 5.

4.1.1.2 Facies 2 Gravel

Facies 2 occurs in cores K1, K8, and K9 on the Kootenay River and cores B20, B30, B40, and B50 on the Beaver River. Thickness' of this facies vary from 0.1m to 0.2m, with an average penetrated thickness of 0.1m. Facies 2 contains pebble clasts, no larger than the core barrel (7.5 cm), usually contained within a sand matrix. It always occurs at the base of the cores and is overlain by sand with pebbles (facies 3), clean sand (facies 5), or sand with silt and/or organic litter layers (facies 6), probably by an erosional contact.

This facies is interpreted as glacio-fluvial or alluvial fan depending on its location. Gravel is found at two locations on the Kootenay River, core K1, located on the east side of the valley, and cores K8 and K9, on the west side of the valley. The gravel on the east side of the valley is interpreted as glacial fluvial. The gravel located on the west side of the valley is near a small tributary creek actively depositing an alluvial fan deposit.

Gravel found on the north side of the Beaver River valley, inside bend of the melt-water channel, is interpreted as glacial-fluvial and is thought to be a large paleo-point bar. This paleo-point bar would have been deposited from a large flow that formed the Beaver River valley during deglaciation.

4.1.1.3 Facies 3 Sand with Pebbles

Facies 3 occurs in cores K1, K3, K4, K5, K6, and K7 on the Kootenay River and cores B40, B50, B60, B80, B100, B150, B200 and B250 on the Beaver River. The thickness of this facies varied from 0.65m to 1.1m, with an average thickness of 0.4m. Its mode is coarse sand, but rarely is medium sand. It contains numerous-to-minor pebbles with occasional silt rip-ups, and may contain numerous-to-minor wood fragments, organic litter, or shell fragments (Figure 4-6).

Facies 3 occurs at the base of the cores or mid-sequence in eddy accretion deposits. Facies 3 predictably occurs at the base of the alluvial sediment, and is underlain by massive silt (facies 1) or gravel (facies 2). Clean sand (facies 5) usually overlies facies 3, but less frequently sand with silt and/or organic litter layers (facies 6) is found. When occurring mid-sequence, facies 3 may be underlain or overlain by massive silt (facies 1), but may also occur overlain or underlain by facies 5 and facies 6.

Facies 3 is interpreted as a channel bed lag, deposited in the channel thalweg at the highest velocities during floods. When present at the core base, facies 3 is interpreted as being deposited by main channel flow, and when present mid-sequence, it is deposited in perched channels (reverse flow) which forms in the eddy accretion channel settings.

4.1.1.4 Facies 4 Organic litter and Wood

Organic litter and Wood fragments is a minor facies, with only 10 occurrences, found in cores K7, K6, K3, K4, K5, B40, B60, B150 and B250. Thickness' of this facies vary from 0.05m to 0.25m, with an average thickness of 0.15m. It is black, generally fibrous with wood fragments, and may contain some medium sand. Facies 4 is overlain and underlain by clean sand (facies 5) or sand with silt and/or organic litter layers (facies 6).

Facies 4 is interpreted as waterlogged organic litter and wood fragments deposited within the channel on the downstream side of dunes or sand waves during low flows and are subsequently buried by downchannel readvance of the bedform in the next high flow. These have been commonly observed by D.G. Smith (Pers. Com. 1997).

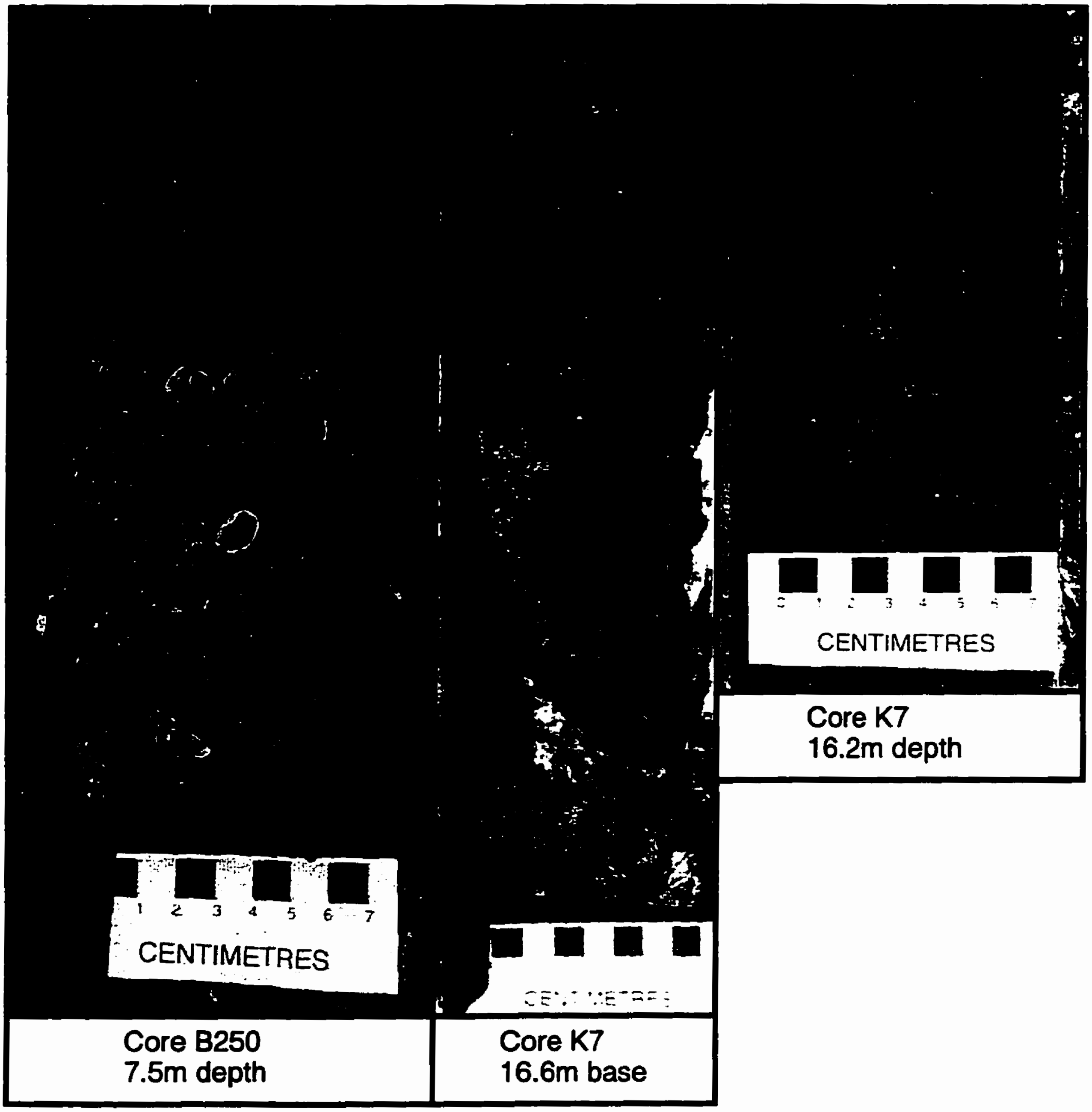


Figure 4-6. Examples of facies 3, sand with pebbles, from the Beaver and Kootenay rivers.

4.1.1.5 Facies 5 Clean Sand

Facies 5 occurs in all cores in both rivers and is the most abundant facies, found in 63 stratigraphic intervals. The thickness of this facies varies from 0.1m to 4.2m, with an average thickness of 0.35m. The dominant grain size is medium sand, but it may also consist of fine sand (Figure 4-7). Facies 5 may also contain minor silt layers or minor organics. It occurs throughout all cores, but most commonly occurs in the lower half of each sequence. It is commonly overlain and underlain by facies 6 (sand with silt and/or organic litter layers), but occasionally is found in contact with any other facies.

Facies 5 is interpreted as lateral accretion point bar or eddy accretion sand. Deposition occurs on the accretion surfaces of the point bar or eddy accretion, during bankfull discharge, when the channel is actively migrating.

4.1.1.6 Facies 6 Sand with Silt and/or Organic Litter Layers

Facies 6 occurs in all cores in both rivers and is the second most abundant facies with 61 occurrences. The thickness of this facies varies from 0.1m to 5.8m, with an average thickness of 1.25m. The grain size ranges from silty-fine sand to medium sand. It contains minor-to-numerous silt layers up to 5cm thick, and/or minor-to-numerous organic litter layers (Figure 4-8). Shell fragments may also be present. It occurs throughout all cores, but is most commonly found in the upper half of each sequence. It is usually overlain and underlain by facies 5 (clean sand), and is commonly overlain by silt and sand with rootlets (facies 7) when at the top of a sequence. However, it may be found in contact with any other facies.

Facies 6 is interpreted as a lateral accretion deposit. Deposition occurs on the accretion surfaces of the point bar or eddy accretion high upon the accretion slope where velocities are lowest during bankfull discharge, or during base flow discharge when velocities are low and the channel is not actively migrating.

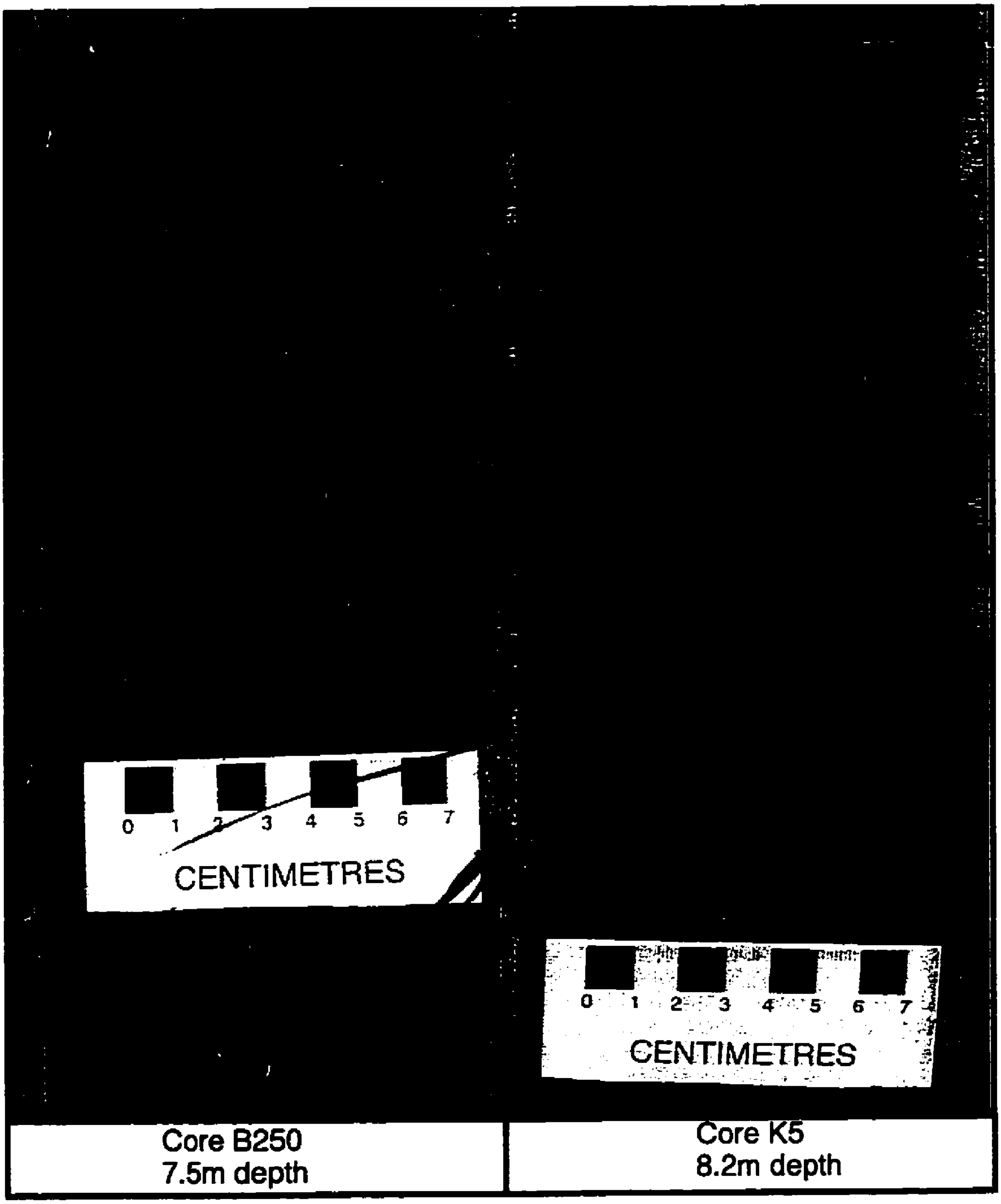


Figure 4-7. Examples of facies 5, clean sand, from the Beaver and Kootenay rivers.

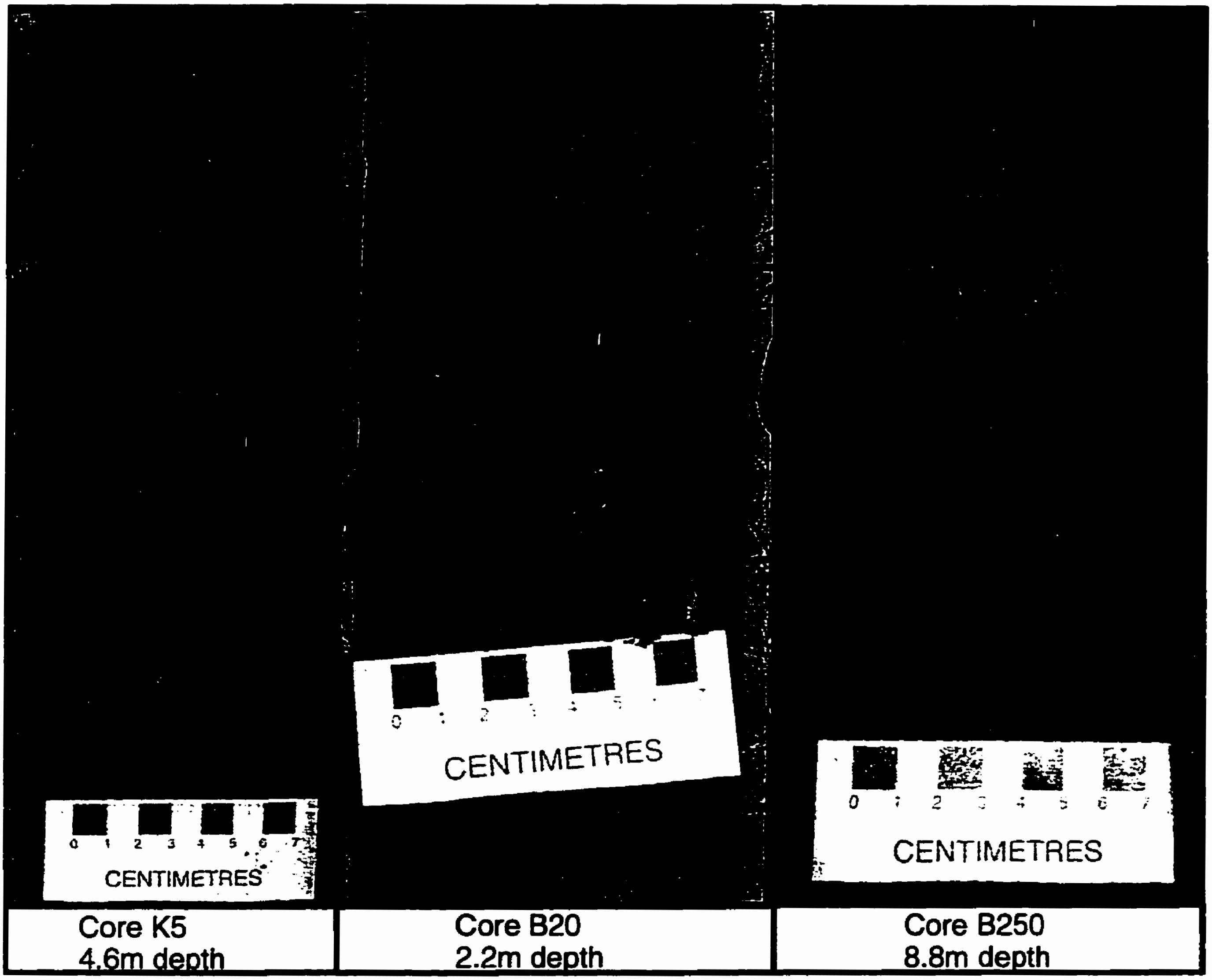


Figure 4-8. Examples of facies 6, sand with silt and/or litter layers, from the Beaver and Kootenay river

4.1.1.7 Facies 7 Silt and Sand with Rootlets

Facies 7 occurs in all cores in both rivers with 19 occurrences. Thickness' of this facies vary from 0.15m to 1.7m, with an average thickness of 0.6m. The grain size ranges from clay-silt to silty-fine sand. Facies 7 contains numerous rootlets and minor-to-numerous organics. It occurs at the top of all cores, at the floodplain surface. It is generally underlain by sand with silt and/or organic litter layers (facies 6). However, less commonly it may be found in contact with clean sand (facies 5).

Facies 7 is interpreted as overbank sediment deposited during high flows or floods. The upper portion of the facies may be a soil horizon churned by pedogenic processes. The roots found in this facies are from actively growing plants on the floodplain surface, or from plants that were buried by vertical accretion of these deposits during flood.

4.1.2 Lithofacies Successions

Facies successions are sequences of vertically stacked facies deposited by a distinct geomorphic process. Two facies successions are recognized from the Kootenay and Beaver river logs. The two facies successions that will be discussed are: 1) point bars, and 2) eddy accretions.

4.1.2.1 Point Bar Succession

Locations of point bar deposits were identified from scroll patterns on aerial photographs. The point bar facies succession, from the Kootenay and Beaver rivers, are shown in logs K2, K3, B100 and B150 (Figure 4-9). These logs show a generalized facies succession typical of the point bar model (Smith 1987a, Piet 1992). At the base of the point bar succession, sand with pebbles (facies 3) are in erosional contact with the underlying lacustrine silt or fluvial gravel. A thick sequence of clean sand (facies 5), and sand with silt and/or organic litter layers (facies 6) overlies sand with pebbles (facies 3). Facies 5 generally occurs more commonly in the lower half of the facies succession, with facies 6 being more prevalent in the top half. Organic litter and wood layers (facies 4) may occur at any interval in the sequence. The sequence is always capped by silt and sand, with rootlets (facies 7), which overlies facies 6.

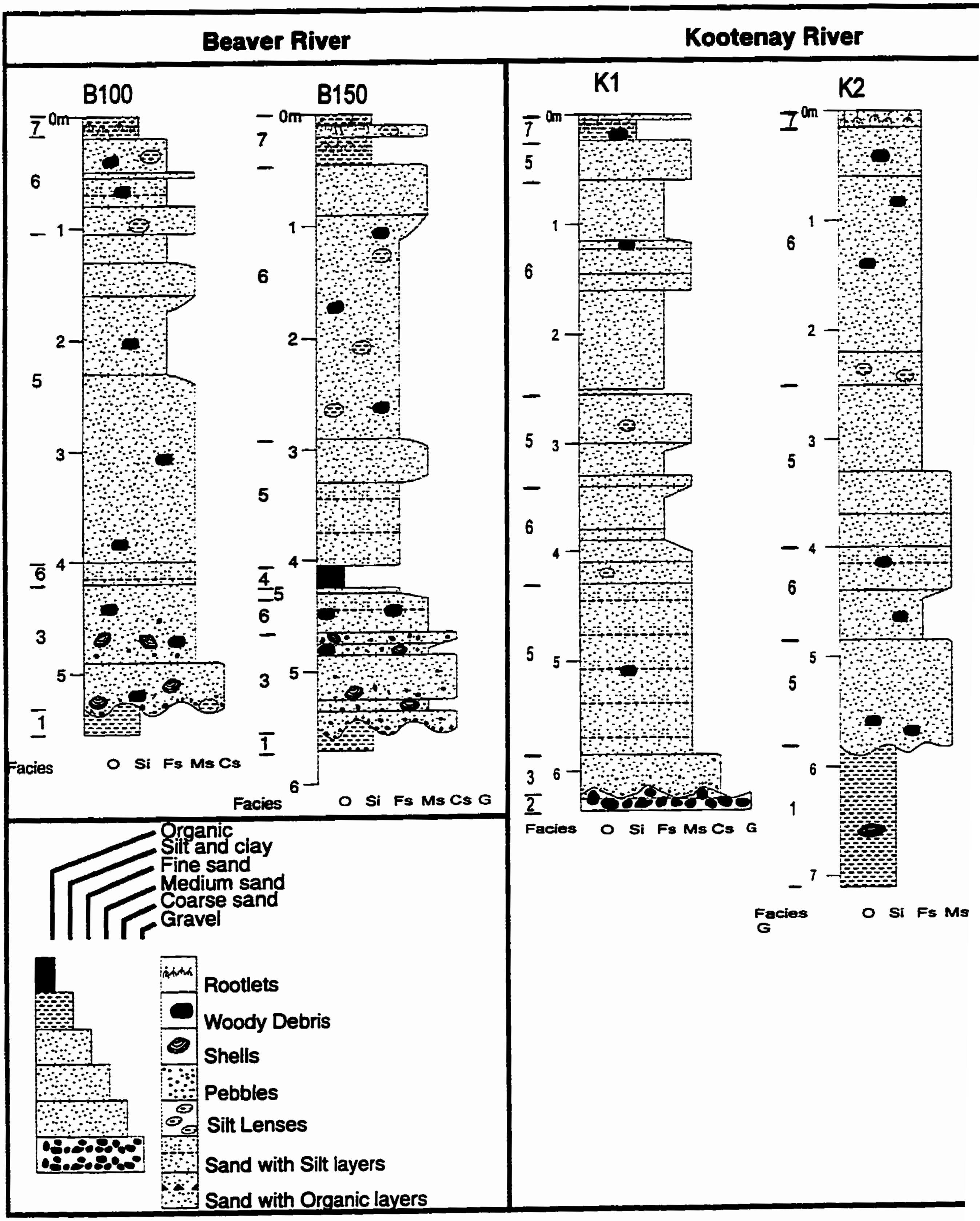


Figure 4-9. Lithostratigraphic logs from point bars on the Beaver and Kootenay Rivers.

The sequence generally fines upward in grain size, but may have coarser grain sizes superimposed upon the fining upward sequence. Sedimentary structures were not preserved through the vibracoring process and were not observed in any cores. Point bar facies successions are present in cores K1, K2, K3, K4, B80, B100, B150, B200, and B250

4.1.2.2 Eddy Accretion Succession

Locations of eddy accretion deposits were identified by their scroll patterns reverse to that of adjacent point bars. Eddy accretion facies successions, from the Kootenay and Beaver Rivers, shown in logs K6, K7, B40 and B60 (Figure 4-10), are similar to those of the point bar model (Smith 1987; Piet 1992). At the base of the eddy accretion successions, sand with pebbles (facies 3) is in erosional contact with the underlying lacustrine silt or fluvial gravel. A thick sequence of clean sand (facies 5), and sand with silt and/or organic litter layers (facies 6) overlies sand with pebbles (facies 3) at the succession base. Mid-sequence, a massive silt layer (facies 1) usually overlies facies 5 or facies 6. This silt layer may occur more than once within the sequence. Usually overlying the massive silt layer is sand with pebbles, clean sand, or sand with silt and/or organic litter layers. The sequence continues with facies 5 and 6, with facies 6 underlying silt and sand with rootlets (facies 7) which always occurs at the top of each log.

Facies 5 generally occurs more commonly in the lower half of the succession; with facies 6 being more prevalent in the top half. Organic litter and wood layers (facies 4) may occur at any random interval within the sequence. As with point bars, this sequence generally fines upward in grain size. The sequence may have coarser grain sizes superimposed upon the fining upward trend, and is further complicated by the occurrence of a silt occurring mid-sequence. If the sequence contains a thick, massive silt layer occurring mid-sequence, it may appear to be two fining upward grain size trends. If seen in ancient rocks, this apparent double fining upward sequence may be misinterpreted as the product of two superimposed point bar deposits, rather than its correct interpretation as one eddy accretion deposit.

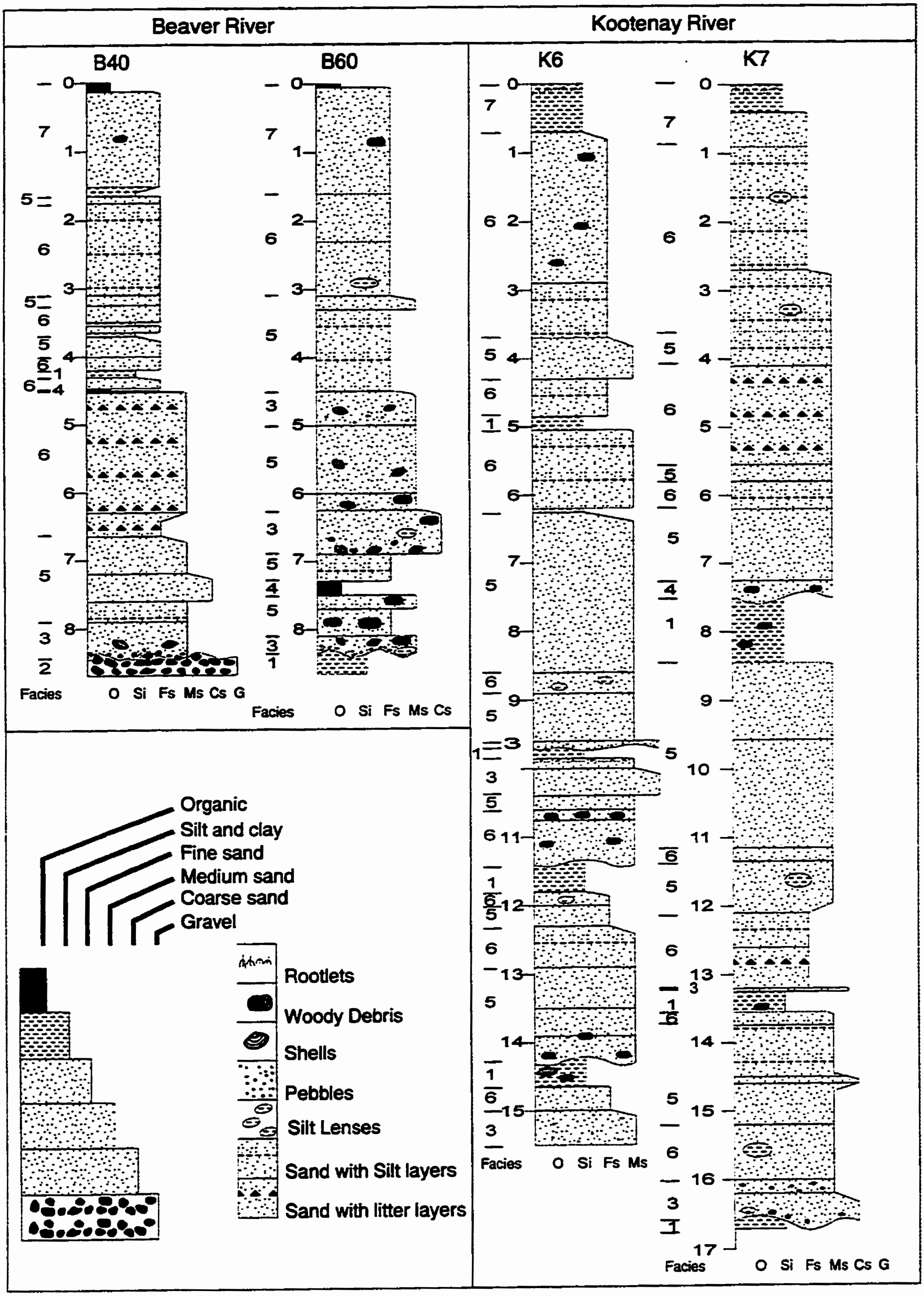


Figure 4-10. Lithostratigraphic logs from eddy accretions on the Beaver and Kootenay rivers.

Eddy accretion deposits, occurring adjacent to the valley walls, are the thickest alluvial sediments within the valley cross-sectional profiles. Eddy accretion facies successions are present in cores K9, K8, K7, K6, K5, B20, B30, B40, B50, B60 and the lower portion of B250 where eddy accretion deposits are truncated by point bar deposits.

4.2 Comparison of Field and Laboratory Grain size Determination

The grain size of five samples were determined through sieving in the lab (Folk 1974) to compare with grain sizes measured in the field using a 16 power handlens and a grain size chart. These data indicate that the field observations are 0.5 to 1.5 greater in phi size as compared to the laboratory measurement. This bias is believed to be due to the fine sand grains not being easily detected and estimated through the handlens. In my view, this is not a significant problem and therefore the field observed grain sizes were presented in all lithostratigraphic logs.

4.3 Kootenay River Cross-Sectional Profile

The Kootenay River stratigraphic cross-sectional profile was compiled from nine logs taken across the 1km wide floodplain (Figure 4-11). The profile is deepest (17m) on the west side of the floodplain and shallows toward the east (6m, K1, Figure 4-11). The deepest portion of the profile corresponds to the eddy accretion deposit, while the shallowest portion corresponds to the point bar. Eddy accretion deposits form 40% ($5650m^2$) of the alluvial material in the cross-valley profile, while point bar deposits form 60% ($9200m^2$) of the total cross-section.

Kootenay River vibracores show only one deep scour, located on the west side of the floodplain. However, a corresponding deep scour may be present on the east valley margin. Down-valley of the study reach the river meandering is limited by a silt and clay wetland preventing channel migration, and "holding" the river in place. The lack of down-valley migration past the east portion of the study meander reach, limits the formation of eddy accretions on the east side of the valley near the study reach. Because there are no meanders down valley of the study reach, meanders with eddy accretions do not migrate and scour as they pass the east valley wall. Only the point bar deposits,

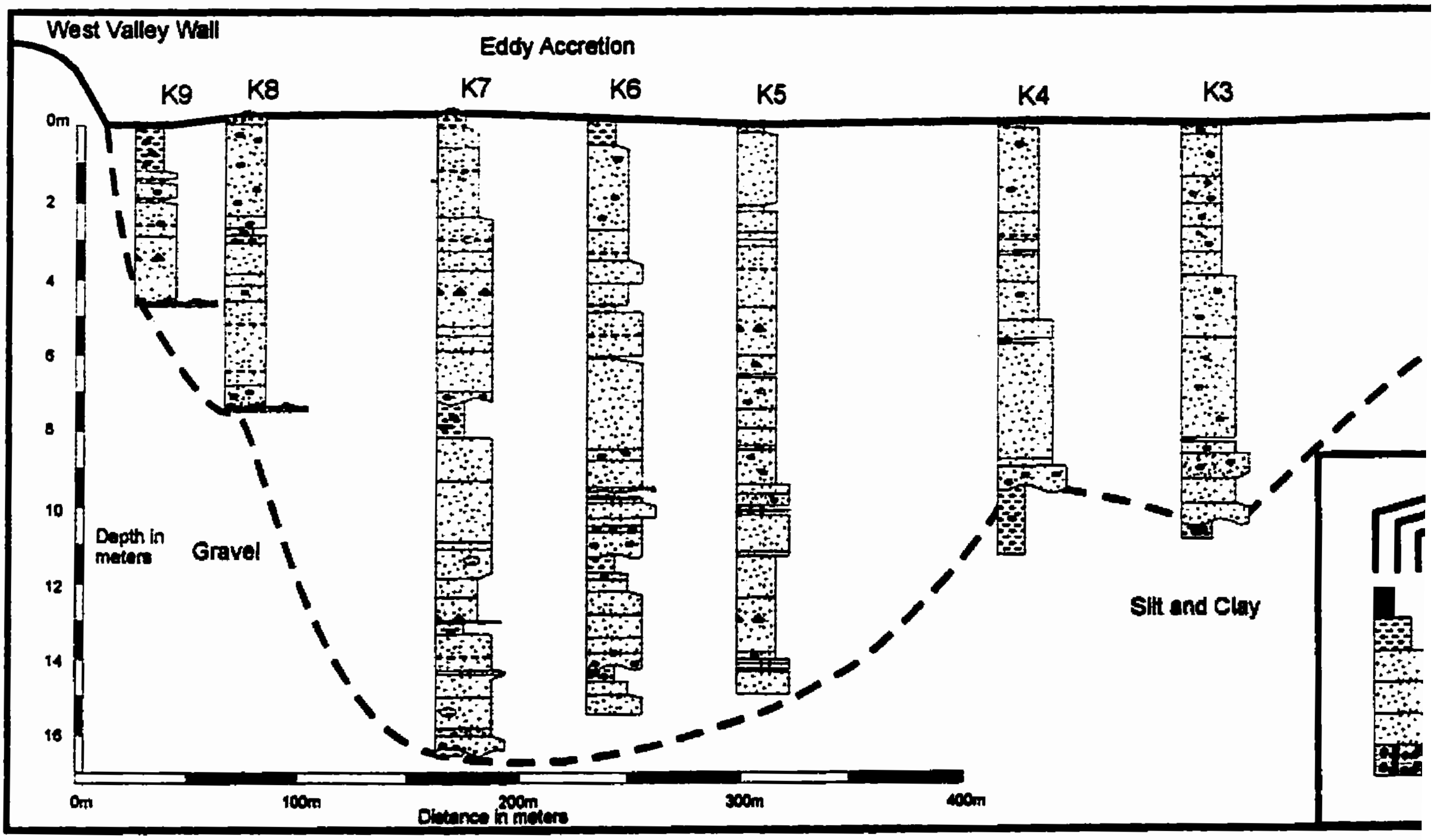
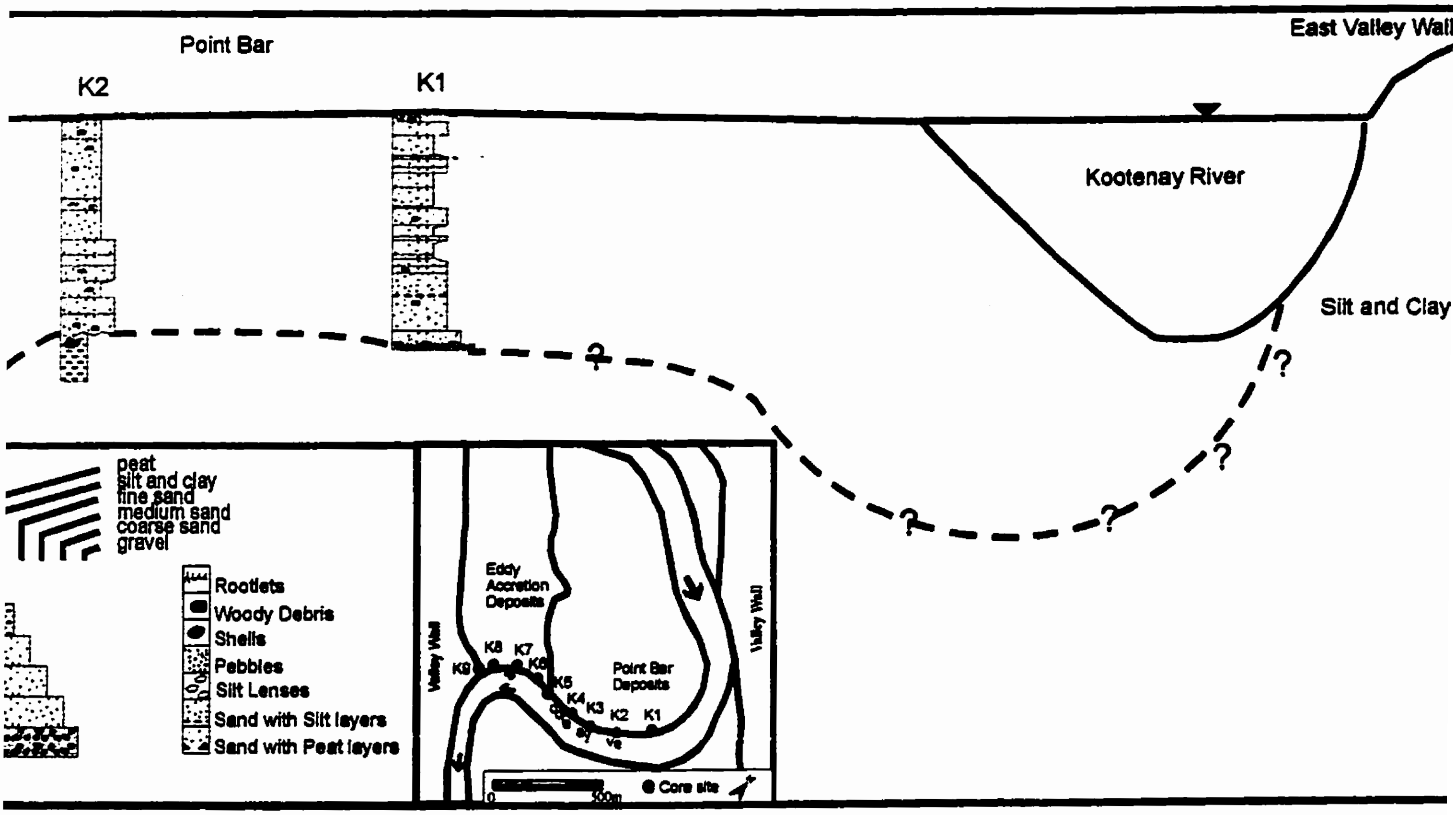


Figure 4-11. Lithostratigraphic profile from west to east on the Kootenay River valley.
Eddy accretion deposits occur on the west valley side and point bar deposits occur on the east side.
Eddy accretions, composed of sand, form the deepest portion of the valley fill.
Vertical exaggeration is 17x.



Point Bar
East Valley Wall
K2
K1
Kootenay River
Silt and Clay
?
peat
silt and clay
fine sand
medium sand
coarse sand
gravel
Rootlets
Woody Debris
Shells
Pebbles
Silt Lenses
Sand with Silt layers
Sand with Peat layers
Eddy Accretion Deposits
Valley Wall
Point Bar Deposits
K9
K8
K7
K6
K5
K4
K3
K2
K1
Core site
0
500m

adjacent to the studied eddy accretion, form on the east side of the Kootenay River floodplain at this location.

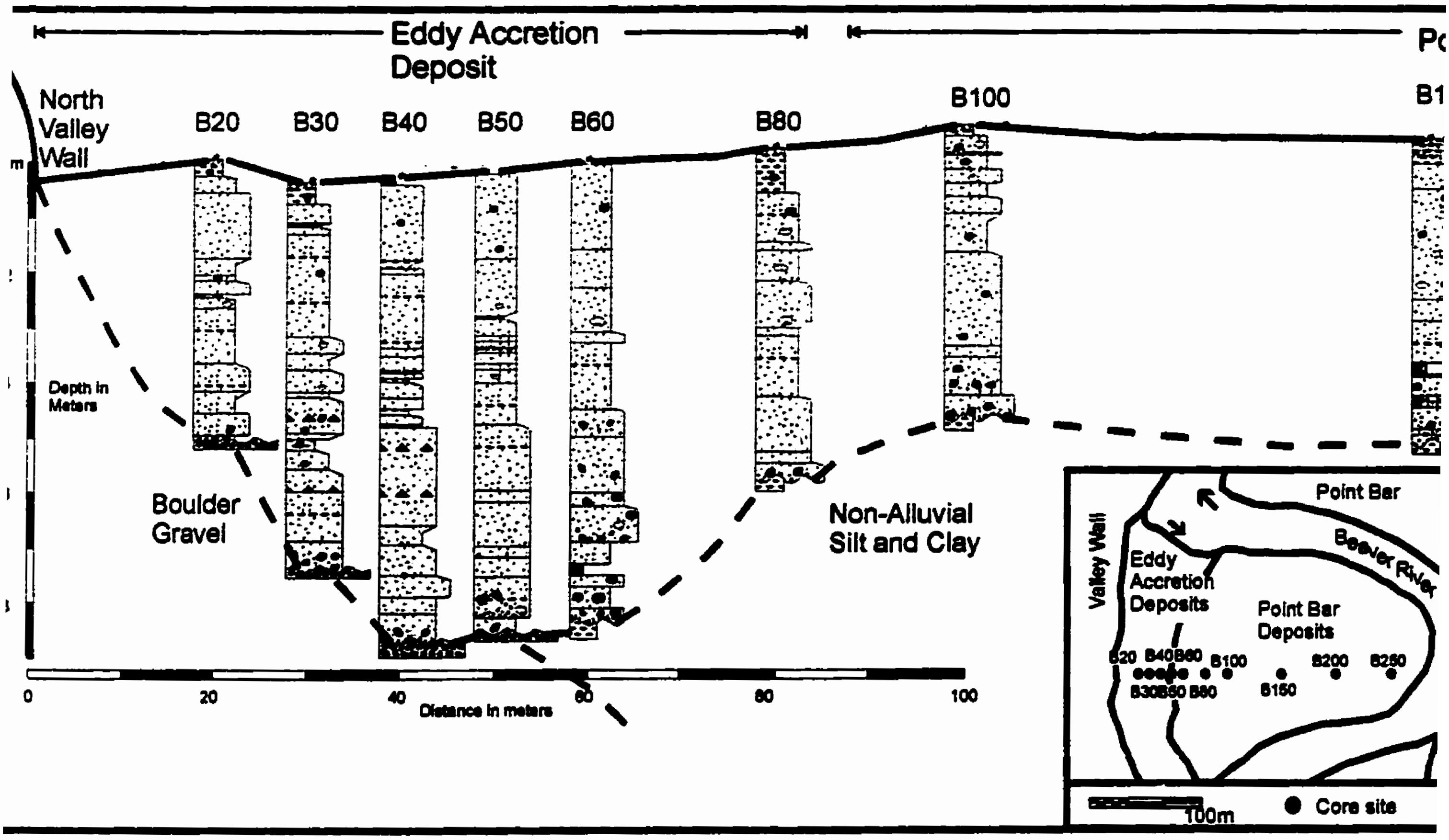
4.4 Beaver River Profile

The Beaver River stratigraphic cross-sectional profile was compiled from ten logs taken across the 0.3km wide floodplain (Figure 4-12). The profile is deepest (9m) on both floodplain sides and shallowest mid-valley (5m). Eddy accretion deposits on the north floodplain side form the deepest portion of the profile. Alluvial sands are shallowest at the mid-valley point bar, which on the south floodplain side, overlies a deeper eddy accretion. Eddy accretion deposits form 50% (1040m^2) of the total alluvial material in the cross-valley profile, while point bar deposits form 50% (1000m^2) of the total cross-section.

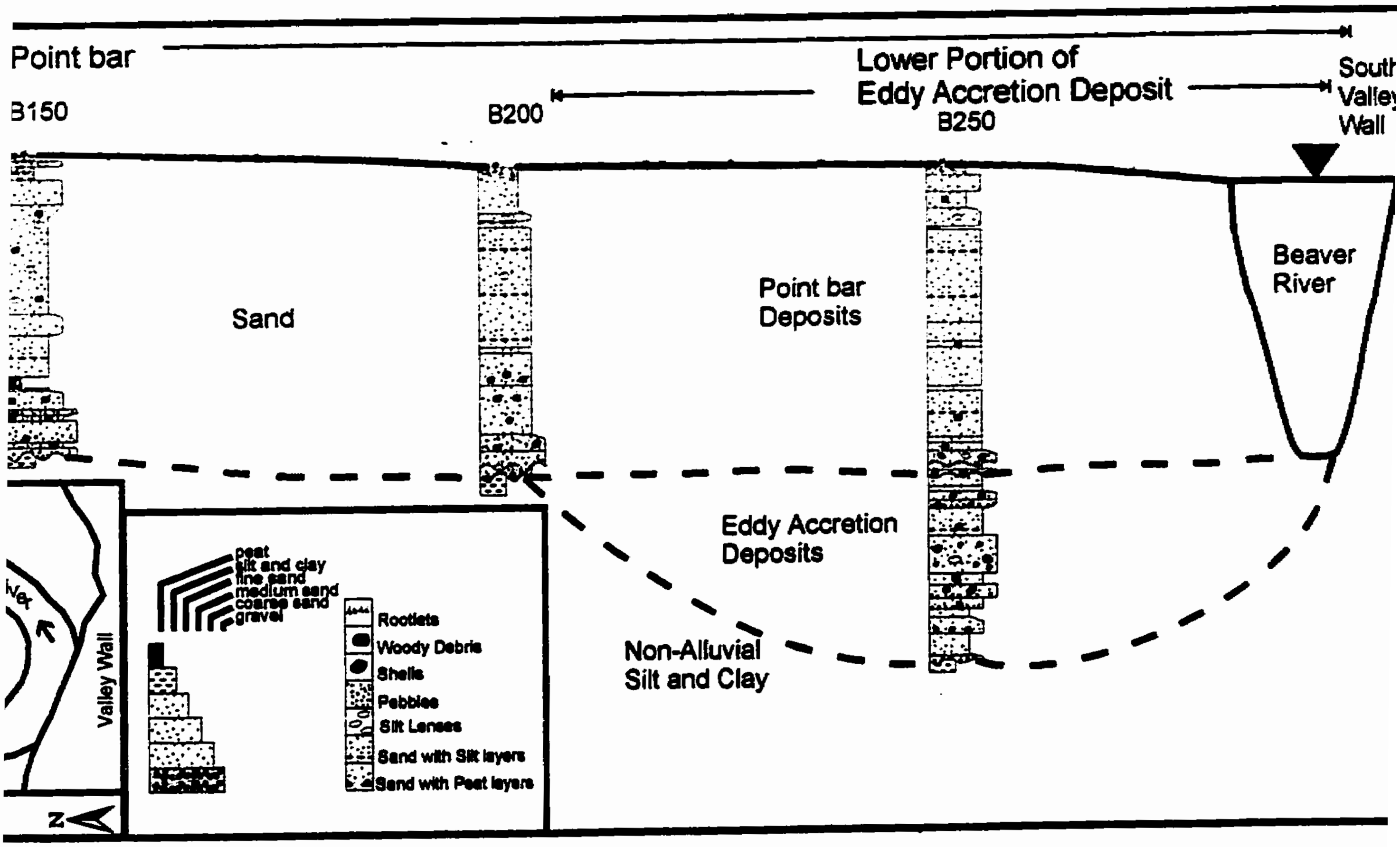
The Beaver River profile shows two deep scours, one on each margin of the floodplain, indicating that eddy accretions are active on both valley sides. Point bar deposits occur mid-valley and continue to the south valley side (as seen on aerial photographs) over a deep scour. Scour pools adjacent to point bars do not erode as deeply as eddy accretion scours. Each meander wavelength contains only one eddy accretion and one point bar. To produce eddy accretion deposits on both sides of a valley two meander wavelengths must pass a point in the valley. Therefore, the active eddy accretion that is now one meander wavelength downvalley must have formed the deep scour and fill on the south side of the valley when it was active in that location. Therefore, the point bar deposit on the south valley side unconformably overlies the lower portion of an eddy accretion. The upper portion of the eddy accretion was "planed off" by the migration of the point bar, while the lower portion remains in place.

4.5 Comparison of Eddy Accretion and Point Bar Deposits

A comparison of eddy accretion and point bar sedimentology is shown in logs K2 and K6, for the Kootenay, and B60 and B150 for the Beaver (Figure 4-13). Eddy accretion and point bar deposits have four important differences. First, eddy accretion deposits are between 1.5 to 2 times thicker than adjacent point bar deposits. Second,



'igure 4-12. Lithostratigraphic profile taken from north to south on the Beaver River floodplain. Eddy accretion deposits occur on the north and south sides of the valley and point bar deposits occur mid-valley and on the south valley side. Eddy accretions form the deepest portion of the valley fill. Vertical exaggeration is 6x.



Point bar
Lower Portion of
Eddy Accretion Deposit
B150
B200
B250
South
Valley
Wall
Sand
Point bar
Deposits
Beaver
River
Eddy Accretion
Deposits
Non-Alluvial
Silt and Clay
Valley Wall
peat
silt and clay
fine sand
medium sand
coarse sand
gravel
Rootlets
Woody Debris
Shells
Pebbles
Silt Lenses
Sand with Silt layers
Sand with Peat layers
N

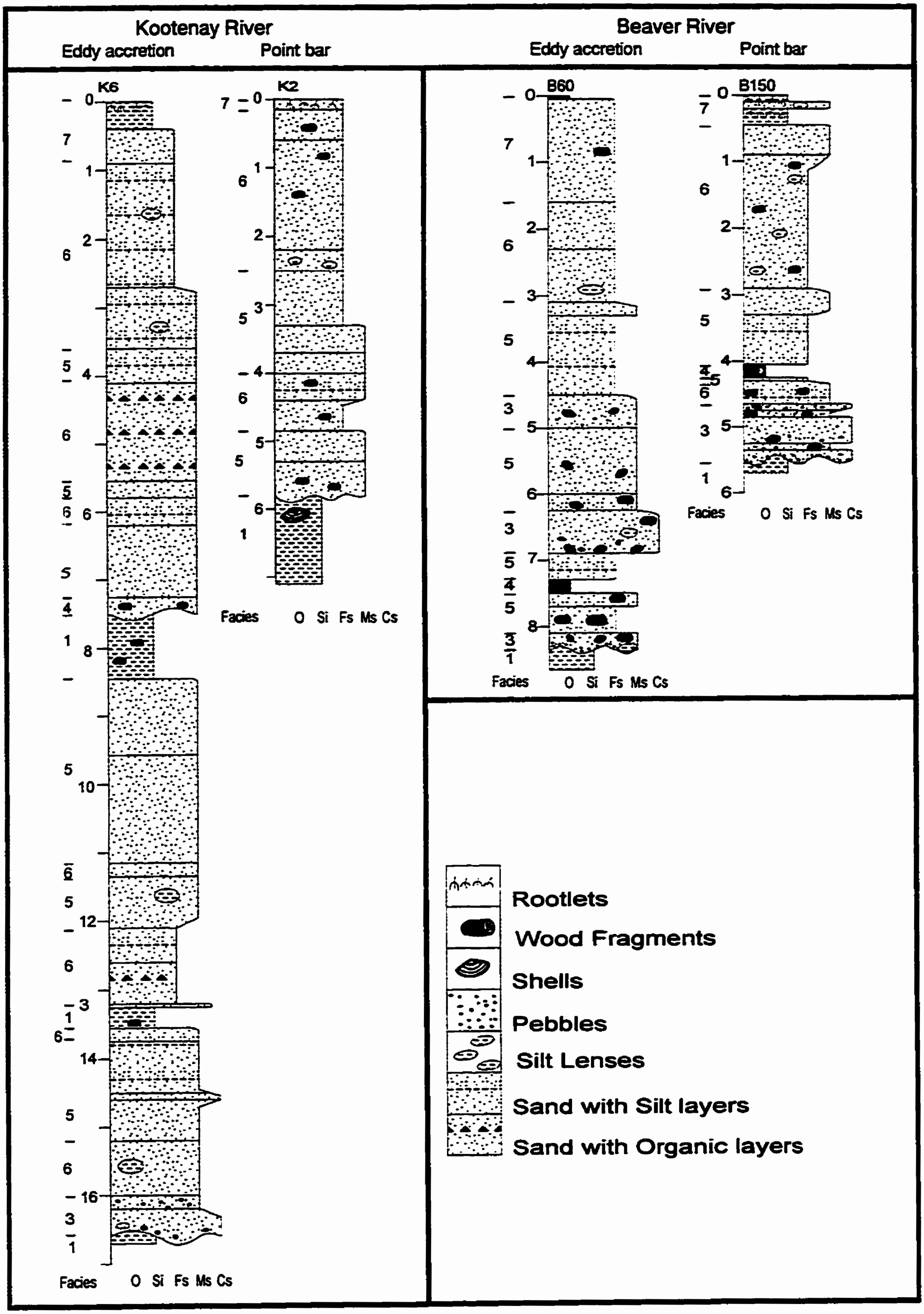


Figure 4-13. Comparison of lithostratigraphic logs taken from eddy accretions and point bars on the Kootenay and Beaver rivers. Eddy accretion sand is approximately twice as thick as the adjacent point bar sand.

eddy accretion sedimentology may include massive silt layers at any interval but most commonly occurring mid-sequence. Similar layers are absent in point bar deposits. Eddy accretion deposits may be misinterpreted as two superimposed point bar deposits because point bar thickness of adjacent eddy accretion deposits. Third, eddy accretion deposits contain more silt and organic litter in the upper portion of the sequence than point bars. Fourth, eddy accretion deposits exhibit a higher degree of grain size variability (heterogeneity) than point bars sequences. This heterogeneity is likely due to the complex nature of flow in eddy accretion channels where high and low velocities occur in close proximity.

4.6 Channel Bottom Profiles

On the Kootenay River, two eddy accretion channels and one point bar channel were extensively bottom-profiled at bankfull stage. Six eddy accretion channels, and adjacent point bar channels, were bottom-profiled on the Beaver River at 1.7m below bankfull discharge. Profiles were taken perpendicular to channel banks to obtain true cross-sections.

Locations of all bottom profiles are shown in Figure 4-14, and the profiles (echograms) are displayed in Figure 4-15, 4-16, and 4-17. All profiles at eddy accretions show deep scours, a mid-channel ridge, and a perched channel at bankfull discharge. On the Kootenay, the eddy accretion scour depth varies between 14 and 16m, whereas the adjacent point bars are 8m deep. On the Beaver River, eddy accretion scour depth varies between 5.5 and 8m, with point bar depths ranging from 4 to 4.5m, relative to bankfull stage. Depth of the eddy accretion mid-channel ridge varies between 6 to 7m on the Kootenay, and 2 to 3m on the Beaver. Depth of the eddy accretion perched channel varies between 10 and 11m on the Kootenay, and 3m and 4m on the Beaver.

All point bar channel bottom-profiles clearly show a gently sloping lateral accretion surface on the up-valley channel bank, and a steep cutbank on the down-valley bank (Figure 4-15, K2; 4-16, B2,B4; and 4-17, B6). Eddy accretion profiles usually show one perched channel on the upvalley bank, a ridge mid-channel, and a deep scour with a steep cutbank on the downvalley bank. Profile B5 (Figure 4-17) shows two perched

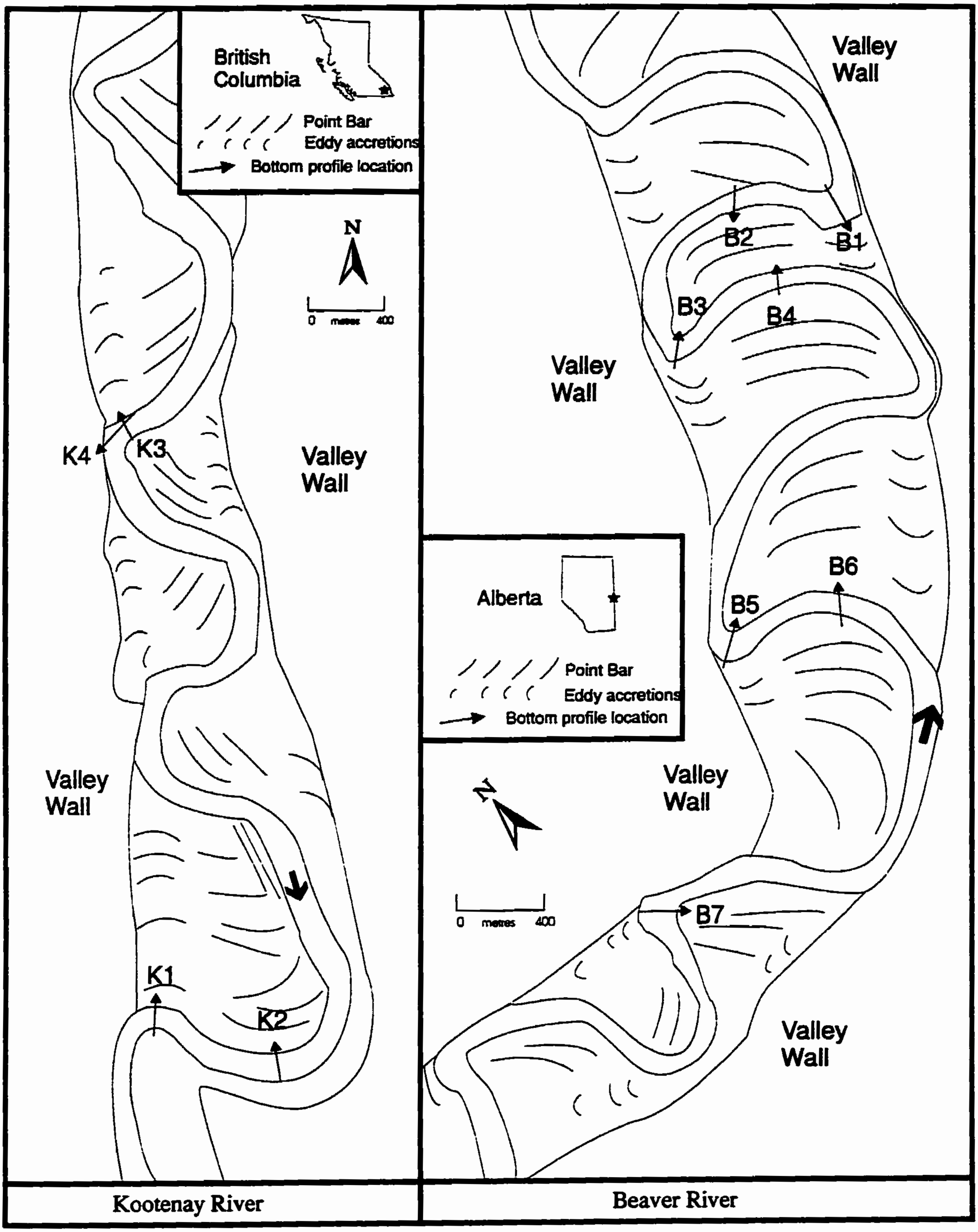


Figure 4-14. Locations of bottom profiles from the Kootenay and Beaver rivers. All profiles (Figures 4-15 to 4-17) are taken from the left bank facing downstream.

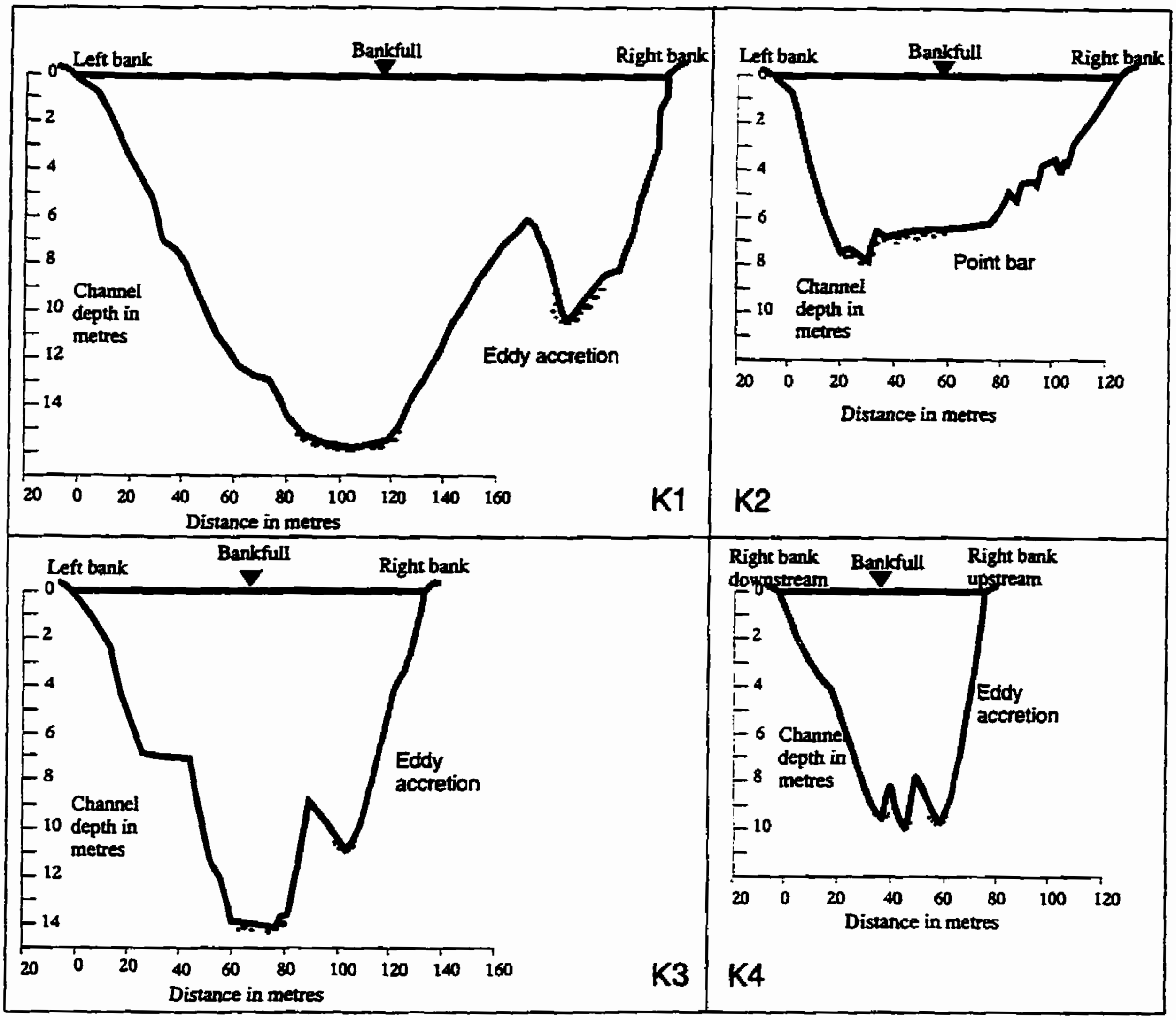


Figure 4-15. Bottom profiles of eddy accretion and point bar channels on the Kootenay River, British Columbia. Profiles were taken at bankfull stage.

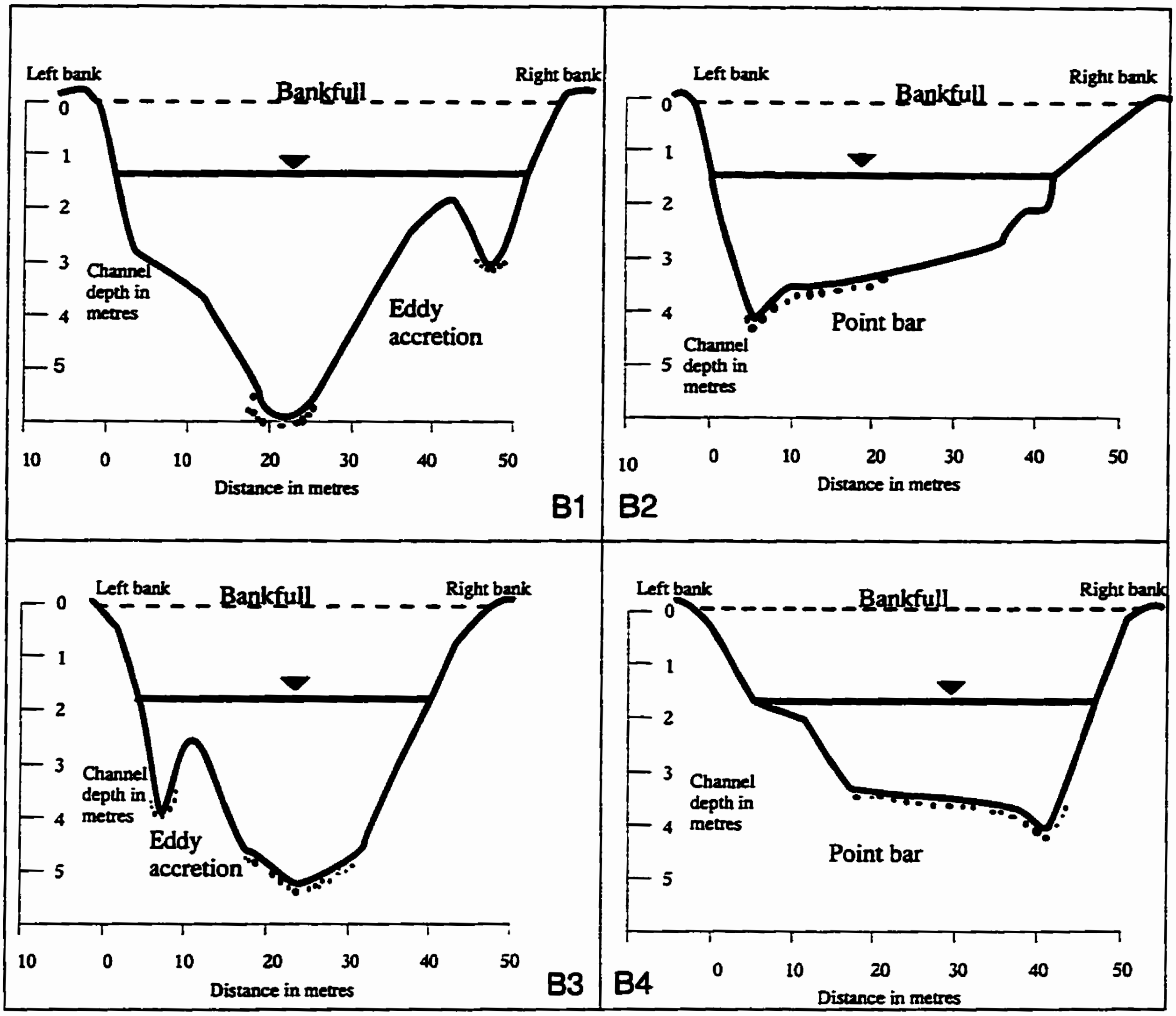


Figure 4-16. Bottom profiles of eddy accretion and adjacent point bar channels on the Beaver River, Alberta. Profiles were taken at 1.5 m below bankfull stage.

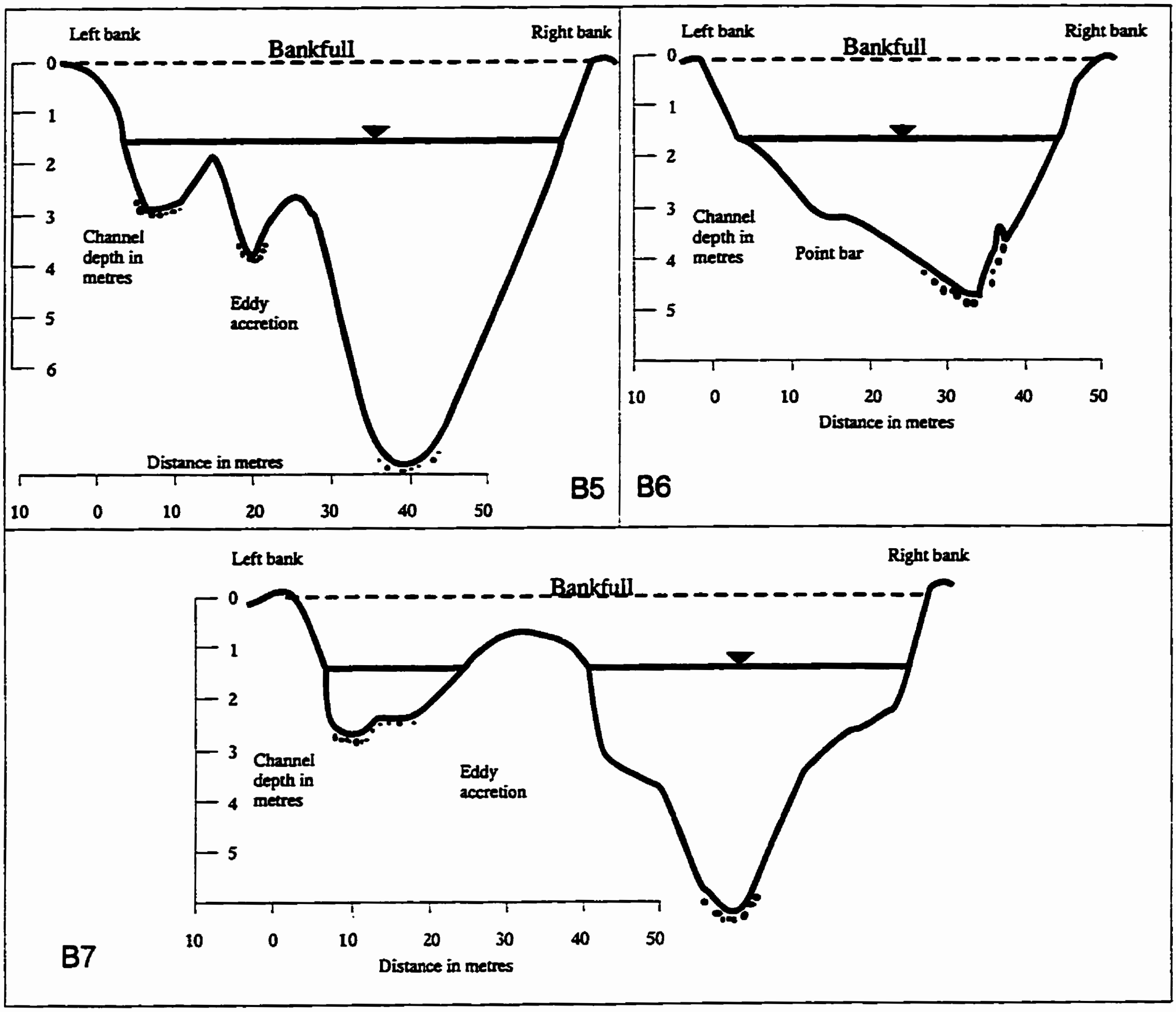


Figure 4-17. Bottom profiles of eddy accretion and adjacent point bar channels on the Beaver River, Alberta. Profiles were taken at 1.5 m below bankfull stage

channels and mid-channel ridges on the upvalley bank. The perched channels become deeper from the left to right bank, indicating that the dominant perched channel is shifting as the channel migrates. An island and/or mid-channel ridge, depending on stage, was present in Profile B7 (Figure 4-17). During bankfull discharge, this island would be shallowly submerged (1m). Profile K4 (Figure 4-15), taken across the right bank of a Kootenay River eddy accretion, shows the mid-channel ridge and the perched channel.

4.7 Velocity Profile

A velocity profile was measured in an eddy accretion channel of the Kootenay River main study reach (same location as K1 in Figure 4-14). The profile shows the reverse flow of the perched channel, the turbulent flow in the separation zone (over the mid-channel ridge), and the normal flow in the main channel (Figure 4-18 and 4-19). Velocity measurements, taken at bankfull discharge, show the highest velocities in the main channel at 1.6 m/s, no velocities at the separation zone ridge and velocities up to 0.7 m/s in the perched channel. The discharge in the main channel scour (normal flow) was 810 m^3/s, while the perched channel (reverse flow) discharge was 190 m^3/s. The perched channel carries 23% of the main channel discharge.

The deepest scour in the channel corresponds with the highest velocities. Low velocities correspond to the separation zone ridge, and the elevated velocities in the perched channel correspond to the secondary scour. The velocity profile shows that the perched channel carries considerable flow and actively scours at bankfull discharge. The highest velocities were measured at the eddy accretion main channel base, below the cutbank. These high velocities create the largest shear stress and the deepest scour as seen in eddy accretion bottom profiles.

Due to significant upwelling at the separation zone, the flow direction could not be accurately measured. The dominant flow direction at the surface was reverse over the separation zone but some of the flow was probably normal. This may have pushed the line of zero velocity into the main channel on the velocity profile. But, it may lie anywhere in the separation zone and likely moves over time under different flow conditions.

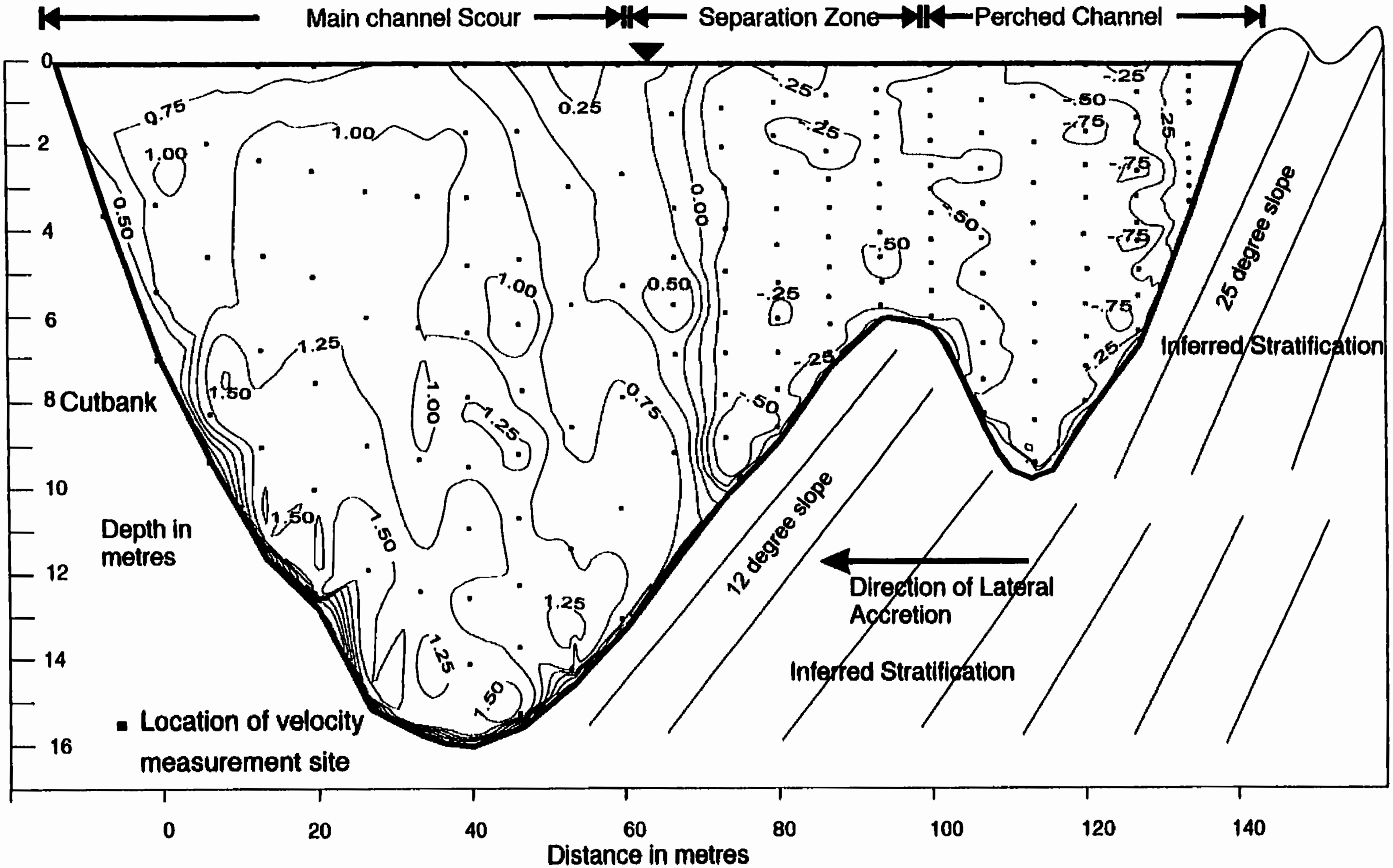


Figure 4-18. Velocity profile from the Kootenay River eddy accretion channel. Flow velocities are highest in the main deep channel scour, slow over the mid-channel ridge, and high but reversed in the perched channel. Velocity readings are in m/s. Note the highest velocities are near the bed at left bank of the main channel scour.

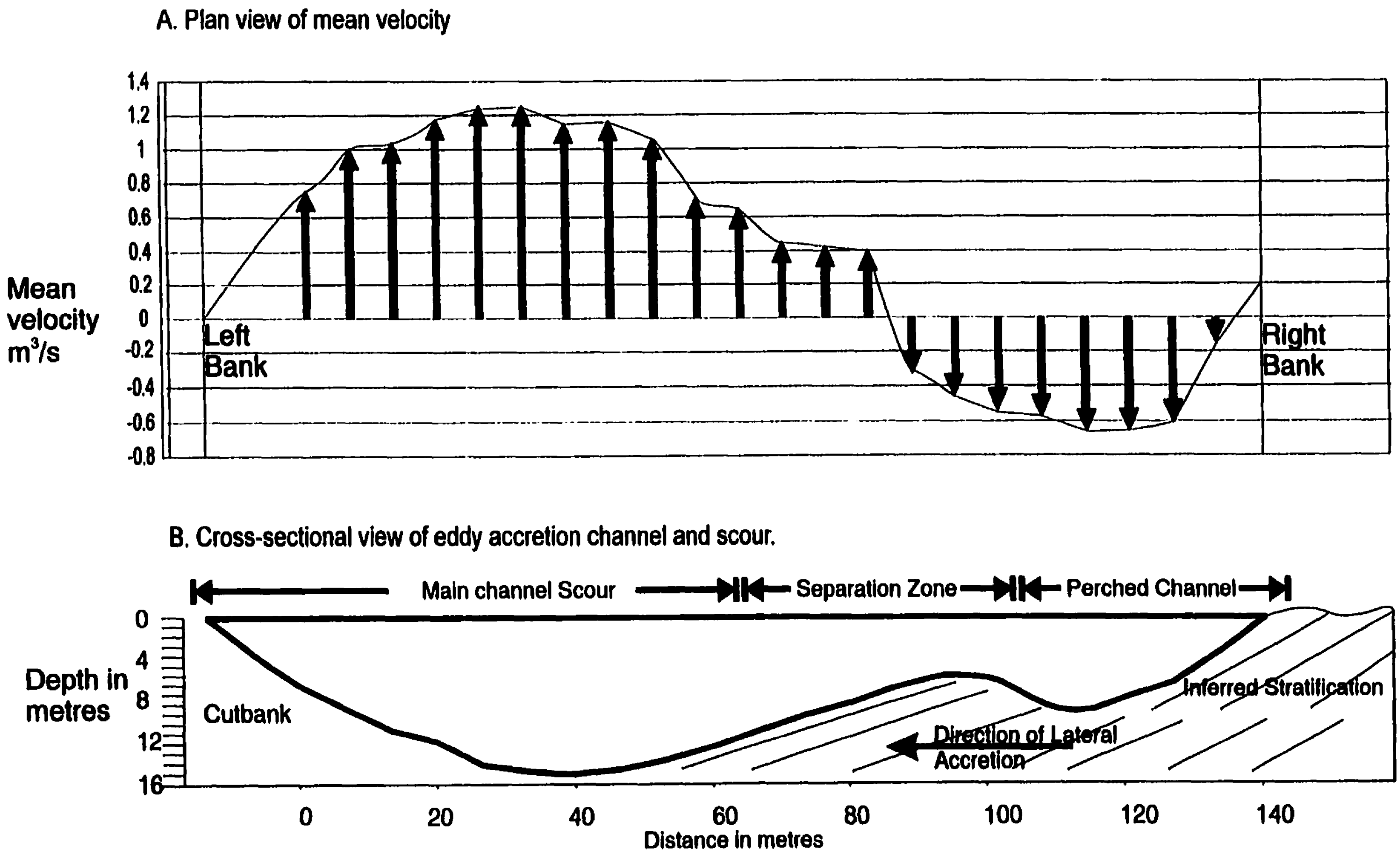


Figure 4-19. (A) Plan view of average velocities in a vertical column, from the Kootenay River at the eddy accretion channel scour. (B) Cross-sectional bottom profile beneath the velocity profile.

5. CHAPTER FIVE DISCUSSION

5.1 Eddy Accretion Depositional Processes

The process of eddy accretion deposition was inferred through the interpretation of aerial photographs, lithostratigraphic logs, bottom profiles, a flow velocity profile, and previous research. Data from lithostratigraphic logs, determined the sedimentology and facies successions. Geophysical bottom profiles (echo soundings) and a cross-sectional velocity profile were used to examine channel morphology and hydraulic characteristics. When combined, the data exhibited four main depositional zones: (1) the main channel zone, (2) the separation zone ridge, (3) the perched channel zone, and (4) the overbank zone (Figure 5-1). Together, these zones form new floodplain land in the downvalley direction.

The main channel zone is located on the downvalley side of the channel profile (Figure 5-1), bounded by the cutbank on the downvalley side and the separation zone ridge (or island) on the other. The separation zone ridge (or island) forms the upvalley bank of the main channel and the downvalley bank of the perched channel. Finally, the perched channel is bounded by the separation zone ridge on one side and the perched channel accretion surface on the other (Figure 5-1).

Flow behavior in an eddy accretion channel may be separated into three main parts: (1) normal (downstream) flow in the main channel, (2) reverse flow (eddy) in the perched channel, and (3) turbulent flow with significant upwelling in the separation zone. Flow reversal occurs when flow impacts a resistant deposit, usually the valley wall, at a right angle (Carey 1969). Within the channel water 'piles up' against the resistant valley side, forcing upstream (reverse) flow on the upvalley portion of the channel. The impingement causes flow separation in the main channel and creates a large eddy. The eddy flows within the perched channel and carves a semi-circle into the floodplain. The reverse flow eventually loses energy and rejoins the main channel flow. The eddy recirculates flow into the main channel, thereby increasing discharge and velocity of the flow, and causing the deepest depth of scour in the fluvial system.

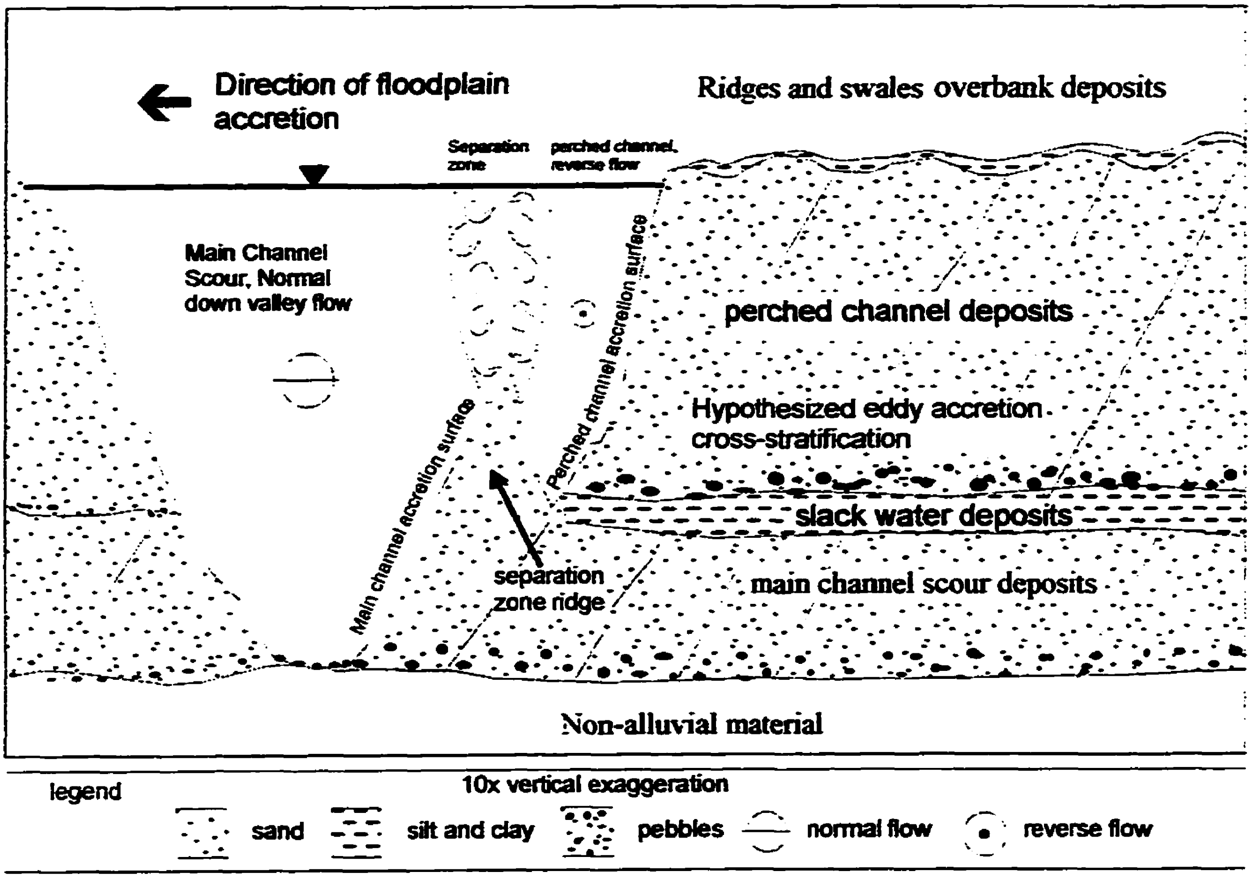


Figure 5-1. A schematic diagram of the longitudinal valley profile, across river flow, of an eddy accretion. Normal flow occupies the left, main channel scour and reverse flow (eddy) occupies the right perched channel. The depositional system is prograding down-valley with active accretion surfaces sloping down-valley forming the 12 to 25 degree hypothesized inclined stratification.

5.1.1 Main Channel Zone

The main channel zone is located on the downvalley side of the channel profile, bounded by the cutbank on one side and the separation zone ridge or island on the other. The main channel zone is the deepest portion of the channel profile, the flow direction is down stream, it carries the largest discharge, and has the highest velocities. On the Kootenay and Beaver rivers, the main channel zone is the deepest part of the entire river (17m on the Kootenay and 9m on the Beaver), scouring into lacustrine silts and clays (Scour at point bar channels are 6m on the Kootenay and 5m on the Beaver).

Two facies are associated with the main channel: (1) a coarse channel lag (facies 3) and (2) laterally-accreted sand (facies 5 and facies 6). The channel lag, transported only at bankfull discharge, is characterized by coarse sand to pea-sized gravel with silt-clay rip-ups and unconformably overlies deeper non-alluvial sediments.

The laterally-accreted deposits generally fine upward from the channel lag. Medium sand is the modal grain size, with coarse and fine sand occurring less frequently. Silt, organic layers, and wood fragments also occur within the sequence. The laterally-accreted sand is deposited by the normal (downstream) flow in the main channel. Deposition occurs on the accretion surface as the channel migrates on accordance with cutbank erosion. Cutbank erosion widens channels and expands flow, thereby lowering velocities. This process keeps the main channel width consistent and is similar to point bar lateral accretion.

Lateral-accretion in the main channel and point bars are similar. Both laterally accrete and the average slope of the main channel accretion surface is approximately 12°, the same as all point bar slopes (including tidal estuary channels) (Smith pers. com. 1996). The slope angles indicate that similar depositional processes are involved in the eddy accretion main channel and point bars. But due to the complex nature of the channel, it is hypothesized that sand is not deposited on the main channel accretion surface by traction currents (migrating bedforms) as occurs on point bars, but instead it is hypothesized that sand is thrown into suspension to lose its upward turbulent flow velocities near the separation zone resulting in sand falling onto the accretion slope. As sand falls out of suspension when velocities decrease near the separation zone, avalanching occurs down the separation zone ridge because it over-steepens. This suspension fallout forms a ridge between the normal and reverse flow but also occurs in the same manner on the main channel accretion surface.

As the channel cutbank erodes, the main channel width is maintained by the separation zone and ridge prograding downvalley. The ridge progrades into the main channel by over-steepening the main channel accretion surface. Avalanching of sand occurs into the main channel when the ridge becomes too steep and exceeds the under water angle of repose.. At lower-than-bankfull discharge or rapid drawdown conditions, slumping of the accretion surfaces may occur.

5.1.2 Separation Zone Ridge

The separation zone ridge forms upvalley from the main channel and downvalley from the perched channel. The separation zone ridge is the shallowest part of the eddy accretion channel sub-environments, has the lowest velocities and is characterized by significant upwelling at the water surface. As discussed above, this zone separates the normal flow of the main channel from the reverse flow of the perched channel. In the separation zone, mixing of the normal and the reverse flow causes significant macroturbulence and upwelling. This turbulence and upwelling causes a lowering of velocities and a decrease in flow competence, allowing deposition of sand. Sand, carried by suspension into the separation zone turbulent flow is deposited as a ridge between the main channel and the perched channel. In the Kootenay River, the separation zone ridge studied may not be preserved but instead be eroded by the perched channel as it progrades downvalley with the main channel (Figure 5-1).

The ridge may be preserved if it breaks the water surface and becomes an island. Many active eddy accretions, including the active eddy accretion downvalley of the Beaver River core sites (Figure 5-2), contain islands. Former islands are visible in the eddy accretion scroll patterns on aerial photographs. The islands form when an up-stream point bar progrades faster than an adjacent eddy accretion causing the eddy accretion channel to widen and velocities to decrease in the separation zone. Sand is then

Figure 5-2. Main channel flow of Beaver River flows towards the lower left of the photo. The channel on the right side of the island flows up stream (reverse flow eddy). Note the inflatable boat for scale in the lower right.

deposited on the separation zone ridge and if it breaks the water surface forms an island. At low stage, the island becomes vegetated by grasses, causing a further reduction of velocity and continued deposition. Reverse flow continues in eddy accretion perched channels with islands, but the separation zone is eliminated because the islands form the upvalley portion of the main channel and the downvalley portion of the perched channel. The process of perched channel abandonment and fill will be discussed in the next section.

5.1.3 Perched Channel Zone

Perched channels are located on the upvalley portion of the eddy accretion channel, bounded by the separation zone ridge or island on one side and the perched channel accretion surface on the other. The main channel and perched channel may prograde downvalley simultaneously if an island is not formed. The perched channel scours into sediment deposited by the main channel accretion surface and the separation zone ridge. As the perched channel progrades, the separation zone ridge is removed, while the downvalley main channel portion migrates.

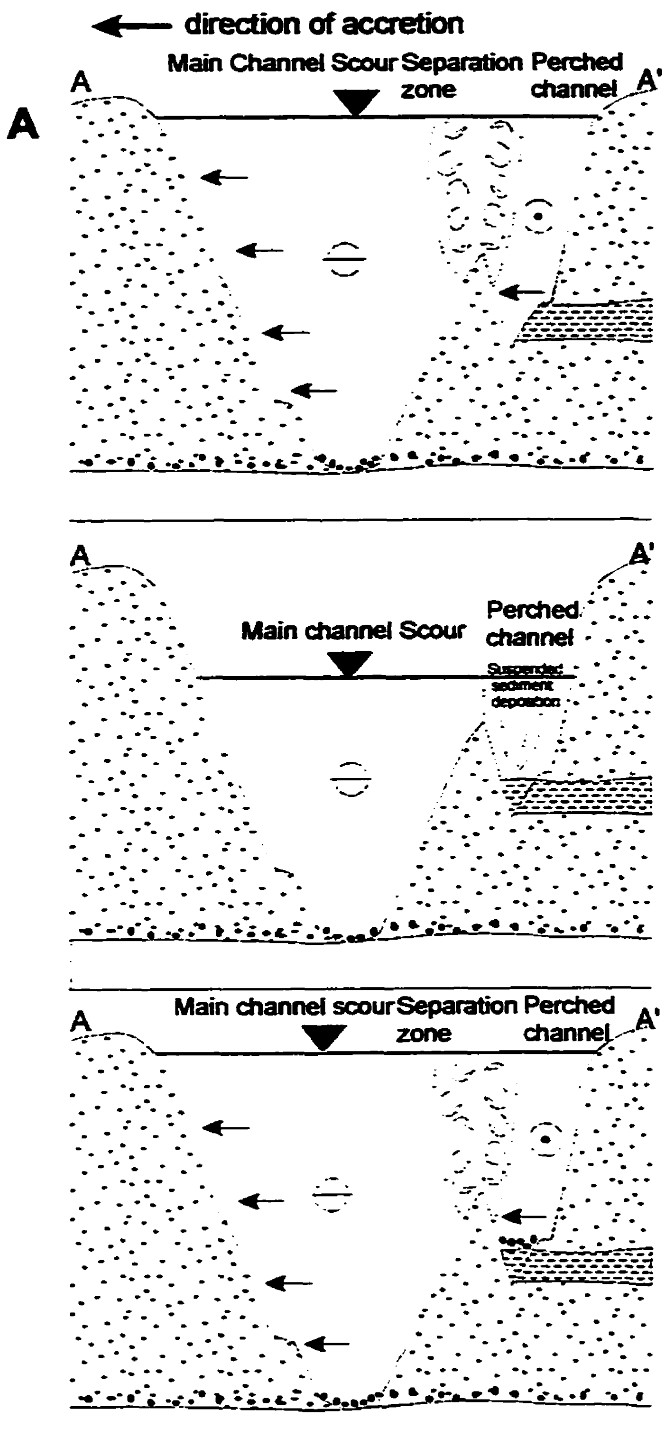
Three deposits are associated with the perched channel: (1) coarse channel lag (facies 3), (2) laterally-accreted deposits (facies 5 and facies 6), and (3) slack water deposits (facies 7). The channel lag and the laterally-accreted deposits are similar to those deposited by the main channel. An unconformity is created at bankfull discharge when flow in the perched channel scours into the underlying deposits. A coarse channel lag, transported only at bankfull discharge, forms on the base of the perched channel. This coarse lag unconformably overlies the main channel deposits and is characterized by coarse to medium sand with pebbles. Laterally-accreted sand is deposited by the reverse flow in the perched channel. These sediments generally fine upward from the channel lag. In the rivers studied, medium sand was the modal grain size, with coarse and fine sand occurring less frequently. Silt and/or organic layers, and wood fragments may also occur within the sequence.

The third deposit associated with perched channels are slack water deposits. These deposits form during lower stages when the perched channel is partially cutoff (reduced flow) from the main channel by the separation zone ridge (Figure 5-3). At these low stages, when the river is in a lower energy regime, flow separation does not occur and the back eddy is inactive. At this time velocities fall to almost zero allowing deposition of silts from suspension onto the base of the perched channel (Figure 5-3B). These thick massive silt layers (up to 70cm in the Kootenay) appear similar to bioturbated lacustrine deposits. When river stage increases, and the perched channel becomes reactivated, massive silts are scoured on which a coarse channel lag is deposited over this unconformity. Lateral accretion resumes as the channel migrates downvalley (Figure 5-3C).

Thick silt layers are absent from rivers low in suspended sediment load. The eddy accretion deposit studied on the Kootenay River contained thick massive silt layers approximately mid-sequence, while the Beaver River eddy accretion contained few thin silt layers within the sequence. The Kootenay River is glacially-fed with a very high silt content and these silts are deposited in the perched channel during low flows. The Beaver River water is clean, receiving little silt from the muskeg-dominated watershed, which may explain the absence of silt layers.

As flow impacts the valley wall it separates and carries sand into the perched channel, transporting it upstream. Deposition occurs as sediment settles from suspension onto the perched accretion surface by the reverse flow. Sediment then avalanches down the accretion surface depositing at a 25° slope angle. Much of the sand is probably not deposited on the accretion surface, but instead is transported through the perched channel to reenter the main channel flow again.

A small spit-like feature may develop where perched channel flow rejoins the main channel between the eddy accretion and the point bar (Figure 5-4). This feature may expand into the main channel and deflect the flow separation downvalley. The spit may aid in the abandonment of perched channels and formation of new ones. Active spit-like formations were observed on the Kootenay River, but not in the Beaver. These features may be preserved in the floodplain between the eddy accretion and point bar scrolls.



A. Bankfull discharge.
Eddy accretion is active and prograding; separation zone is large and significant mixing of the normal and reverse flow directions occurs. Velocities in the perched channel are high and the bed is actively scoured.

B. Low stage.
The eddy is inactive because flow separation is reduced and velocities fall to almost zero in the perched channel. (*) In rivers with high suspended sediment loads, silt deposits from suspension to form a thick silt layer on the base of the perched channel.

C. Subsequent bankfull discharge.
Flow separation occurs and the eddy accretion activates. The separation zone and perched channel zone are active. The perched channel scours into the silt layer and deposits a channel lag overtop is it progrades downvalley (to the left).

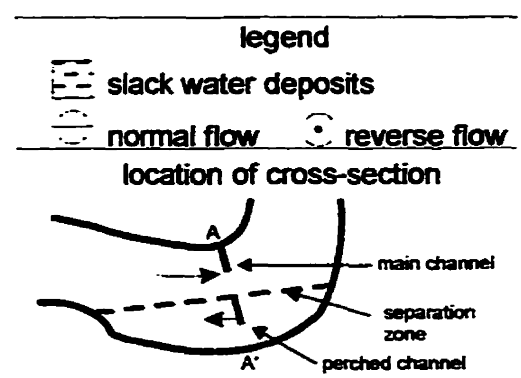


Figure 5-3. Schematic cross-sections of a hypothesized three step process of perched channel silt layer formation. In A, the river is at bankfull discharge and the eddy is actively accreting and scouring laterally. In B, the river is at low discharge and the perched channel is almost cut off from the main channel. Velocities in the perched channel fall and silts are deposited from suspension. In C, the river returns to bankfull discharge, flow separation occurs, and the perched channel reactivates, scouring into the silt layer.

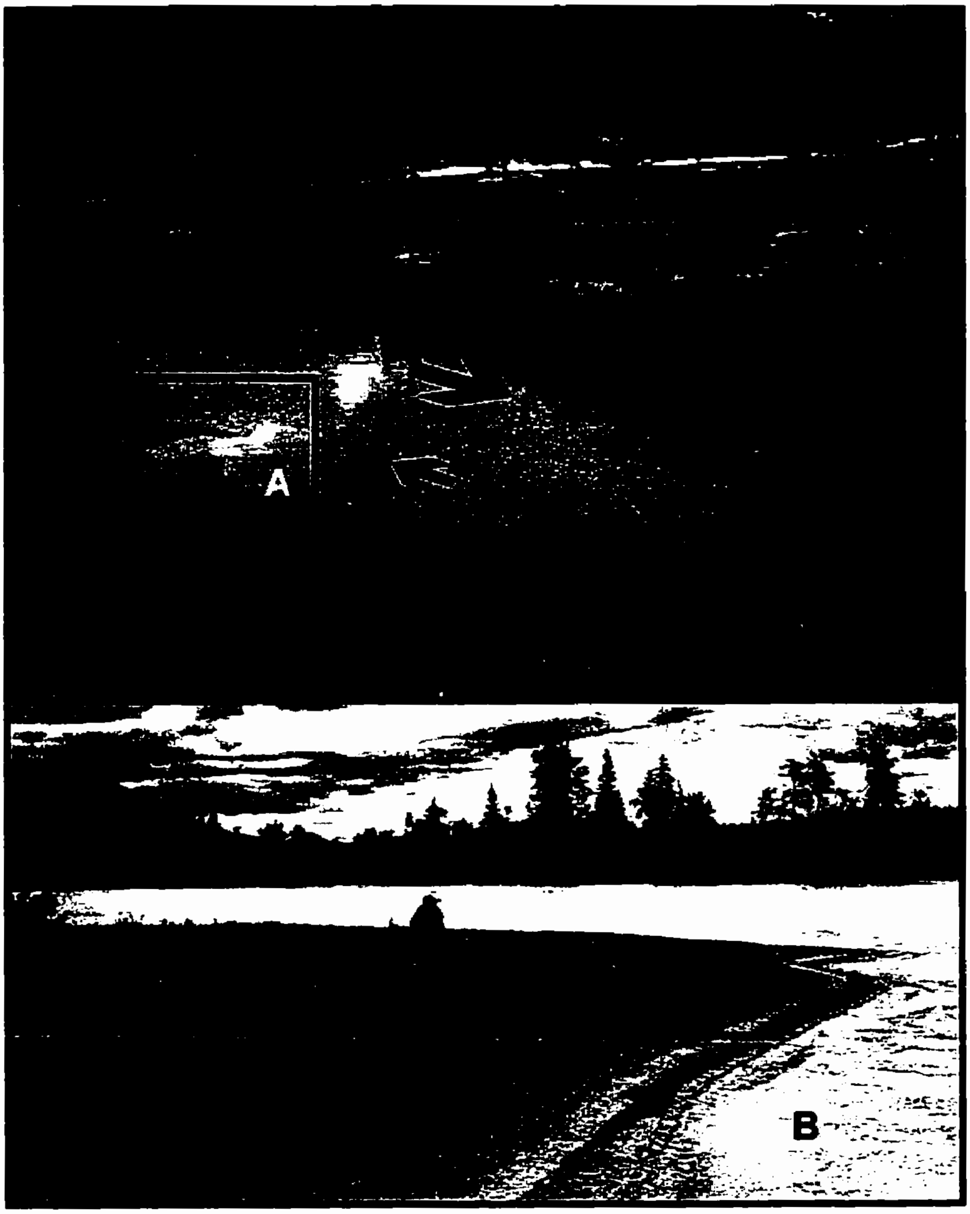


Figure 5-4. (A) Spit-like feature deposited near bankfull discharge, on the upstream end of the Kootenay River eddy accretion perched channel.
(B) Close up of a person on recently formed spit-like feature. At this lower stage, the spit has become part of the floodplain.

Over time the main channel and adjacent point bar simultaneously migrate downvalley, but the perched channel may be stabilized behind a separation zone island. The perched channel moves downvalley in a series of episodic movements leaving behind former islands and perched channels within the floodplain. When the main channel has left the perched channel far enough behind in the floodplain, it will become abandoned and a new perched channel will develop on the upvalley portion of the main channel. Normally eddy accretion channels contain one perched channel (Figure 5-5A), but, secondary perched channels were observed forming and fully developed on the Beaver River within the main channel (Figure 5-5B,C). During episodic movements the primary perched channel may be abandoned by the main channel as the main channel migrates downvalley and a new perched channel develops within the main channel (Figure 5-5B,C). Primary and secondary perched channels remain active for some time until the primary perched channel is completely abandoned to join the floodplain and infill with mud. These abandoned perched channels are commonly seen around islands in the scroll pattern of the floodplain.

5.1.4 Overbank Zone

The overbank zone covers the entire floodplain and is active only during floods. During flood, silty water flows across floodplains and deposits silt out of suspension. Deposition occurs due to the decrease in velocity and reduced turbulence as a result of flow expansion and increased flow resistance over the floodplain. These deposits are referred to as overbank or vertical accretion deposits because they build up vertically through time as opposed to laterally (point bar deposits). Overbank deposits are most commonly silt, but close to the channel can be fine sand and silt, or clay where flood waters pond during falling stage. Mud cracks are common, created after the flood recedes, and due to the abundance of vegetation on the floodplain, root traces are also common (Allen 1965a).

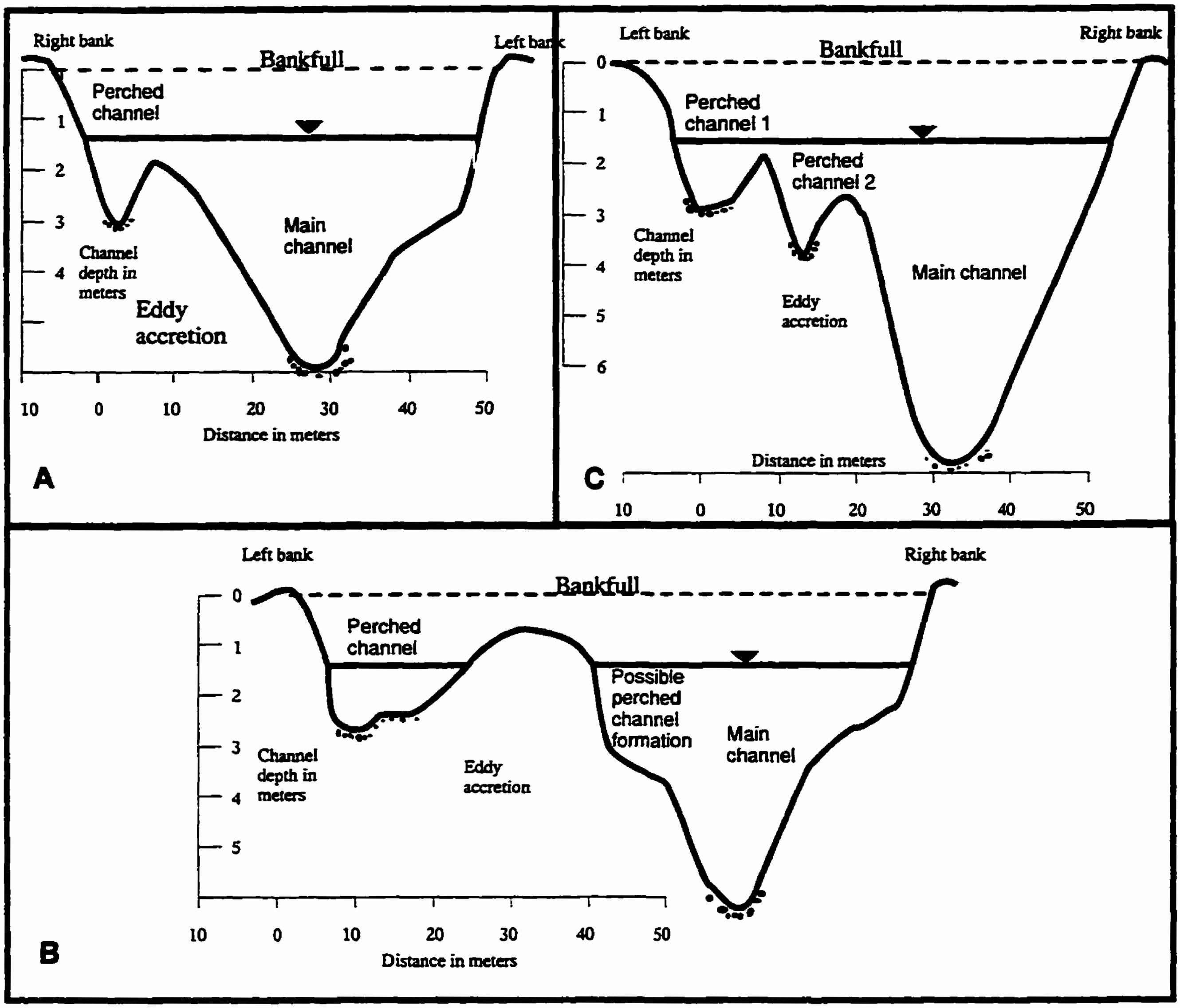


Figure 5-5. Bottom profiles of eddy accretions on the Beaver River, Alberta, showing possible perch channel abandonment. Bottom profile locations are shown in Figure 4-14. (A; B1 Figure 4-14) A typical eddy accretion channel with a perched channel, main channel, and separation zone ridge. (B; B5 Figure 4-14) A large separation zone ridge which becomes an island at low stage. It also shows the formation of a second perched channel within the main channel. (C; B7 Figure 4-14) A channel with a second perched channel (perched channel 2) and separation zone ridge, formed within the main channel. Profiles were taken at 1.5 m below bankfull discharge.

5.2 Eddy Accretion / Concave-Bank Bench Evolution

Page and Nanson (1982) examined the formation of concave-bank benches on a reach of the Murrumbidgee River, New South Wales, Australia. They identified concave-bank bench evolution from aerial photographs and field surveys of the river and produced a general model from separation zone islands (benches) at different stages of development. Their model involves sequential phases of convex bank retreat and flow expansion, basal bar-bench nucleus, and mature bench formation (Figure 1-7). This model is based on aerial photographs, and limited field data. By incorporating new eddy accretion field data from the Kootenay and Beaver rivers into the generalized concave-bank bench evolution model (Page and Nanson 1982) and using new terminology, a revised model may be suggested (Figure 5-6). The revised model may not be entirely correct due to the differences between concave-bank benches and eddy accretions, but it represents a first attempt to incorporate new field data into the model.

Page and Nansons (1982) model contains 6 migration phases. First, there is separation zone development within the channel (Figure 5-6A). Second, the separation zone strengthens forming a ridge between the main and perched channels. Third, cutbank erosion and adjacent point bar or spit like growth occurs as the main channel migrates and the separation zone and ridge enlarge (Figure 5-6B). Fourth, an island develops within the separation zone (Figure 5-6C). Fifth, continued point bar growth and cutbank erosion as the main channel migrates forces the development of a new separation zone downvalley from the first (Figure 5-6E). Finally, a second island forms in the new separation zone while the old island becomes part of the floodplain and the former perched channel is abandoned (Figure 5-6F).

The generalized concave-bank bench evolution model (Page and Nanson 1982) shows a plan-view of concave-bank bench migration based on aerial photographs. Incorporation of channel bottom profile and velocity profile field data from the Kootenay and Beaver rivers shows the processes of island formation and perched channel abandonment during channel migration. Continued research on concave-bank bench and eddy accretion evolution should test the validity of the revised model.

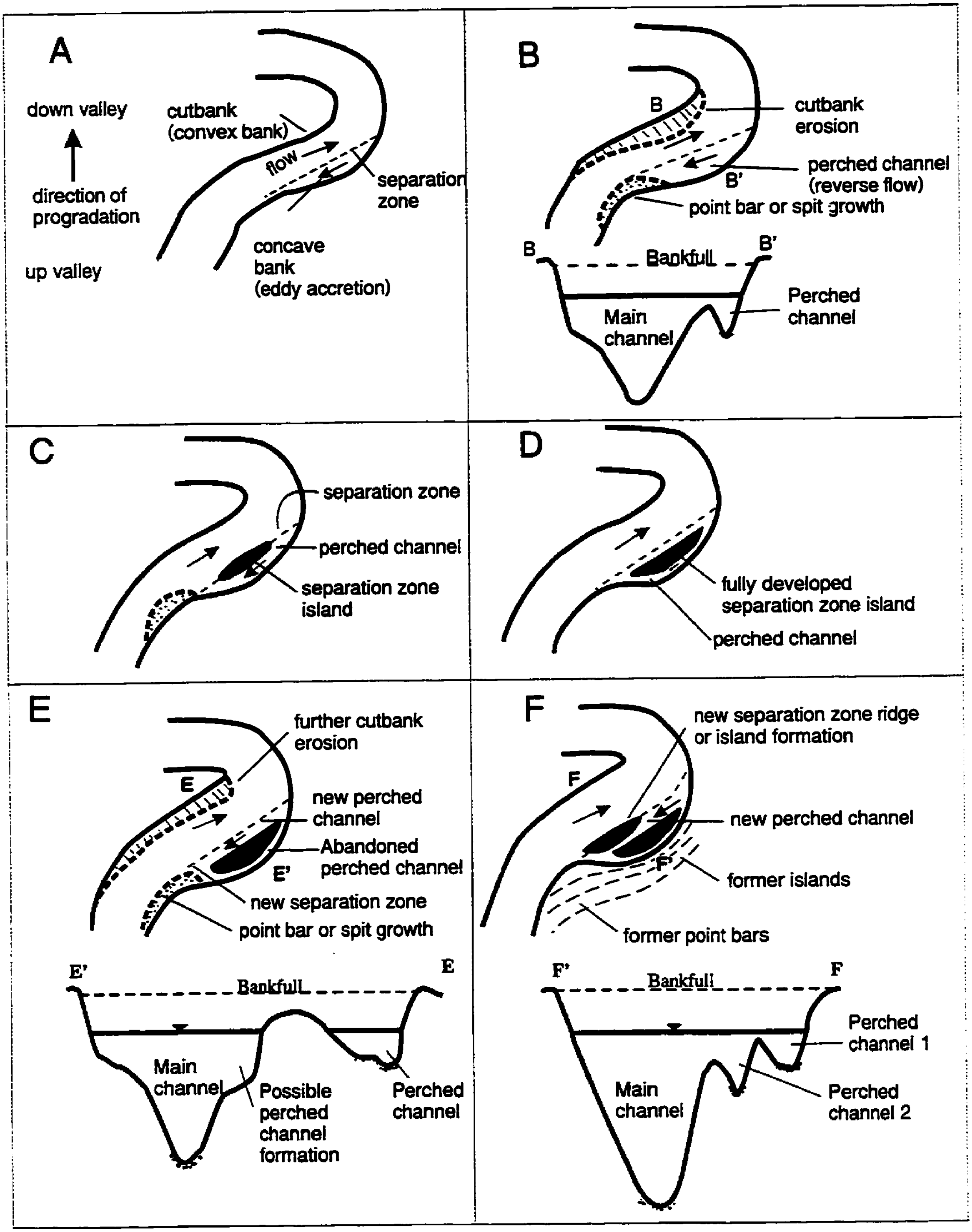


Figure 5-6. Reinterpretation of concave-bank bench generalized formation model incorporating channel profile and velocity data. (Modified from Page and Nanson 1982)

5.3 Comparison of Beaver and Kootenay River Eddy Accretions

There are three main hydrologic and sedimentological differences between the Kootenay and Beaver rivers. First, the Kootenay River eddy accretion deposits are deeper than those in the Beaver because of higher Kootenay discharge creates a deeper scour. Second, massive mid-sequence silt layers (facies 1) in the Kootenay are more common and thicker than those in the Beaver River. This is most likely due to the higher suspended sediment loads in the glacially fed Kootenay River. The Beaver River flows from small lakes and muskegs which are low in suspended sediment and thus the silt layers are smaller. Third, grain sizes of Kootenay River deposits are slightly coarser than the Beaver, probably also due to the larger discharge and higher shear stress of the Kootenay as compared to the Beaver. In general, the contrasts between the Kootenay and Beaver rivers are primarily due to differences in discharge and sediment source.

5.4 Confined Valley Architectural Geometry

A three dimensional model of eddy accretion alluvial geometry for confined meanders was developed from the Kootenay and Beaver rivers on the basis of previously published research, lithostratigraphic cross-sectional profiles from vibracores and aerial photographs (Figure 5-7). The data indicates that in confined valleys 25-30 % of the total floodplain surface and up to 50% of the valley cross-sectional area, may contain eddy accretion deposits both sides of a valley, where river channels impinge at 90°on their resistant valley walls. In such sites eddy accretion deposits are twice as thick as adjacent mid-valley point bar deposits. In meandering river valleys in which eddy accretions flank both valley walls, alluvial sand bodies have a 'dumbbell' geometry in the subsurface. The bulging weights, on each side of the 'dumbbell' represent thicker eddy accretion deposits along valley margins, while the dumbbell handle represent the thinner mid-valley point bar deposits.

This confined meandering river valley-fill geometry may have occurred in ancient sedimentary rocks (incised valley-fills) associated with marine lowstand environments. These deposits would most likely be preserved as lower sequences in incised valley-fills and may be capped by sediments associated with marine transgressions. To create an

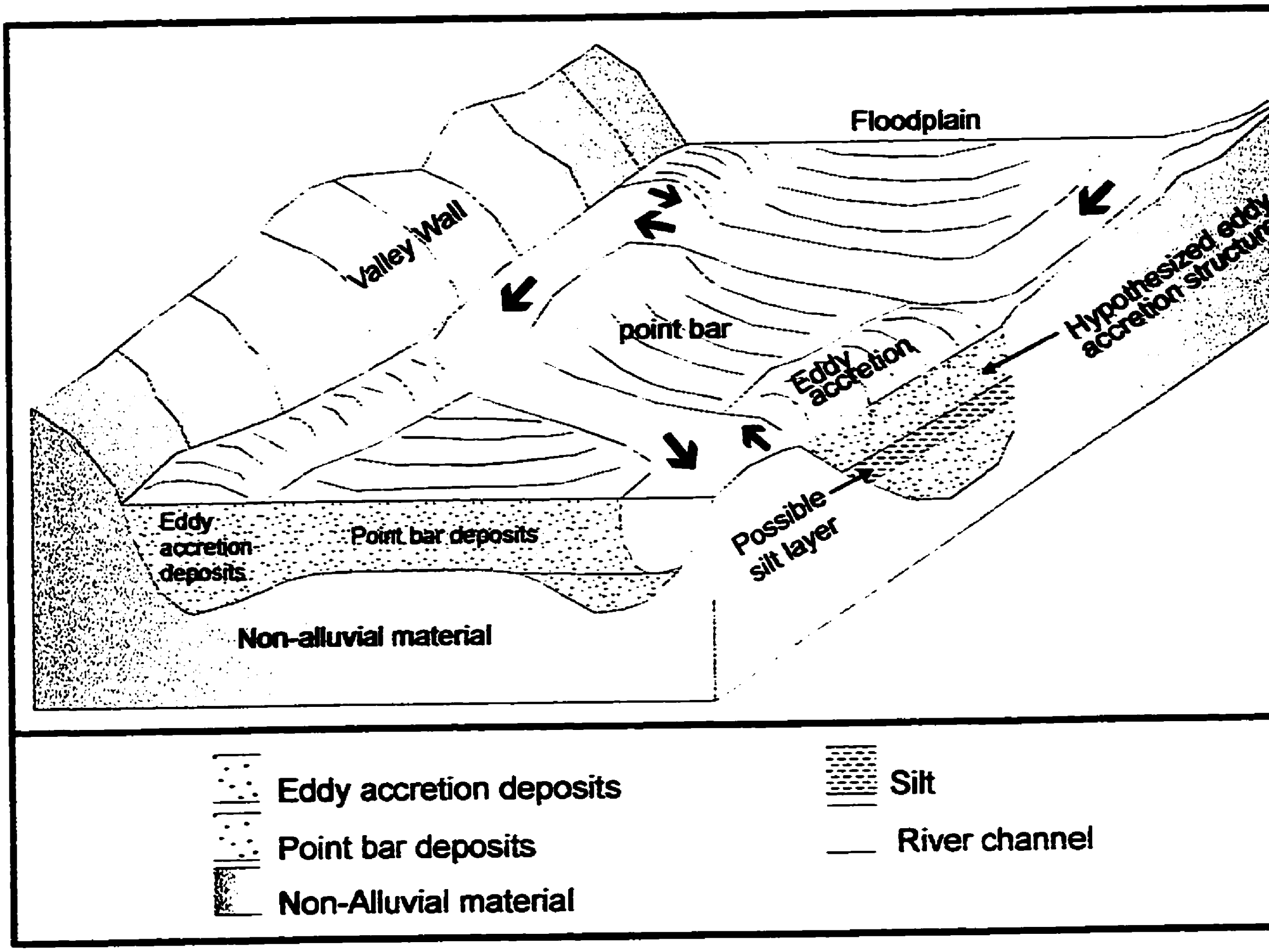


Figure 5-7. Three dimensional model of a hypothetical confined meandering river valley in which eddy accretions occur. Eddy accretions deposits flank the sides of the valley while point bar depo occur mid-valley.

incised valley-fill, sea level must first lower, to force paleo-valley incision, then during lowstand periods eddy accretions likely form as rivers meandered confined by the incised valley walls. If the valley-width to channel-width ratio is in the range that eddy accretions form in confined valleys (6:1 to 9:1), the valley-fill geometry should resemble eddy accretion alluvial geometry similar to modern examples, with the thickest sand occurring adjacent to valley walls. Subsequent base level rise and induced sea level transgression may cause infilling of the valley preserving the underlying alluvial sand. This style of valley-fill could form reservoirs and preferred fluid flow fairways for oil, gas, or water.

5.5 Recognition of Eddy Accretions in Cores or Outcrops of Ancient Rocks

The most reliable feature in recognizing eddy accretion deposits in ancient rocks is sand body geometry. This geometry may be observed in accessible outcrop or high resolution seismic surveys. In incised valley-fills, eddy accretions deposits would be located on one or both sides of a paleovalley and would be approximately twice as thick as adjacent point bar sands. There are four features within the eddy accretion facies succession that may indicate their presence in ancient rocks:

1) Eddy accretion deposits may contain a massive silt layer without rootlets or mud cracks or trace fossils (unlike overbank deposits), within the sand, mid-sequence. A channel lag may be preserved above and/or below silt layers.

2) Two stratigraphic paleo-current zones may be preserved within an eddy accretion and may show a 180° difference above and below a mid-sequence silt layer and lag deposits if preserved.

3) The eddy accretion sands, above the mid-sequence silt layer and/or lag deposit, is muddier and finer in grain size than sand below the silt layer and/or lag.

4) Although not observed in vibracores due to disturbance, steeply dipping inclined stratification (up to 25°) is thought to dominate the internal stratification of eddy accretions; such stratification may be present in outcrops or cores.

5.6 Occurrence of Eddy Accretions in Confined Meandering River Valleys

In order to determine the relationship between valley width, channel width and the occurrence of eddy accretions, valley widths and corresponding channel widths from 17 river reaches on 11 rivers, in Alberta and British Columbia, were measured from 1:50 000 topographic maps. The floodplain and valley morphology was noted as (1) unconfined, (2) confined with eddy accretions or (3) confined without eddy accretions. Channel width was used as a proxy of bankfull discharge. All measurements were taken on a reach by reach basis since the same river may contain more than one valley morphology. The Chinchaga, Hay, Pembina, Liard, and Milk rivers contained unconfined reaches. The Red Deer, Milk and Athabasca rivers contained confined reaches without eddy accretions. The Clearwater, Fort Nelson, Beaver, and Kootenay rivers contained confined reaches with eddy accretions.

The occurrence of eddy accretions within confined valleys is predictable. Eddy accretions form in two types of meandering river valleys: (1) unconfined floodplains where meander belt channels impinge on resistant valley walls at 90°, and (2) confined floodplains where nearly every meander wavelength impinges upon a resistant valley wall. For the purpose of this discussion a confined valley is defined as a valley containing no oxbow (neck) cutoffs, because channel confinement limits the intersection of meandering channels, preventing neck cutoffs from occurring. Eddy accretions are not formed on confined valleys that are too narrow because in these settings meandering channels ricochet off each valley wall at approximately 45° (eg. Red Deer River near Dinosaur provincial park).

Based on these few rivers, some relationships between eddy accretion formation and channel-width to valley-width ratio may be suggested (Figure 5-8). In unconfined rivers with floodplain-width to channel-width ratios greater than 9:1 eddy accretions may form where meander belts impinge upon resistant valley walls, but are otherwise unrelated to valley width. In confined rivers with floodplain-width to channel-width ratios less than 6:1 eddy accretions do not form, but instead river channels ricochet from valley wall to valley wall. Confined valley eddy accretions seem to form in a narrow

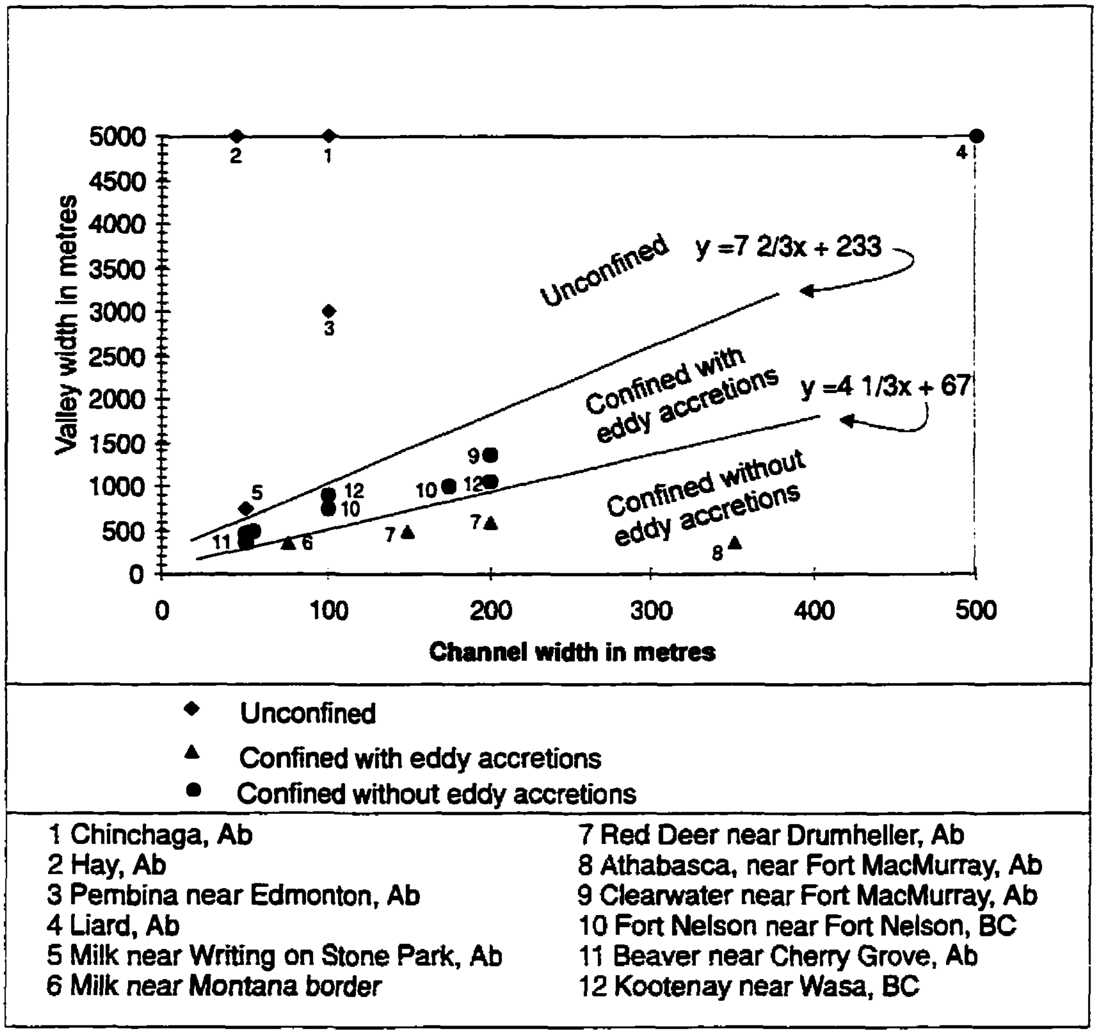


Figure 5-8. Meandering river floodplain-width plotted against channel-width for a sample of Alberta and B.C. rivers. Rivers reaches were recorded as unconfined, confined rivers with eddy accretions, and confined rivers without eddy accretions. Eddy accretions are shown to occur in a narrow range of valley width to channel width ratios (between 6:1 and 9:1). In unconfined rivers eddy accretions may form where meander belts impinge upon resistant valley walls, but are otherwise unrelated to floodplain width. Valley widths and corresponding channel widths were measured from 1:50 000 topographic maps in 17 river reaches on 11 rivers, in Alberta and British Columbia.

range of floodplain-width to channel-width ratio between 6:1 and 9:1 (Figure 5-8). In valleys with such floodplain-width to channel-width ratios eddy accretions may be expected to occur.

5.7 Implications

This research has produced a better understanding of a sub-environment within natural meandering rivers. Due to the greater depth of eddy accretion scour holes, as compared to depths of point bar channels, eddy accretion scours may be important over-wintering fish habitat in northern rivers. Fish require deep pools to survive harsh northern winters, such scour holes are created by eddy accretions and form the deepest portions of these rivers. In addition, they may be important summer (low flow) resting habitat for fish. Understanding of eddy accretion depositional processes provide a good argument against partial river stabilization (Carey 1969). This is due to possible excessive erosion on the eddy accretion cutbank causing the loss of land to the river if correct measures are not taken. Also, knowledge of the probable depth of scour may aid in better location of buried pipelines and cables at river crossings.

Finally, this research is important because eddy accretions are potentially thick aquifers and major fairways for fluid movement in deeply buried ancient rocks. In ancient rock sequences, equivalent thick fluvial sandstones may be considered as preferred exploration targets by the oil and gas industry. Understanding the depositional processes involved within eddy accretions provides insight into the sediments, their identification and location in the subsurface rocks.

6. CHAPTER SIX CONCLUSIONS AND RECOMENDATIONS

6.1 Conclusions

Scour in eddy accretions form by powerful reverse flow caused by river channels impacting resistant valley walls at a 90° angle (refer to Figure 1-1). Eddy accretions migrate downvalley simultaneously with the point bar, creating a diagnostic scroll pattern reverse to that of point bars on aerial photographs and maps. Commonly in confined settings, eddy accretion deposits occupy 25 to 30 percent of the floodplain surface and up to 50% of the valley cross-sectional area, typically form at floodplain-width to channel-width ratios of between 6:1 and 9:1. Results from two confined sand bed meandering rivers in British Columbia and Alberta, Canada, indicate that eddy accretion deposits are twice as thick as adjacent point bars. Eddy accretion deposits often form on both sides of confined floodplains that are laterally bounded by resistant bedrock, clay, glacial till or gravel. Steeply dipping (12° to 25°) downvalley inclined stratification, possibly separated midway by a horizontal silt bed, is thought to dominate the internal sedimentary structure of eddy accretions.

In some cases the sedimentology of eddy accretions may seem to consist of two fining upward sequences dominated by clean medium sand. A coarse sand channel lag with pebbles and silt rip-ups forms the base of the deposit above which sands fine upward. A thick massive silt layer located mid-sequence may be present above a lower fining upward trend on rivers with high suspended sediment loads, and may separate upper and lower fining upward trends. Unconformably overlaying the mid-sequence silt layer, a second coarse sand channel lag with pebbles is present, over which sand fines upward into over-bank silts. This apparent double fining upward sequence may be misinterpreted as the product of two superimposed point bars.

The process of eddy accretion deposition was inferred through the interpretation of aerial photographs, lithostratigraphic logs, bottom profiles, and one velocity profile. From the data four main depositional zones (the main channel zone, the separation zone ridge or island, the perched channel zone and the overbank zone) are recognized. These depositional zones work together to create the eddy accretion complex and new floodplain land.

Eddy accretion deposits have potential as thick aquifers and major fairways for fluid movement in incised river valley-fills associated with marine lowstands. In deeply buried ancient rock sequences, eddy accretion fluvial sandstones may be considered as preferred exploration targets by the oil and gas industry.

6.2 Recommendations

There is confusion in the literature over the terms concave-bank bench and eddy accretions (Carey 1969, Woodyer 1975, Hickin 1979; Page and Nanson 1982; Nanson and Page 1983; Page 1983). Due to the differences in the definitions of eddy accretions (Carey 1969) and concave-bank benches (Woodyer 1975), I propose that they are related, but different features. To determine the differences, I also suggest that a subsurface study of concave bench deposits be the next step in meandering river research.

The depositional processes cited in this report are untested at present. Future field work is needed to confirm my interpretations. Detailed velocity profiles and three-dimensional views of eddy accretion channel bottoms could be used to test my hypotheses. These measurements need to be taken at bankfull discharge as well as lower stages to determine the erosional and depositional processes occurring at different energy regimes. Finally, continued vibracoring and sedimentology related projects, in different river settings, should be performed on eddy accretion deposits. This will increase the data base on eddy accretions and confirm or reject my hypotheses.

The internal sedimentary structure of eddy accretions is yet unknown. Through the use of ground penetrating radar (GPR) in confined meandering rivers with eddy accretions, their structure may be determined. Clean sand is needed for GPR to work well. The Beaver River may provide an excellent target due to its low silt content. The geometry of alluvial sand may also be confirmed using this method.

Finally, geologists should look for eddy accretion deposits in ancient rocks. Outcrops are the most likely location to recognize ancient eddy accretions and it may be possible to observe their valley-fill geometry. Although difficult to determine in cores, eddy accretions may be identified through their facies succession because they are different from (steeper stratification, multiple channel lags, and massive silt layers), although similar to, those of point bars.

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8. PERSONAL COMMUNICATION

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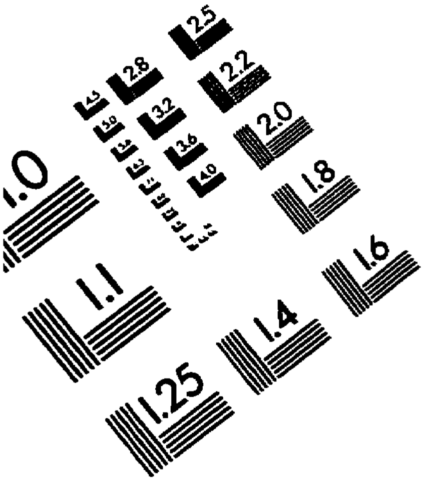
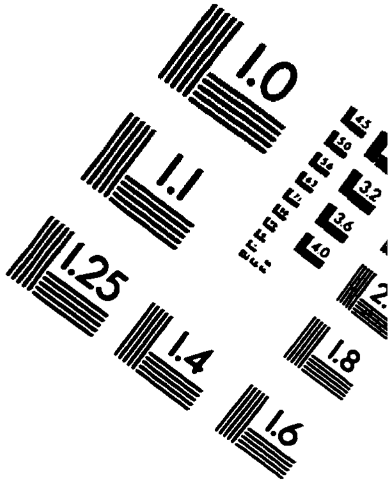
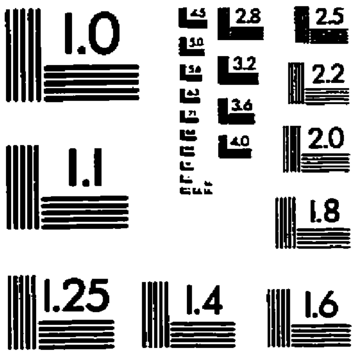
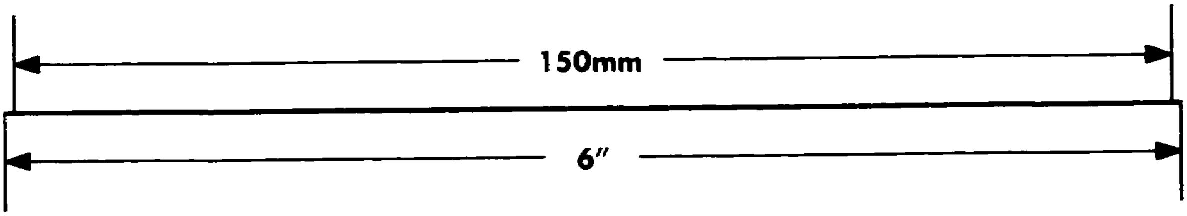
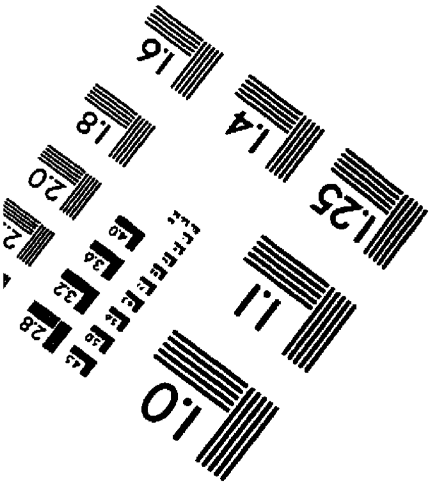
IMAGE EVALUATION TEST TARGET (QA-3)

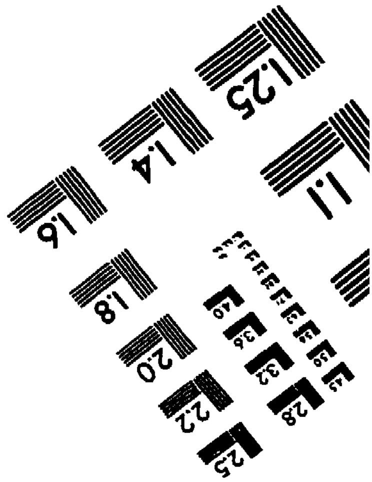












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