FLOODPLAIN CONSTRUCTION AND OVERBANK DEPOSITION IN A WANDERING REACH OF THE FRASER RIVER, CHILLIWACK, B.C.

by

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ABSTRACT

The Fraser River near Chilliwack, B.C. is classified as a wandering gravel bed river based on its geomorphology and sedimentology. The adjacent floodplain has been constructed by the infill of chutes and accretion of mid channel islands in a manner similar to processes presently occurring in the active channel.

The objectives of the study were: i) to describe the nature of chute infill and island accretion in the active channel zone; ii) to describe the geomorphology and sedimentology of swales on the floodplain; iii) to assess whether or not the processes responsible for present floodplain construction are similar to those which created the historical floodplain; iv) to assess the relative importance of overbank deposition for a wandering river floodplain.

The active channel was found to contain bar platforms, vegetated islands, a hierarchy of major channels and a hierarchy of chutes. The development and infill of chutes is most important since it is the mechanism by which islands are accreted to the floodplain. The geomorphic features of chutes include chute-head bars and lobes, scour holes, chute-bed features such as sand sheets, dunes and ripples, chute-side channels and bank benches.

Twenty-eight pits in the chutes of seven islands were excavated to study the sedimentology of the active channel zone. Sediments were found to be massive to thinly laminated, thickly bedded (facies Sh) with facies St, Sp and Sr found occasionally. Sediments generally fine upwards although there is no consistent transition in sediment size from bed to bed. Sediments fine down-chute largely as a function of the increasing thickness and occurrence of backwater fines. The chute-side channel has a single unit fining upwards sequence over an erosional base or may consist of a silt plug.

The floodplain is covered with a ridge and swale topography showing the location of paleochutes. Relief diminishes away from the river and the floodplain surface dips away from the river. This suggests progressive south to north floodplain construction and coincident vertical aggradation.

Forty-five vibracore boreholes were drilled in three swales on the floodplain to study the paleochute sediments. Infilling of swales by local farmers made it impossible to locate the exact head and tail of the chute. The following sedimentary features were found: i) Sediments fined from upstream to downstream and backwater fines thickened in the same direction; ii) Sediments were massive to thinly laminated, thickly bedded (facies Sh) sands and silts; iii) Overlying the sands were 1-3 m of overbank silts and very fine sands which comprise approximately 50 per cent of the material above the gravel. iv) The sediments generally fine upwards although there was no consistent transition in grain size from bed to bed.

Gravel elevation across the floodplain decreases from the river distally suggesting progressive south to north floodplain construction and vertical aggradation. Radiocarbon dating yielded an age of 715 ± 65 BP for the proximal zone swale and 2380 ± 75 BP for the midfloodplain zone; again suggesting progressive floodplain construction.

It is concluded that the Fraser River floodplain near Chilliwack, B.C. has been constructed by the accretion of vegetated islands by chute infill in a wandering gravel bed river. The processes presently responsible for island accretion are similar to those which constructed the floodplain. It is further concluded that overbank deposits of silt and very fine sand make up a significant portion (approximately 50%) of the 'above gravel' sediment profile.

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CHAPTER ONE

INTRODUCTION TO THE STUDY

1.1 Introduction

Floodplain construction by multichannel rivers is a poorly understood phenomenon. Floodplains associated with the recently recognized wandering style of river (Neill, 1973; Church, 1983) however, are more extensive than floodplains associated with the more traditional braided and anastomosing planforms. Since floodplain sediments reflect the preserved portion of within channel deposition, research into channel processes and floodplain construction in the wandering river environment has become increasingly important. This thesis reports on the geomorphology and sedimentology of a wandering reach of the Fraser River near Chilliwack, B.C. and its associated floodplain.

The classical braided rivers such as the White River (Fahnestock, 1963), the Brahmaputra (Coleman, 1969), the Donjek (Williams and Rust, 1969) and the Tana (Collinson,1970) are not described as having floodplains per se. Instead, these braided rivers may completely occupy various portions of the valley floor. The floodplains of anastomosing rivers are described by Smith (1973, 1983, 1986) and Smith and Putnam (1980) as being island surfaces within the channel zone. The stability of anastomosing rivers means there is little or no lateral accretion and hence no (lateral) floodplain construction. Anastomosing rivers therefore, display a high degree of lateral stability, while braided rivers are highly unstable.

More recently, a semi-stable fluvial environment which displays lateral accretion of vegetated islands and the wandering of the main thalweg among these islands has been described. This style of river was first named a 'wandering gravel river' by Neill (1973) and has since been described by Church (1983) and Desloges and Church (1987), and recognised by Carson (1984b), Brierley (in prep.) and Kellerhals and Church (in press).

Unlike the braided and anastomosed planforms, wandering rivers often build extensive floodplains (Desloges and Church, 1987). Research into floodplain construction in the wandering river environment is still at a preliminary stage and the sediments of this fluvial style are as yet not described in detail (Desloges and Church, 1987, Roberts, unpublished manuscript).

The Fraser River at Chilliwack, British Columbia is a wandering gravel bed river. Relative to other areas of the Fraser, this reach of the river and its associated floodplain has received little attention.

The Fraser river now occupies the northern portion of the valley in the Chilliwack area. The channel contains many relatively stable, vegetated islands as well as more mobile gravel bars. Some of the islands appear to be at various stages of becoming accreted to the floodplain. The floodplain of up to 10 km in width has a ridge and swale topography outlining accreted islands and paleochannels.

These general observations led to the hypothesis that the floodplain has been constructed of islands which have accreted to the floodplain progressively from south to north and that the accretionary processes occuring in the active channel zone are similar to those which created the historic floodplain.

It is suggested therefore, that the construction of the floodplain depends on two main processes: i) the formation of islands in the channel, and ii) the attachment of these islands to the floodplain through channel infilling.

It is proposed that, if there is a similarity between the sediments of the floodplain and the active channel zone, then this similarity may be demonstrated by a comparison of the infilled chutes in the active channel zone and the swales on the floodplain. This aspect of the study is particularly important since chute infill appears to be the mechanism by which islands are attached to the floodplain. The sedimentology of infilling chutes in the wandering style of river has received virtually no attention in the literature.

1.2 Objectives of the Study

The lack of research into the geomorphology and sedimentology of wandering rivers and their floodplains, as well as the paucity of information on the Fraser River upstream of the delta, presents an opportunity to fill an information void. In order to test the floodplain construction hypothesis presented above, the study was designed with the following objectives:

i) To describe the nature of island accretion in the active channel zone of the Fraser River near Chilliwack, B.C. Particular attention will be paid to the geomorphology and sedimentology of chute infill resulting in island accretion.

ii) To describe the geomorphology and sedimentology of swales on the Fraser River floodplain at Chilliwack and to compare these results with accretionary processes in the active channel zone (objective i).

iii) To assess whether the processes responsible for present floodplain construction are similar to those which created the historical floodplain. A secondary question is whether the floodplain was constructed progessively from south to north or was pieced together through a series of avulsions or abandonments.

iv) To assess the relative importance of overbank deposition for a wandering river floodplain.

1.3 The Study Area

1.3.1 Location

The Fraser River follows an infilled glacial valley and preglacial trough between the Cascade Mountains to the south and the Coast Mountains to the north (Fig. 1.1). Upstream of the study area, the Fraser River drains an area of 218,000 km^2 and flows over a length of 1300 km.

The study area is bounded on the east by the Agassiz bridge and Cheam landslide, on the west by the Chilliwack alluvial fan, Chilliwack city and west end of Island 22, on the north by the north bank of the river and on the south by the Cascade Mountains (Fig. 1.2).

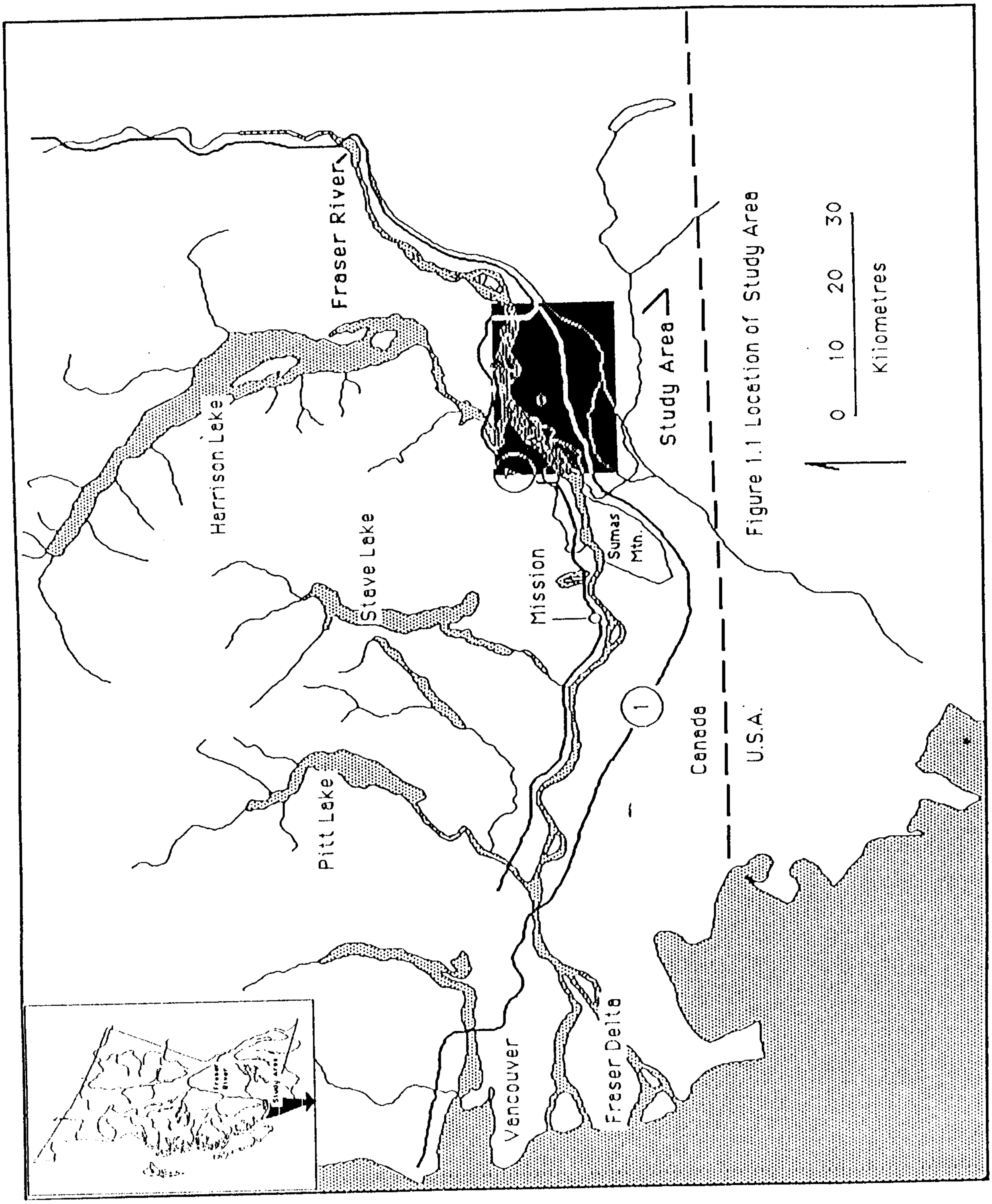


Figure 1.1 Location of Study Area

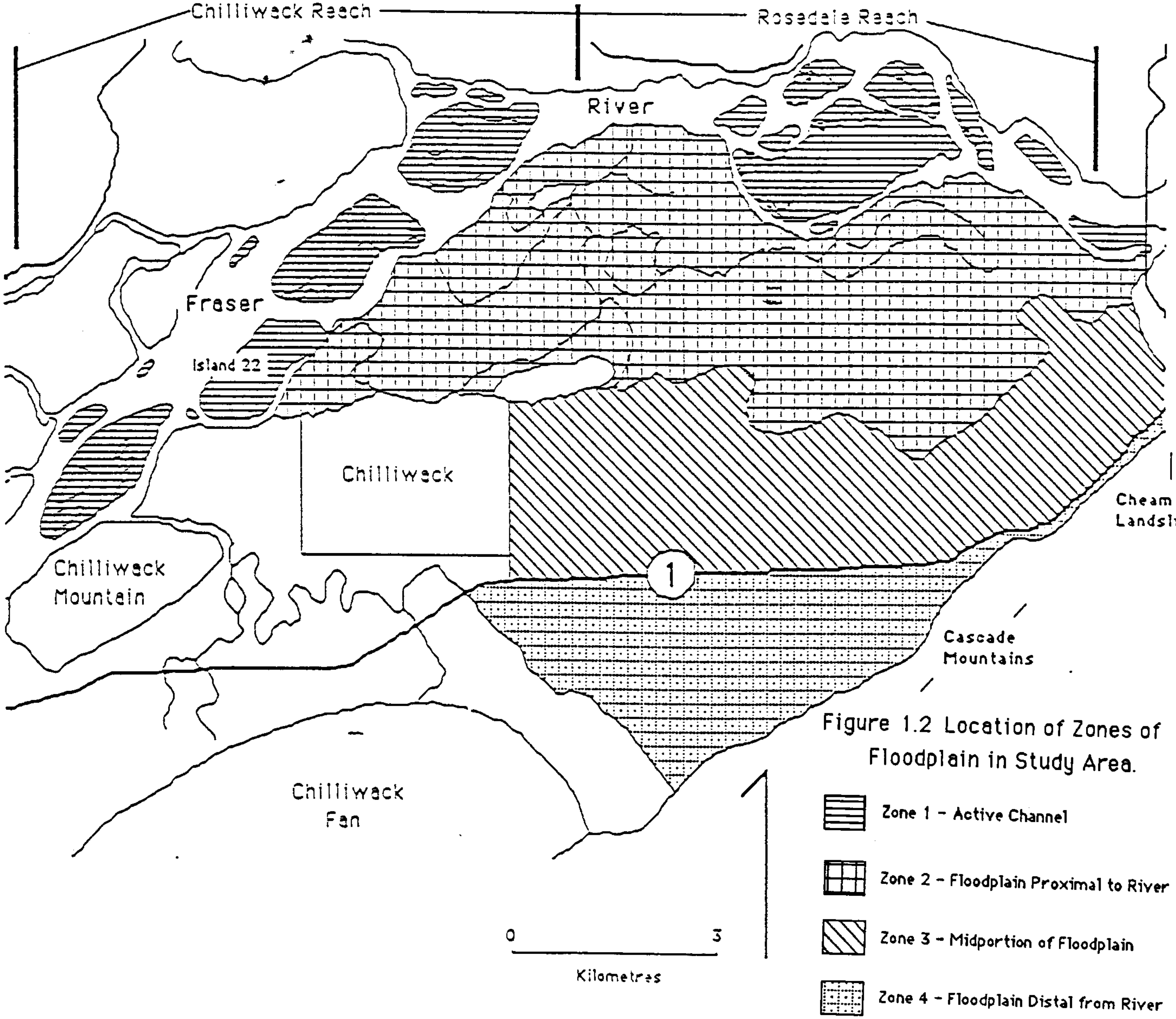


Figure 1.2 Location of Zones of Floodplain in Study Area.

The study area is further subdivided into four zones encompassing the active channel zone (zone 1) and the proximal (zone 2), midportion (zone 3) and distal (zone 4) portions of the floodplain (Fig. 1.2). These zones were delineated by geomorphic evidence that will be discussed in a later section (section 6.2.1).

The active channel zone (zone 1) in the study area is divided into two reaches (Fig. 1.2). These reaches correspond with those outlined by McLean and Mannerstrom (1985).

1.3.2 The Fraser River

i) *Geomorphic Setting*

The Fraser River within the study area has a wandering channel planform. The low sinuosity (sinuosity 1.2) channel occasionally splits around vegetated islands and is in some places braided (braiding index 5.0, Rust, 1978a). There is a complete range from well established, vegetated islands to mobile, low elevation, unvegetated bars within the channel. The vegetated islands are gravel based, have 0.5-3.0 m of sand and interbedded silts overlying the gravels, and are capped with silty sands or sandy silts.

Gravel forming the channel bars is of pebble to cobble size. Bar surfaces and channel beds are often armoured with imbricated gravel. McLean and Mannerstrom (1985) report that subsurface grain size is approximately 27 mm while surface grain sizes average 40 mm.

The channel bed is composed of gravel with some coarse sand while the banks are composed of sands and sandy silts held in place by vegetation roots. The channel is moderately stable with some islands in the channel over 100 years of age. There is irregular lateral accretion whereby islands are progressively accreted to the floodplain by the infill of chute channels.

ii)*Hydrology*

The discharge and stage of the river is highly variable and the annual flood normally occurs with the spring freshet from May-July. The mean annual flood is 8790 m^3/s, mean June flow is 7180 m^3/s, the mean annual flow (1910-1983) is 2730 m^3/s, the minimum daily flow from 1966-1984 was 410 m^3/s and the highest recorded floods were in 1894 (18,600 m^3/s) and in 1948 (16,700 m^3/s) as reported by McLean and Mannerstrom (1985). Bankfull discharge varies between 11,000 and 12,000 m^3/s with a return period of greater than 10 years. Overflow for lower elevation bars and some of the less developed islands and chute channels is closer to 8500 m^3/s with a return period of 2 years (McLean and Mannerstrom, 1985).

Some components of the hydraulic geometry measured by McLean and Mannerstrom (1985) for the study reach are as follows:

	d(m)	w(m)	w/d	v(m/s)	Slope	Q(m^3/s)
Rosedale Reach	3.06	527	172	1.80	.00047	2900
Chilliwack Reach	2.66	930	350	1.37	.00018	3400

where d is channel mean depth, w is channel width, v is mean flow velocity and Q is discharge.These values correspond to the long term (1910-1983) mean discharge.

iii) *Sediment Transport*

McLean and Church (1986) carried out sediment transport surveys in the study area at the Agassiz bridge and found that the suspended load of 16,747,000 tonnes per year is 35 per cent sand, 50 per cent silt and 15 per cent clay. Over 60 per cent of the total suspended sediment load is transported in May and June and displays a hystersis effect. From 1967 to 1982 174,000 tonnes of bed load per year (85 per cent gravel, 15 per cent sand) was carried into the study reach. Only 1.5 per cent of the bed load reaching Mission is gravel. McLean and Church (1986) estimate that since 1950, approximately 5 million tonnes of gravel have been deposited between Agassiz bridge and Mission (Fig. 1.1).

iv) *Floodplain*

All four zones of the study area (Fig. 1.2) are within the 200 year flood stage (Fraser River Board, 1964). The surface of the active floodplain is crossed by sloughs in the proximal zone (zone 2, Fig. 1.2) and by ridge and swale topography in zones 2, 3 and 4. This ridge and swale topography outlines the location of former islands as well as what appears to be former sloughs and channels (paleochannels).

This portion of the Fraser Valley has been farmed since approximately 1860 (Sinclair, 1961; Gibbard, 1977). In these past 127 or so years, a considerable amount of land clearing and depression filling have taken place. Discussions with local farmers have revealed that many depressions have been infilled in the last 20-30 years alone. It is therefore likely that the dissection of the floodplain by swales was even more pronounced in the past than is presently found.

1.4 Thesis Organization

Chapter two reviews the literature relevant to multiple channel rivers and floodplains as well as recent research in the study area. Chapter three describes the methods used in gathering and presenting the data for this study. The geomorphology of the active channel zone is presented in chapter four. The sedimentology of the chutes of islands in the active channel is described in chapter five. The geomorphology and sedimentology of the floodplain is presented in chapter six as well as a comparison of the geomorphology and sedimentology of the active channel zone with the floodplain. Chapter seven presents a summary and the conclusions to the study.

CHAPTER TWO

BACKGROUND LITERATURE

2.1 Study Area

Compared to the Fraser River Delta, the geomorphology and sediments of the lower Fraser Valley have received very little attention (Clague et al, 1983). Armstrong's (1981) surficial geology study in the Fraser lowland describes the glacial history of the Fraser River and the postglacial history as it relates to the Fraser glaciation. Except for gravel bar lithologies in the Chilliwack to Hope reach, no information is given regarding the contemporary Fraser River. Sinclair (1961) wrote a history of the Sumas dyking project that also included a discussion of part of the Fraser floodplain. Mathews (1977), Armstrong (1981) and Clague et al (1983) reported on the postglacial history of the area but for the most part these studies concentrated on glacial sediments and deglaciation east of the study area.

More recently, the vegetation succession on islands of the Fraser River in the Chilliwack-Agassiz area were studied by Boniface (1985). This study showed the close relationship between vegetation succession and island stability. An example shows where the complete removal of the tree cover (as through logging) has destroyed the protective cover and the island was quickly removed through erosion.

Church et al (1984) reviewed the reference material on sedimentation and morphology of the lower Fraser River and listed the available Federal and Provincial aerial photography in the area. McLean and Mannerstrom (1985) discuss the characteristics of the channel zone, its bars and islands and provide information on the history of instability of the Hope to Mission reach. McLean (1985) describes the hydrographic survey carried out on the Fraser River between the Agassiz-Rosedale bridge and the town of Mission. The last report in the series (McLean and Church, 1986) reports estimates of annual bed and suspended load transport rates in the Fraser River between Agassiz and Mission.

2.2 The Multiple Channel River and Its Floodplain

2.2.1 Introduction

Leopold and Wolman (1957) proposed the existence of three basic river planforms (braided, meandering, straight) to which a fourth (the anastomosed pattern) has been added (Smith, 1973; Smith and Putnam, 1980). More recently, a wandering river planform (Neill, 1973; Church, 1983; Desloges and Church, 1987) has been proposed. It has been suggested that these planforms occur along a continuum (Leopold and Wolman, 1957; Knighton, 1984). The criteria used to distinguish between these planforms however, has been the subject of much debate.

Since the 1970s there has been increasing recognition of channel process in the multichannel river environment. Facies models have been developed showing the type of sediments preserved from the depositional environments of the various planforms (Miall, 1977, 1978; Rust, 1978b; Jackson, 1978; Smith and Putnam, 1980; Rust and Legun, 1983). Facies models, however, tend to model channel sediments rather than floodplain sediments which have a higher potential for preservation in the rock record (Bridge and Leeder, 1979).

Compared to the analysis of river processes, the formation of floodplains has received much less attention. A few well known reviews are found in Wolman and Leopold (1957), Lattman (1960), Allen (1965) and Lewin (1978). Past preoccupation with the point bar model of floodplain construction (Wolman and Leopold, 1957; Allen, 1965) has left a gap in our knowledge in the preservation processes of sediments from other than the meandering environment (Leopold et al, 1964; Morisawa, 1968; Leeder, 1982; Richards, 1982; Knighton, 1984).

The following is a review of the relevant literature regarding the geomorphic and sedimentologic features which have been used to distinguish between multiple channel river planforms (section 2.2.2) and the geomorphic and sedimentologic characteristics of multichannel river floodplains. Particular attention will be given to the wandering river planform.

2.2.2 Multiple Channel Planforms

i) *Geomorphology*

River planform classification schemes generally can be grouped into three distinct types. The work by Leopold and Wolman (1957) and Leopold and Maddock (1953) distinguished between planform types based on hydraulic geometry. Schumm (1968, 1985) proposed a channel classification scheme based on river stability, river sediment size and mode of transport (bedload, mixed load, suspended load). More recently, there have been attempts to classify river patterns by geomorphic setting or by the degrees to which a river braids or is sinuous (Rust, 1978a), and the types of bars and islands within the river (Kellerhals et al, 1976).

Hydraulic Geometry

Leopold and Wolman (1957, p60) provided an empirical separation between braided and meandering rivers showing that braided streams tend to occur on steeper slopes than meandering streams for a given discharge. This view was furthered by Chang (1979) who argued that regime rivers adjust to minimize stream power (γQs). For each stream pattern, Chang (1979) shows that there exists a minimum stream power per unit channel length which allows an equilibrium planform to develop. Braided streams, Chang argues, tend to have slopes which are steeper at a given discharge than do meandering streams.

Morisawa (1968) suggested that multiple channels are a characteristic of streams with a high and variable discharge, easily erodible banks and an abundant bedload. Brotherton (1979) furthered this idea by arguing that braided rivers have easily erodible banks and sediment with a low transportability. In contrast, Parker (1976) suggests that differentiation between braided and meandering regimes is independent of sediment transport. He further suggests that braiding is largely a function of larger w/d ratios and steeper slopes than occur in meandering rivers. Hong and Davies (1979) suggest that the occurence of braiding is dependent mainly on stream slope, Froude number and w/d ratios and is independent of such factors as erosion of bank material and excessive sediment load.

The importance of a high w/d ratio and a steep slope in braided rivers is also discussed by Miall (1977) and Chang (1979, 1980).

Stability and Sediment Size

Despite the popularity of using the slope/discharge curves for distinguishing braided and meandering streams, Carson (1984c) shows that there is merely a weak statistical relationship between the variables. He further suggests that there is a family of slope/discharge curves based on bed material size by arguing that active gravel streams must necessarily plot higher on slope/discharge curves due to the greater power needed to move the bed material. Carson (1984c) then argues that the real prerequisite for braiding appears to be abundant bed load which results in local shoaling of the thalweg and the development of bars. Channel pattern then must consider the sediment size carried by the stream.

Carson (1984a, b) described the initiation of wandering and braided patterns by local shoaling of the channel in some gravel bed rivers. Shoaling occurs due to i) attenuation of discharge by the loss of water into gravel and ii) the deposition of large gravel loads. Carson (1984b) suggests that 'The prerequisite for wandering and braiding seems to be that transport rates of bed-calibre material into a reach be sufficiently high to ensure shallow channels and thus force dissection of lateral bars and floodplain.'.

An important point is that braided and wandering river patterns have many similarities. Carson (1984b) states 'To what extent wandering and braiding are characterized by different sets of processes is still not clear.'. He further suggests that braiding is controlled almost exclusively by deposition of mid-channel bars while wandering is more of an erosional pattern formed by dissection of the active floodplain by the flow. This view was suggested by Church (1983) and is also expressed by Desloges and Church (1987).

Carson (1984b) presents a classification scheme (his Fig. 22, p. 97) in which two types of wandering river are distinguished. The 'Wandering Type I' is characterized by a relatively low bed material supply rate and a high bank erodibility. This type is similar to a meandering river but with highly dissected, very wide point bars. The 'Wandering Type II' pattern is characterized by a high relative bed material supply rate and a low to medium bank erodibility. This type of wandering river is similar to the Bella Coola River described by Church (1983).

The 'Wandering Type II' pattern is distinguished from the braided pattern by the high erodibility of the banks of braided rivers compared to the low to moderate erodibility of the banks of wandering rivers. This low to moderate degree of erodibility is indicative of a moderate level of stability (semi-stable) in wandering rivers as opposed to a high degree of instability in braided rivers. The semi-stable wandering environment is largely a result of vegetation on islands and floodplain banks. Indeed Carson (1984b) states that 'Morphologically, they differ from true "braided" reaches in their smaller bankfull width, their smaller degree of channel splitting and the dominance of vegetated island-tracts of floodplain rather than bare bars.'

The idea of stability has for some time been an important concept in river patterns (Schumm, 1968, 1985). Smith (1976), Hickin (1984) and Schumm (1985) among many others have shown that vegetation is able to greatly enhance the lateral stability of channels in the fluvial environment. Changes in channel pattern due to stability enhancing vegetation was demonstrated by Schumm and Lichty (1963) in the Cimarron River, Turner (1972) and Burkham (1972) in the Gila River project and by Graf (1978) in the Green River, Utah.

The type of sediment and degree of stability has become a critical factor in determining pattern in the multiple channel environment. The anastomosing pattern, for which specific definitions were proposed by Smith (1973, 1983, 1986) and Smith and Putnam (1980), is dependent on a high degree of vegetated, silt island stability. The classic braided stream on the other hand, contains unstable, generally unvegetated sandy or gravel bars with the rare vegetated, semi-stable islands (Krigstrom, 1962; Coleman, 1969; Williams and Rust, 1969; Collinson, 1970; Miall, 1977,1978; Cant, 1978; Rust, 1978b).

The stability of wandering rivers lies between the two extremes of unstable braided and highly stable anastomosing rivers. They usually contain gravel based, sand capped, vegetated islands (Church, 1983; Desloges and Church, 1987). The sands are generally erodible but a degree of stability is imparted to island banks when there is vegetation growing on them. Although Church (1983) and Desloges and Church (1987) suggest that the wandering river pattern is laterally unstable, the very presence of mature forests on mid channel islands suggest there is at least a degree of stability in this environment that does not exist in braided rivers. The wandering river pattern may then be referred to as a semi-stable environment.

It seems that, when flood flows occur in wandering rivers, the water is unable to move these semi-stable islands as a braided river might move its bars. The main thalweg, therefore, is forced to wander or switch around these islands rather than migrate across them. On the other hand, a degree of instability is demonstrated by the fact that enough erosion and/or deposition occurs to force the thalweg to wander. This point is in contrast to the highly stable channels of anastomosing rivers.

Geomorphic Setting

The disagreement on what causes variation in planform has led to a more descriptive approach to fluvial architecture (Friend, 1983; Kellerhals and Church, in press). Rust (1978a) recognised that sinuous streams could braid, and braided streams could meander; so he devised a system whereby the degree of sinuousity and the degree of braiding could be quantified. Kellerhals et al (1976) outlined a classification of floodplain and channel features that include codification of river channel patterns, islands, bars and lateral activity of the river channel. A similar description of channel patterns based on degree and character of sinuosity, braiding and anabranching is given in Brice (cited in Schumm, 1985, p.8). Kellerhals and Church (in press) discuss the importance of including this information in river descriptions 'since its main objective is to recognize the many factors that make up a fluvial landscape and to describe them in a systematic manner ...'.

ii) *Sedimentology*

Braided Rivers

Sediments of some of the classic braided rivers have been described by Doeglas (1962) for the Durance and Ardeche Rivers, by Krigstrom (1962) for some sandur plains in Iceland, McKee et al (1967) for the ephemeral Bijou Creek, Colorado, Coleman (1969) for the Brahmaputra, Collinson (1970) on the Tana River, Smith (1971) for the Platte River and Cant and Walker (1978) for the South Saskatchewan River. Reviews of the braided river environment have been made by Miall (1977,1978) and in Rust (1978b).

Most braided rivers have gravel or sand beds; silt bed, braided rivers are rare (Rust, 1978b). Bars in the braided river tend to be unvegetated, unstable and mobile (Coleman, 1969; Hein and Walker, 1977). This results in the sediments of the braided environment having a high degree of cross stratification with facies Gm, St and Sp being most common (Miall, 1978). Rust (1978b) describes proximal braided river sediments as laterally and vertically variable (his Table 1, p.608) and distal sediments as having upwards fining cycles. Doeglas (1962) characterizes braided sediments as generally fining upwards with medium and coarse sands interbedded with silty sands and sandy silts.

Anastomosed Rivers

Anastomosing has taken on a very specific meaning in the recent, fluvial literature. Modern and ancient examples are given in Smith (1973, 1983, 1986), Smith and Putnam (1980) and Smith and Smith (1980). Rust and Legun (1983) and Rust and Nanson (1986) provide variations on the same theme from an arid environment in Coopers Creek, Australia.

The basic model developed by Smith and Smith (1980) describes an environment with sinuous anabranches dividing very stable vegetated islands. The stability of the islands and a rapid rate of basin subsidence produces very thick vertical facies sequences. The fine units are overbank silts, muds and sandy silts which are deposited in ponds, marshes and bogs while the coarser channel units are composed of thick, vertically stacked sequences of sand or fine gravel. No sedimentary structure is described for the sediments.

Wandering Gravel Rivers

The wandering gravel bed river has been identified relatively recently. Neill (1973) first suggested the name 'wandering gravel river ' for the Athabasca River in Alberta. Church (1983) has recognized the pattern for the Bella Coola River but except for stating that the river banks consist of 0-2 m of sand over gravel (p.172) the sediments were not described.

The only description of sediments from the wandering gravel bed rivers that can be found in the readily available fluvial literature is by Desloges and Church (1987) although Carson (1984b) suggests that many of the New Zealand rivers he studied should be reclassified as wandering rivers. The lack of description of the sediments of wandering rivers makes it important to discuss this environment with respect to the less stable braided river and the more stable anasomosing river environments.

Desloges and Church (1987) identify unstable reaches in the wandering Bella Coola river which are referred to as 'sedimentation zones' and in which medial bars and islands dominate the channel. Stable reaches were also identified which have 'relatively high channel sinuosities (1.2-1.5) and consist of a series of bank-attached lateral bars or point bars'.

Desloges and Church (1987) also found that, in the Bella Coola River, islands, lateral bars and point bars consist of a thick gravel platform capped with up to 3 m of sand or silty sand. The most common facies types are Gm and Sh with minor amounts of facies Gp, Ss, Se, St, Sp and Sr. Sequences are often capped with a thin bed of silt (facies Fsc; Desloges and Church, 1987, their Table 1, p. 102). Simple facies sequences of Gm/Sh/Fsc are the most common and appear to be favoured due to 'progressive lateral accretion and the vertical stability of the river.' (Desloges and Church, 1987, p. 107). These simple facies sequences are in sharp contrast to the complex bedding of the braided river (Miall, 1977, 1978; Rust, 1978b) and the thick, uniform bedding sequences of the anastomosing environment (Smith and Putnam, 1980).

Desloges and Church (1987) also report that the channel migrates by lateral accretion and the attachment of islands to the floodplain by avulsion of chutes and sloughs. They did not report, however, on the details of the process of lateral accretion although they did find that the chutes and sloughs are rarely infilled unless 'the slough entrance becomes blocked by large organic debris.'. These chutes and sloughs are often reoccupied during large floods and carry sediments, particularly fines to the back portion of the floodplain.

2.2.3 Multiple Channel Floodplains

i) *Geomorphology*

In a recent review of floodplain geomorphology, Lewin (1978) points out that studies of floodplain geomorphology have been lacking to date. This lack of research is particularly evident for multichannel rivers which are not characterized by large areas of floodplain (Miall, 1977). A few more recent studies, however, (eg. Schmudde, 1963; Cant and Walker, 1978; Baumgart-Kotarba, 1985; Kellerhals and Church, in press) describe how floodplains of multichannel rivers show former channel positions which permit conclusions to be made on the processes responsible for channel shifting. Kellerhals and Church (in press) suggest that, in cases where a significant active floodplain exists, it is safe to assume that the appearance of the floodplain reflects presently active channel processes.

The ideal braided river is usually considered to occupy the entire valley flat during bankfull flood (Krigstrom, 1962; Collinson, 1970) and has received little attention insofar as floodplain research is concerned.. The floodplains of braided rivers (eg. Brahmaputra, Coleman, 1969; Donjek, Williams and Rust, 1969; South Saskatchewan Cant and Walker, 1978) are described as having irregular surfaces outlining old bars and islands which are separated by abandoned channels (Knighton, 1972; Bristow, 1987; Wells and Dorr, 1987). This pattern is created by channel switching or avulsion (Cant and Walker, 1978; Lewin, 1978).

Church (1983) describes the wandering river planform and its pattern of instability but did not deal with its floodplain. Desloges and Church (1987) describe the geomorphology and method of construction for the floodplain of the wandering Bella Coola

River. They report that active sloughs are created by rapid avulsion of one of the channels around a mid channel bar. The lack of infill in these sloughs leads to reoccupation during major floods and further avulsions (channel switching).

In the literature dealing with floodplain construction in multiple channel environments, channel abandonment (Schumm and Lichty, 1963; Knighton, 1972; Bristow, 1987; Wells and Dorr, 1987) or channel avulsion (Cant and Walker, 1978; Desloges and Church, 1987; Kellerhals and Church, in press) is discussed but the process of channel infill is not well described. Doeglas (1962), Burkham (1972) and Costello and Walker (1972) describe some of the sedimentologic features of chute infill but do not give explicit detail as to the accretionary process. The few details regarding island accretion to the floodplain are provided by Rust (1972, his fig. 14), Bluck (1979,1980) and Ramos and others (1987).

The floodplain of a wandering river is very similar to that of a braided river with a surface geomorphology of islands separated by abandoned channels. The method of channel abandonment in the wandering fluvial style, however, still leaves many questions unanswered.

Channel infill and Abandonment

The mechanism of channel abandonment is one of the most important aspects of the lateral accretion of islands to the floodplain. Details of the accretionary processes and resulting abandonment, however, are not well described in the literature. The building of bars and islands is reasonably well known and processes of island migration have been decribed (eg. Bluck, 1980; Baumgart-Kotarba, 1985; Bristow, 1987). The process of infill or abandonment of the chute or channel between the migrating bar or island and the river bank, however, remains undocumented.

Burkham (1972) and Costello and Walker (1972) outline some of the sedimentary features of the channel infill but do not describe the accretionary process. Doeglas (1962), Rust (1972) and particularly Bluck (1979,1980), discuss how the intervening channel is infilled and the island accretes to the floodplain for braided rivers. Doeglas (1962) and Bluck

(1979) show that these channels are filled in by side infill or delta growth of sediment in the chute or channel. This lateral growth of sediment on the sides of the channel provides planar cross-stratified sands in the paleochannels. Doeglas (1962) further suggests that the downstream ends of these channels are filled with fines from backwater sediments while the head is cut off from the main channel by a coarse bar (see also Schumm and Lichty, 1963; Burkham, 1972; Cheetham, 1979).

ii) *Sedimentology*

The most important sedimentologic reports on the braided environments have been described for the channel zone by facies models in Miall (1977, 1978) and Rust (1978b). Sediments of the anastomosed environment are likewise described for the channel (and thus floodplain) by Smith (1973, 1983, 1986), Smith and Putnam (1980) and in ancient systems by Smith and Smith (1980) and Rust and Legun (1983). To date, the little available information on floodplains of the wandering environment is to be found in Desloges and Church (1987).

As discussed in the last section, one of the most important aspects of lateral accretion in the multiple channel environment is the process of channel abandonment and infill. Desloges and Church (1987) state that the sloughs are not infilled (p.106) yet it is hard to understand how abandonment in a vertically stable river, even through avulsion, can occur without some channel degradation or aggradation. Unfilled channels on the floodplain would surely carry backwater during flood and infill with fines when avulsion does not reactivate the sloughs.

Preserved deposits of low sinuosity rivers are generally thought to be lenticular or sheet-like coarse units which only generally fine upwards and have very few if any fines (Bridge and Leeder, 1979). This is due to the instability of multiple channel rivers. Significant thicknesses of overbank fines generally take a considerable amount of time to develop (Alexander and Prior, 1971; Ritter et al, 1973; Bridge and Leeder, 1979). The frequency of lateral reworking of sediments of low sinuosity rivers precludes buildup of overbank fines (vertical accretion deposits).

The recent recognition of the stable (anastomosing) and semi-stable (wandering) environments shows however, that lateral migration can be a slow process, allowing for the buildup of fine materials. Overbank deposits of fine material may then be an important aspect of these environments. The importance of the overbank facies has already been discussed for the anastomosed river in the work of D.G. Smith (*op. cit.*).

Desloges and Church (1987) report that sequences of fines (facies Fsc) up to 1.5 m thick are found in the floodplain areas away from the channel of the Bella Coola River. Although they report that these overbank fines are relatively insignificant, the short turnover time of the floodplain (145-165 years) may be shorter than for other wandering rivers. Longer turnover times would allow for further buildup of overbank deposits increasing their relative importance.

CHAPTER THREE

METHODS

3.1 Active Channel Zone

A study of the islands and chutes was designed to provide a geomorphic and sedimentologic description of the active channel zone. There has been some change in the size, shape and in some cases location of the islands in the active channel zone despite their semi-stable nature. These changes have led to problems in the naming and identification of the islands. Since few of these islands have even local names, they have been given names for the purpose of this study (see Figs. 4.1, 4.2 for location). Four islands were chosen for study in the Rosedale reach based on the advanced degree of chute infilling or maturity across these islands. Carey's Island (CI) carries one of the few locally used names and has been in a relatively stable state for at least 50 years. BCC is Back of Carey's, Centre while BCU is Back of Carey's, Upper (upstream). MI, to the southeast of Carey's Island is referred to as Mike's Island.

Two islands were chosen for study in the Chilliwack reach. Island 22 (Is22) is a name used on older 1:50,000 NTS maps which numbered some of the islands in the river. Island 22 is now a name used locally and the name given to a municipal park located on the northwest shore of the island. GPI refers to Gravel Pit Island, so named in this study for the large gravel removal operation in the channel and along the shore on the south side of the island.

A preliminary survey was carried out in June, 1986 in order to find an efficient method of sediment sampling of island chutes within the active channel zone. Casual observations and pit excavations made during this survey suggested that many of the chute deposits were laid down as large sand sheets above a basal gravel. It was also observed that chute head deposits were coarser than chute tail deposits.

The infilling of chutes requires a length of time greater than was available for observation during this study, thus forcing the substitution of space for time in determining chute infill processes. A study plan involving the collection of four types of data in the active channel zone was devised from the preliminary survey.

The collection of type one data required the excavation of survey pits at the head, mid section and tail of various chutes. Twenty-eight pits were excavated of which 12 were dug in Carey's Island (CI) Main Chute (see Fig. 4.1 for location); this was the most intensively sampled chute. For the Carey's Island chute, pits were dug at the shoulders, in the centre and in the chute-side channel at the head, mid section and tail of the chute. Pits on other islands were excavated at various locations along the chute and used as a comparison to the Main Chute of Carey's Island.

Each pit was approximately one metre wide, two metres long at the top and was dug to gravel where possible. Since in excavating pits in unconsolidated material considerable caving occurs, the pits were dug narrower toward the bottom. Islands were visited in the Rosedale and Chilliwack reaches and a series of pits were dug in all infilling or infilled chutes.

The collection of type two data involved a detailed topographic survey which was carried out on the Carey's Island (CI) Main Chute. The purpose of this survey was to provide detailed field evidence for the topographic features of a chute (chute-head bar, scour hole, chute-side channel, cross-sectional profiles, long profile). This survey was carried out with a Dumpy level and a survey rod. Bench marks to tie in the survey were taken from spot elevations shown on available 1:5000 orthophoto map 92H 021 2 (B.C. Ministry of the Environment, Maps and Surveys Branch, 1974 air photography).

Type three data included the production of geomorphic maps. These maps (eg. Figs. 4.1, 4.2) were reproduced from 1: 25,000 NTS topographic sheets 92H/4f and 92H/4e which were based on 1971 aerial photography. Due to the frequent changes in shape and location of the mid-channel islands, modifications to these maps have been made based on field observations.

Consistent geomorphic symbols are used to represent features on the maps throughout the thesis. These symbols are shown in Figure 3.1. In addition, consistent symbols are used to represent sedimentary texture, structure, grain size and bedding contacts in the sedimentary profile diagrams throughout the thesis. These symbols are shown in Figure 3.2.

The fourth type of data was the casual observation of geomorphic and sedimentologic features. Many of these observations were noted as support for more detailed data and some of these observed features were mapped. Although no measurements were made for casually observed data, this type of data is important to the interpretation of processes in less well developed chutes and the initial stages of chute infill.

3.2 Floodplain

Data collection on the floodplain was carried out by: i) the use of orthophotography; ii) ground survey, and iii) a vibracoring program.

i) *Orthophotography*

Orthophotographic floodplain mapping of the study area was available at a scale of 1:5000. Created from 1974 aerial photography by the B.C. Ministry of the Environment, Surveys and Mapping Branch, these orthophotos contain one metre contours as well as spot elevations across the study area. The availability of these detailed maps allowed for the relatively accurate mapping of floodplain surface forms and relief.

From this orthophotography, all swales outlined by the one metre contours were transferred to a study area map (see Fig. 6.1). These swales outline apparent islands across the floodplain and are initially assumed to be infilled chutes.

Relief and profile changes across the floodplain were determined by selecting 10 spot elevations on ridges and 10 spot elevations in adjacent swale bottoms along each of the floodplain zones (zones 2, 3, 4, Fig. 1.2). These spot elevations were selected so that three elevations were chosen randomly from the upstream and downstream portions of each zone and four elevations were chosen randomly from the middle of the zone.

Figure 3.1 Geomorphic Symbols.

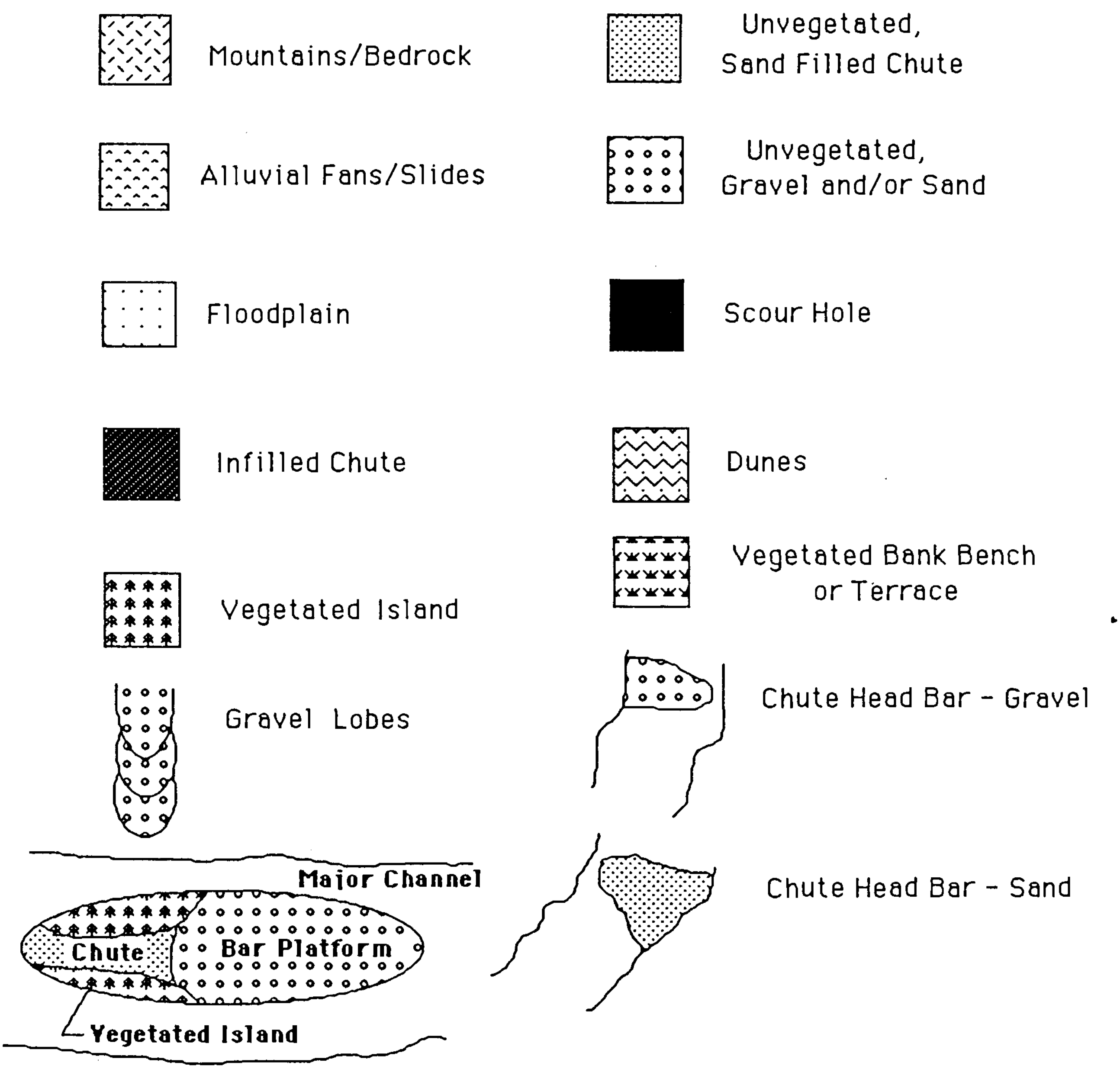
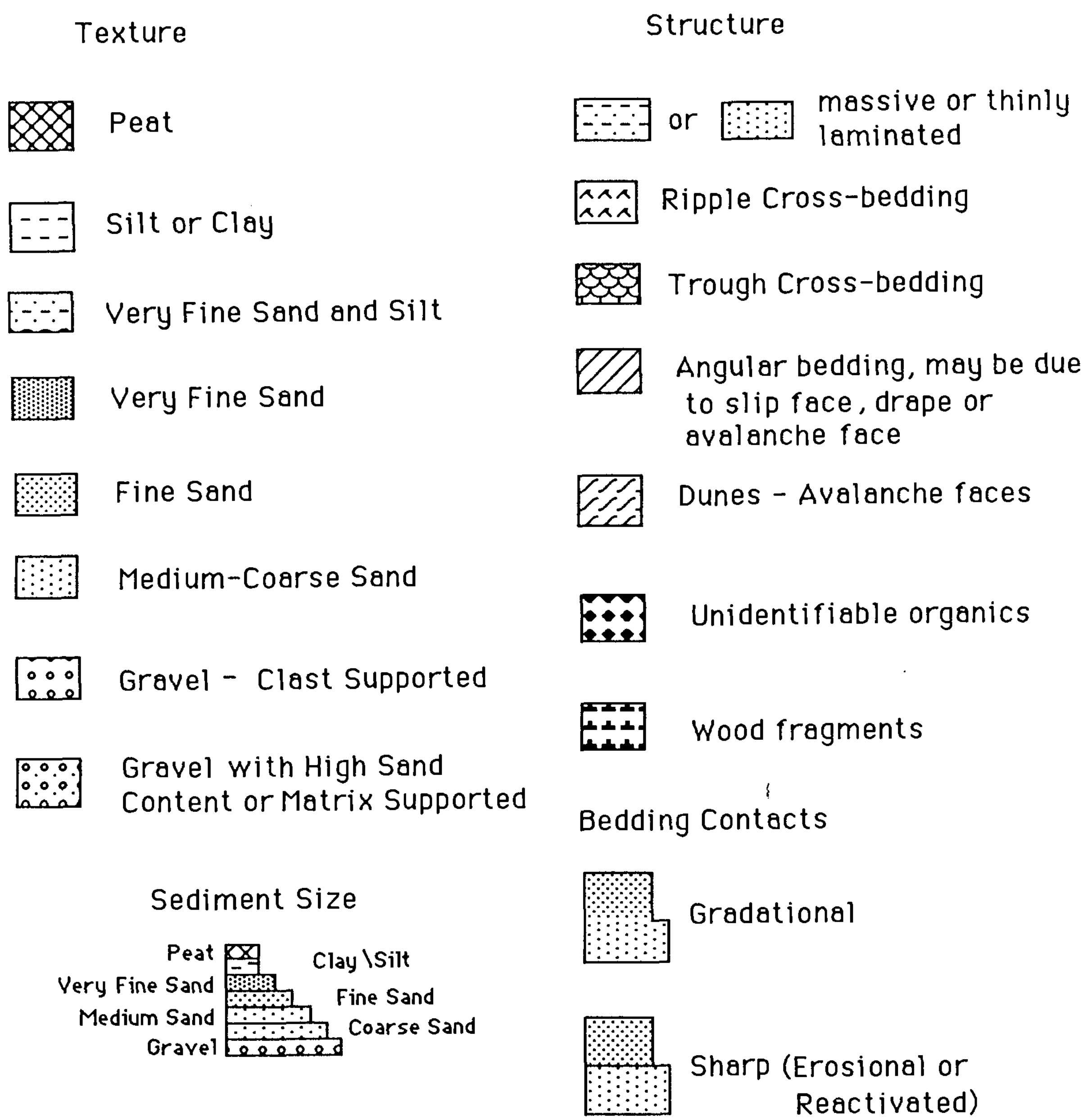


Figure 3.2 Sedimentary Symbols



ii) *Ground Survey*

A ground survey was also used to help determine the changes in relief and profile across the floodplain. The locations of benchmarks used to tie in this survey were supplied by the District of Chilliwack Engineering Office. The primary purpose of this survey was to tie in the elevations of the boreholes chosen for the vibracoring program (described in the following section).

The borehole survey information provided the elevation of cores at the surface of swales as well as allowing the elevation of the basal gravels to be calculated from the depth of the core. With this information the amount of aggradation which had occured across the floodplain was calculated. The survey and borehole data allowed the role of 'above gravel' sediment to be assessed across the three zones of the floodplain.

iii) *Vibracoring Program*

The ground water table across the floodplain in this area is frequently at or near the surface. This, as well as the high costs involved, precludes many excavation projects of a two or three dimensional nature (eg. pits and trenches) from being conducted on the floodplain. A more economical and efficient drilling method was selected for sampling swale sediments in this environment. The sampling method involved the use of a vibracorer.

Swales were selected so that each of the three floodplain zones (Fig. 1.2) were sampled and the longest, most well defined swale in the zone, as delineated from air photos and in the field, was chosen. The location of the swales chosen for borehole study are shown in Figure 3.3. In zone 2 (proximal to river) cross-sections were chosen at the Vaughan Farm (VF, upstream), Muxlow Farm (MF, middle) and Verschuur Farm (VeF, downstream). In zone 3 (midportion) all cross-sections fall within the Birkholz Farm (BF) where the upstream cross-section is BFA, the middle cross-section is BFB and the downstream cross-section is BFC. Zone 4 (distal) cross-sections were referred to as the Kessler Farm cross-sections. The upstream cross-section (KFC) was on the Grass Indian Reserve 15 and the middle cross-section (KFA) and downstream cross-section (KFB) were

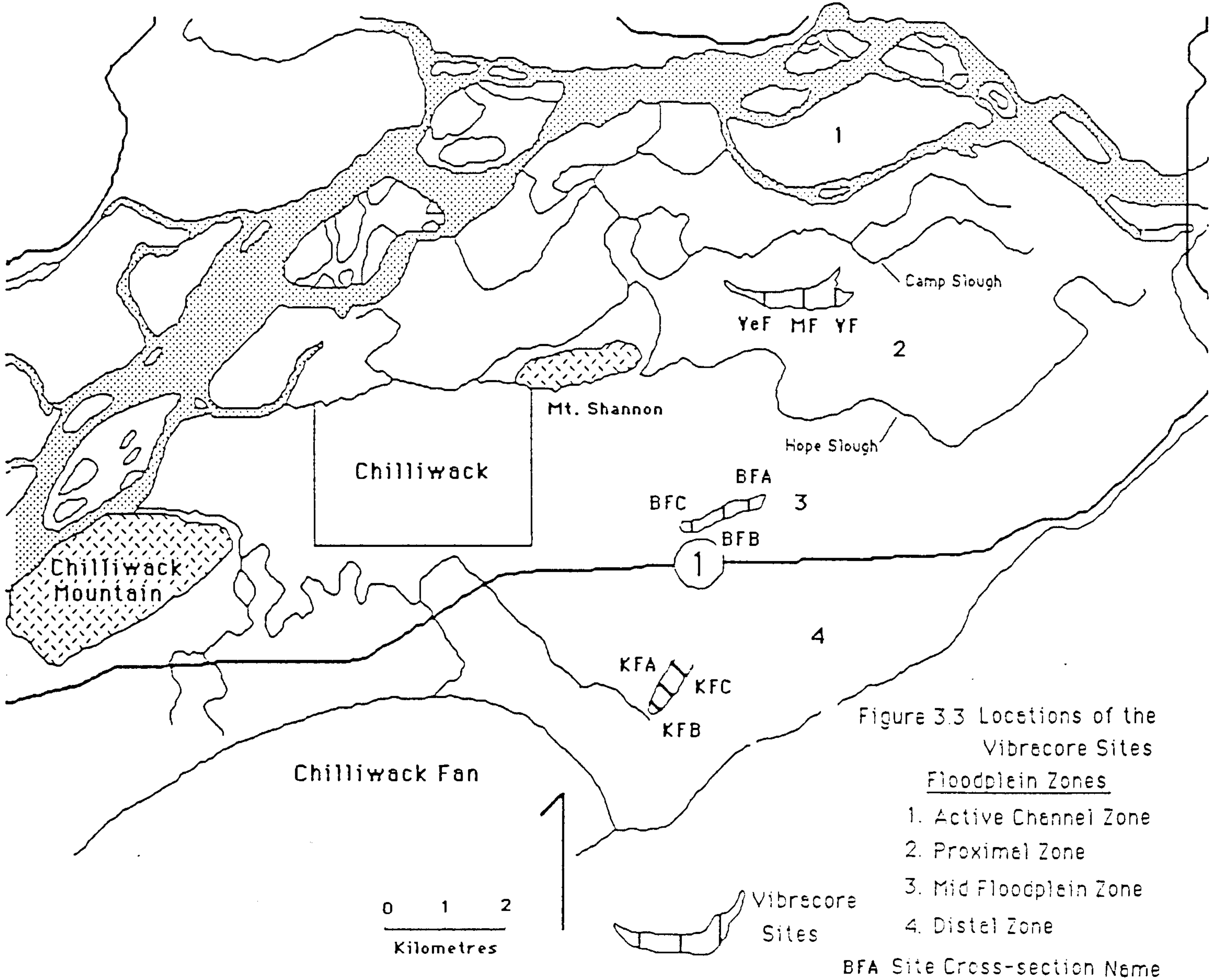


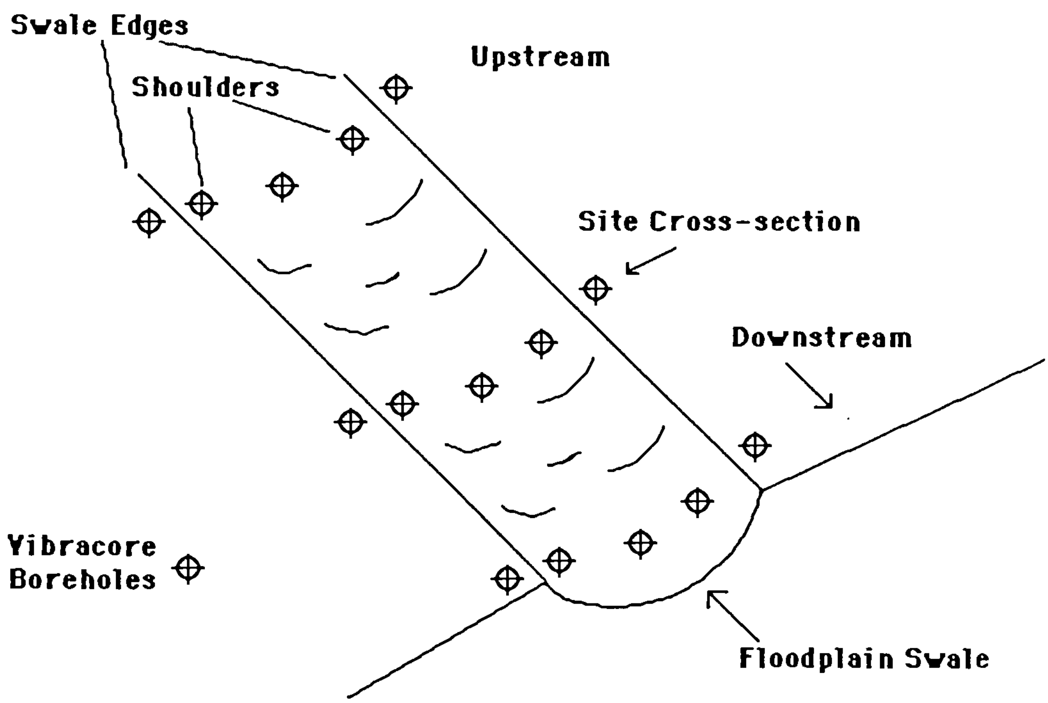
Figure 3.3 Locations of the Vibrecore Sites

Floodplein Zones

1. Active Chennel Zone
2. Proximel Zone
3. Mid Floodplein Zone
4. Distel Zone

BFA Site Cross-section Name

Figure 3.4 Site Design for Vibracoring Floodplain Swales



on the Kessler Farm.

In order to compare swales on the floodplain with similar locations in the active channel zone chutes, a drilling program was designed to sample each swale edge, shoulder, and centre along the upstream, middle and downstream portion of the swale. The site design of this drilling program is shown in Figure 3.4.

Each cross-section had five boreholes drilled using a vibracorer (Smith, 1984) for a total of 15 cores at each site (Fig. 3.4) and a total of 45 cores across the floodplain. Three inch irrigation pipe was used as a core barrel. Cores were drilled to the depth of the available vibracore pipe (usually approximately 5.5 m) or to a point where the vibracorer was stopped by the sediment. It was planned to penetrate to gravel on each core but the compaction of the sediment or depth to gravel prohibited optimum results in some cases.

It was expected that the use of a vibracorer would tend to disturb the bedding structure to some extent. Sedimentary structure may be destroyed or may be too large scale to be detected with the use of a three inch core barrel. It is unlikely that either case occured to a great extent, however, for the following reasons: i) if planar cross-bedding existed, parallel angular bedding contacts would have been detected in the core barrel; they were not; ii) if ripple and other small scale structures were destroyed, thin laminae of silt and sand should also be destroyed; thinly laminated beds were relatively common.

In addition, the process of sediment retrieval results in a measure of stretching or compaction of the core. Although this error was compensated for as much as possible in the field, the precise elevation of each bed displayed in the sedimentary profiles (chapter six) may be in question.

In order to provide temporal data for the hypothesis that the floodplain has been progressively constructing from south to north, samples of organics obtained in the vibracore cores were submitted to the University of Saskatchewan for standard radiocarbon dating. Suitable samples were recovered from cores VF-3 and BFA-3 (see Figs. 6.2, 6.6).

CHAPTER FOUR
GEOMORPHOLOGY OF THE ACTIVE CHANNEL ZONE

4.1 Major Geomorphic Features of the Active Channel Zone

4.1.1 Introduction

In order to explain the construction of the historic floodplain it is important to understand the processes that are building the floodplain today. The results of these present day processes can then be compared to the geomorphology and sedimentology of the existing (or ancient) floodplain.

The major geomorphic features of the active channel zone are: i) bar platforms, ii) vegetated islands, iii) major channels and iv) chute channels. The following section will discuss these features in turn.

The main geomorphic features of the Rosedale and Chilliwack reaches are shown in detail in Figures 4.1 and 4.2 (see Fig. 3.1 for geomorphic symbols).

4.1.2 Bar Platforms

For purposes of this study the relatively flat surfaced depositional features composed of cobble to pebble gravel without a vegetation cover are called bar platforms. These bar platforms are stable during most of the year and are only active when the discharge reaches the threshold of gravel movement which, in this reach, is approximately 5000 m^3/s (McLean and Mannerstrom, 1985). When the gravel is mobilized it is able to modify the bar platform by lateral accretion, alteration of the armoured zone or erosion.

Bar platforms accrete sand on the highest part of their surfaces. This accretion appears to take place when sand is deposited out of suspension during the falling stage of the freshet. Where these bar platforms are capped by sand and silt and are vegetated with mature trees, the features are referred to as islands.

4.1.3 Vegetated Islands

The overall form of the vegetated islands has been described by Boniface (1985, p.12) and McLean and Mannerstrom (1985) and consists of a gravel bar platform which begins to accrete sheets of sand vertically. Once the platform emerges from (low) water it is

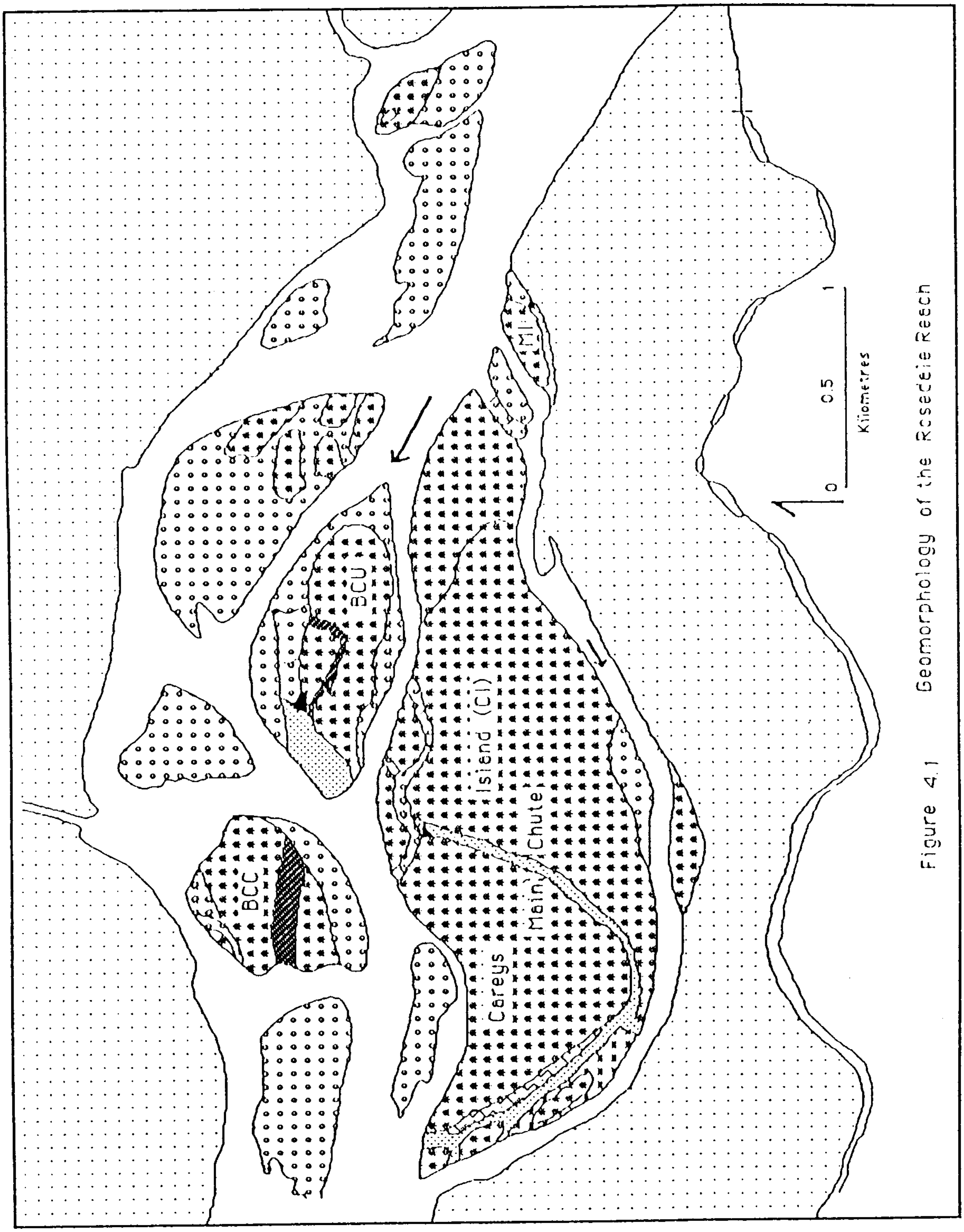


Figure 4.1 Geomorphology of the Rosedale Reach

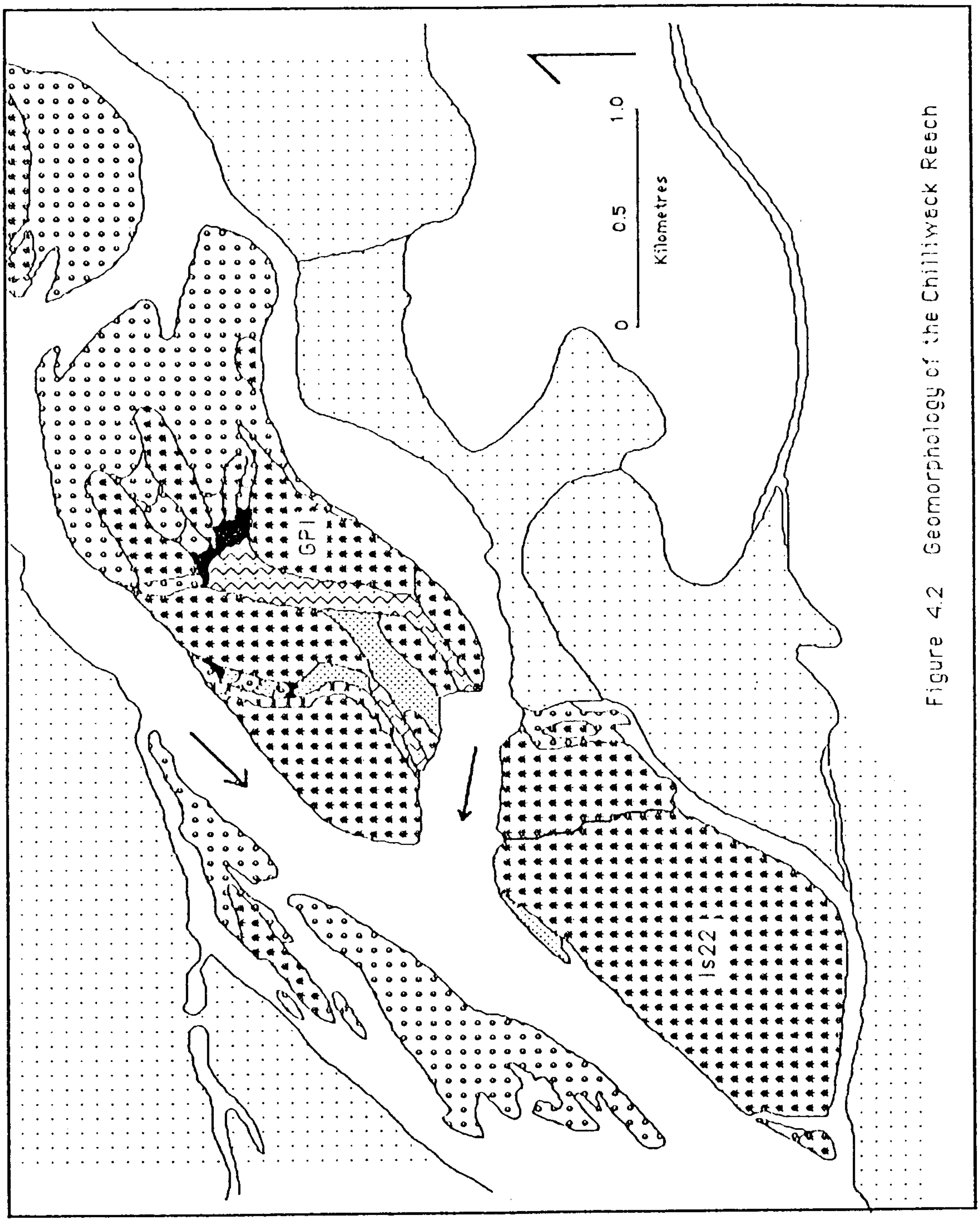


Figure 4.2 Geomorphology of the Chilliwack Reach

soon colonized by vegetation (Boniface, 1985). Once established, the vegetation aids the further accretion of sands and silts and the sequence builds vertically until only the highest floods overtop the islands. The resultant island is composed of a gravel bar platform and overlain with 1-3 metres of sand and silty sand which generally fines upward. The sequence is capped with overbank sandy silts once the island reaches floodplain elevation (McLean and Mannerstrom, 1985). A similar sequence has been described by Desloges and Church (1987) for the wandering Bella Coola River.

Islands in the study area are generally oblong and range in length from several tens of metres to a few kilometres (Figs. 4.1, 4.2). McLean and Mannerstrom (1985) report that portions of some of these islands (CI,Fig. 4.1; Is22, Fig.4.2) have been in place for over 100 years. The islands are vegetated with Black Cottonwood, Willow, Red Alder, Western Red Cedar and/or Western Hemlock at various stages of maturity (Boniface, 1985). It is this vegetation that provides a moderate level of stability to the otherwise unstable sands and sandy silts capping the bar platform (Smith, 1976; Hickin, 1984).

Two processes were observed in the field that are of importance in the early stages of island development. The first is the grounding of floating logs, stumps and other organic debris on the bar platform. This grounded debris often results in the deposition of finer materials on its lee side and provides a small niche on which vegetation may establish itself.

Secondly, local depressions in the bar platform result in cross bar channelization of water. This channelization produces a concentration of flow. As the island is accreted vertically, the flow maintains a channel across the bar platform and a chute results. Chutes are found crossing mid-channel islands or separating islands from the floodplain. The development of chutes therefore seems to be a process dependent on local bar surface and flow conditions. A second mechanism of chute development, by deposition of bank benches, is perhaps even more important and is outlined below.

i) *Bank Benches*

It was observed that lateral bars commonly occur along the side of existing bar platforms. These lateral bars have a flat surface, range in width from a few metres to a few tens of metres, and may occur above or below low water level. These lateral bars or bar terraces were also noted by McLean and Mannerstrom (1985). The development of lateral bars, particularly on bar platforms overlain with vegetated islands, often leads to the development of a bank bench. Where an island is separated from the floodplain by a major channel, the island may grow toward the floodplain by the development of bank benches as shown in Figure 4.3 and discussed below.

Bar platforms underlying an island (Fig. 4.3b) were occasionally observed to have a lower elevation, lateral gravel bar attached to the side of the platform. These lateral bars are relatively wide and flat surfaced and are referred to as a gravel bench in this study.

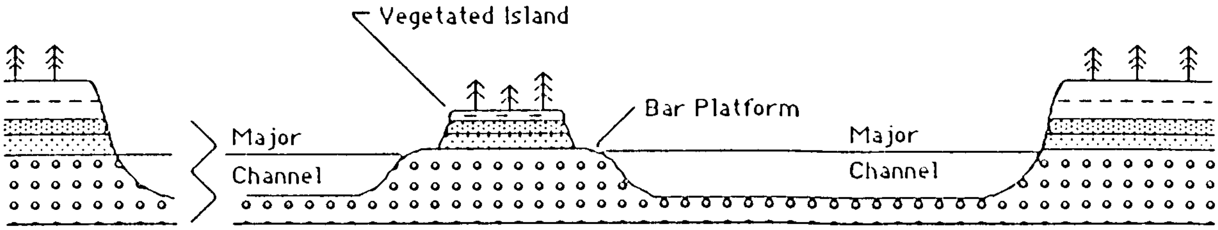
Once the gravel bench is established and accretes vertically to bar platform elevation, sand is deposited in relatively wide, horizontal sand sheets on the new portion of the bar platform and pioneering vegetation stablizes the surface (Fig. 4.3c). The occurence of these sand sheets was often observed on the banks of vegetated islands and are herein referred to as bank benches. As the bank bench accretes sand vertically and builds up to island level the process is again repeated (Fig. 4.3d). Through the growth of gravel benches and the development of bank benches on the gravel surfaces, the island builds toward the floodplain or another island. When the channel separating the two land bodies becomes narrow enough, the channel fills with gravel to an elevation above low water level and a chute is created (Fig. 4.3e).

The development of gravel and bank benches (Fig. 4.3) is based mainly on casual observation and is therefore largely speculative. Gravel benches were observed to occur laterally on many of the islands in the study area, and bank benches were observed at various stages of development (Fig. 4.3).

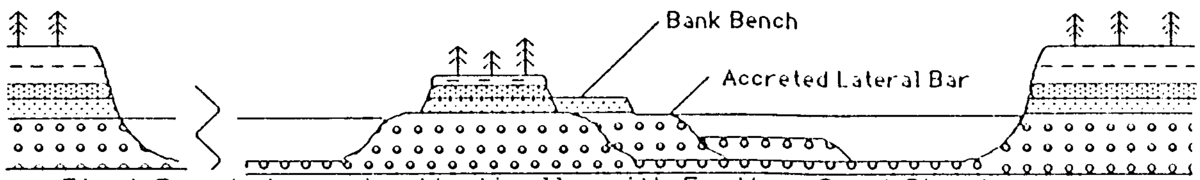
It was observed that, along the south bank of BCC and BCU (Fig. 4.2) within

Figure 4.3 Development of the Bank Bench

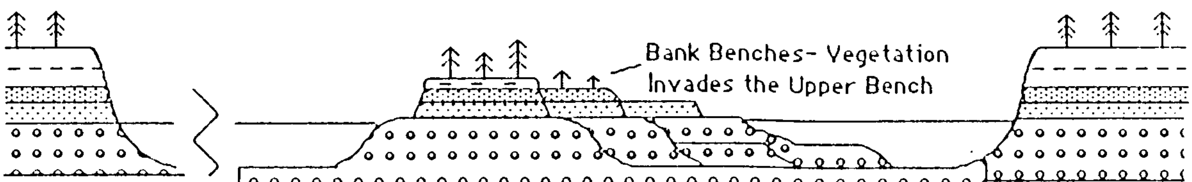
a. Deposition of a Mid Channel Island



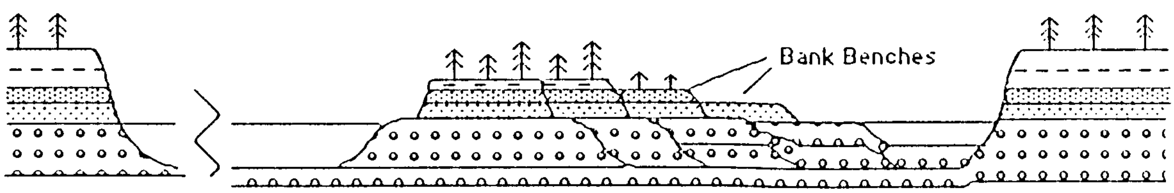
b. Island Develops a Lateral Bar and is Partially Covered by a Horizontal Bench of Sand Sheets.



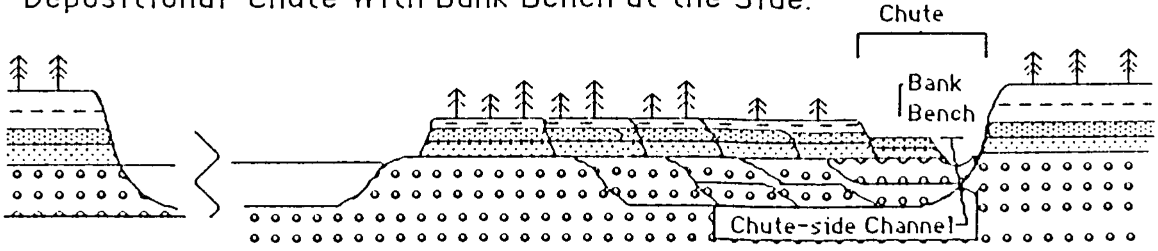
c. First Bench Aggrades Vertically with Further Sand Sheets, Another Lateral Bar Attaches and the Process is Repeated.



d. First Bench Becomes Part of the Island by Accreting a Silt Cap and Aggrading to Island Level. Other Bank Benches Continue to develop.



e. Gravel Fills Channel Between Island and Floodplain Creating a 'Depositional' Chute with Bank Bench at the Side.



10-20 metres of the bar platform, the flow depth was reduced from greater than two metres to less than a half a metre. The more shallow depth was relatively consistent across the 10-20 metres, suggesting a gravel bench was in place (Fig. 4.3b). The gravel bench shown in Figure 4.3d was observed between Carey's Island and the floodplain.

A series of two bank benches were found on the southwest portion of Carey's Island (Fig. 4.1). These benches are attached to a small island south of the main Carey's Island and resemble the bank benches shown in Figure 4.3c. A major channel shown on 1943 aerial photography between this smaller island and the main Carey's Island has now been replaced by a sand filled chute. The bank benches have been colonized by vegetation. The lower bench is approximately 60 cm lower than the upper bench and is colonized by grasses while the upper bench is colonized by young Cottonwood. The small island to the south (Fig. 4.1) is forested with mature Cottonwoods.

A pit was dug into a bank bench on GPI (see Fig. 5.2 and section 5.1.2 i). This bank bench is at a stage of development similar to that shown in Figure 4.3e. One vegetated island is separated from another adjacent island by a 20 m wide bank bench and a 15 m chute-side channel which has a horizontal gravel bed covered with 0.50 m of sand.

The growth of an island by the development of bank benches is often accompanied by erosion on the opposite side of the island. For example, the north bank of Carey's Island (Fig. 4.1) was observed to be a cut bank. The result of erosion on one side and deposition on the other is that the island effectively migrates toward the floodplain.

The term bank bench was used by Taylor and Woodyer (1978) for similar flat surfaced features in Australia but in a lower energy meandering environment. The process of island growth by the addition of lateral bars in a manner similar to that described here was also found to occur by Bristow (1987) in the Brahmaputra River in Bangladesh and by Bluck (1979, 1980) for Scottish rivers. Mature concave bank benches described by Page and Nanson (1982, their stage 3, p.539 and their Figs. 7 and 8) also appear to be similar morphologically.

4.1.4 Major Channels

Major channels are differentiated from chutes since the former carry water all year round while the latter carries water only during flood. There exists a hierarchy of channels within the Fraser River which can be classified by the scheme proposed by Bristow (1987). The hierarchy applies to bankfull stage of the river and, using Bristows work as a guide, is described as follows:

1st order channels: bounded on either side by the banks of the river this channel encompasses the bankfull width of the river.

2nd order channels: bounded on at least one side by an island, 2nd order channels carry water year round and may flow between two islands or between an island and the floodplain.

3rd order channels: bounded on at least one side by an island, 3rd order channels carry water only during flood and are usually referred to as chutes. Chutes usually cross islands or separate two islands but are occasionally found separating an island from the floodplain just prior to attachment (eg. MI, Fig. 4.1; Is22, Fig. 4.2).

Flood flows that will inundate bars and islands below floodplain level (8500 m^3/s) occur approximately every two years (McLean and Mannerstrom, 1985). When this flood level occurs, the river still has a multi-channel planform divided around islands. The 1st order channel under these conditions includes the entire width of the river. 2nd order channels are channels which have divided around islands in the river. The division may occur once or many times within a given reach so that 2nd order channels may flow between islands or between an island and the floodplain. The growth of lateral gravel benches may result in the narrowing of a 2nd order channel. When the channel narrows to the point where it carries water ephemerally (Fig. 4.3e), it is considered to be a 3rd order channel or chute. 3rd order channels are dry during low flow with sediment blocking the upstream end.

4.1.5 Chutes

Channels which are dry during all but flood flows are referred to as chutes in this report and are probably equivalent to Bristow's (1987) 3rd order channels. Chutes usually cross islands or separate two islands but occasionally separate an island from the floodplain.

In terms of floodplain construction, one of the most critical processes in the active channel zone is the process of chute infill. Over time, deposition of sand and silt over the gravel platform results in the infilling of the chute. Once the chute infills between an island and the floodplain, and no longer carries water, the island has accreted to the floodplain.

Since this study is concerned mainly with the infill of chutes in the active channel as well as historic chute infill on the floodplain, bar platforms, vegetated islands and major channels will not be dealt with further. The remainder of this thesis concerns the characteristics of chutes in the active channel (section 4.2 and chapter five) and on the floodplain (chapter six).

4.2 Geomorphology of Active Channel Zone Chutes

The following discussion describes the main geomorphic features found in the active and infilling chutes within the study area. These chute properties consist of i) a coarse chute head-bar or lobe, ii) a scour hole immediately downstream of the chute head bar or lobe, iii) the surface expression of the sediments on the bed of the chute and iv) a chute-side channel. Before discussing the properties of these features however, a chute hierarchy is developed.

4.2.1 Chute Hierarchy

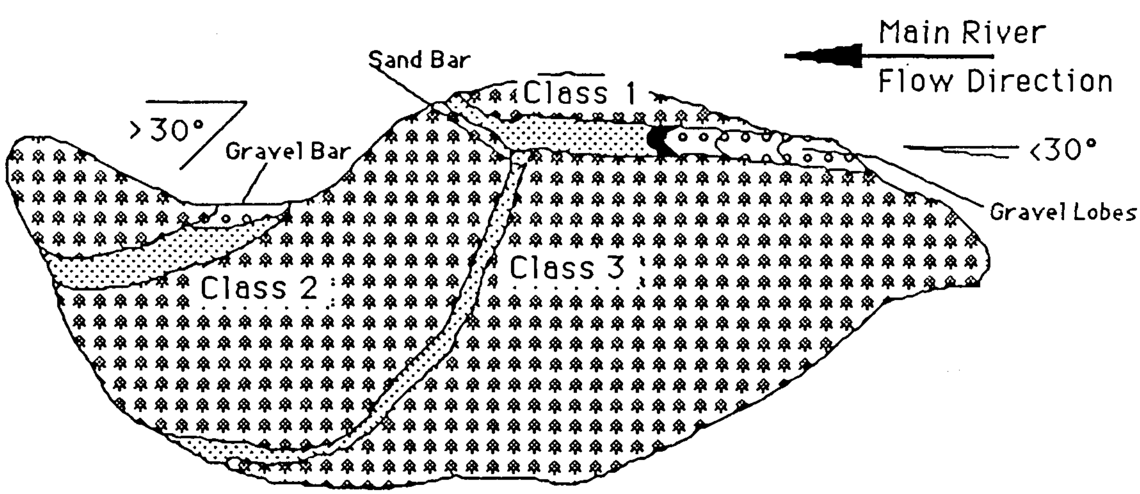
Fifteen chutes on seven islands were mapped during the course of the study (Figs. 4.1, 4.2). During mapping it soon became obvious that the chutes were not the same even though a number of features were shared. The observed chutes were classified into three categories which correspond with the effects of diminishing boundary shear stress. This classification scheme is shown in Figure 4.4 and is discussed below.

Figure 4.4 Hierarchy of Chutes in the Fraser River

Class 1. Chute is Oriented Nearly Parallel to Flow Direction of River. Gravel Lobes Occupy 30-50 Per Cent of the Chute.

Class 2. Chute is Oriented at Greater than 30° Angle to Main River Flow Direction. Gravel Bar Builds Across the Mouth of the Chute in an Upriver Direction.

Class 3. Chute Head Connects to Another Chute as Opposed to the Main River. Sand Bar Builds Across the Head of the Chute.



i) *Class 1 Chute*

The Class 1 chute is directly connected to the main river and is characterized by waves or lobes of gravel entering the chute mouth during flood and moving down the chute in distinct units (Fig. 4.4). It was observed that where these gravel lobes developed, the angle between the chute mouth and main river flow was usually less that approximately 30°. The parallel orientation of this class of chute results in a water surface slope which is similar to that of the main river. The steep water surface slope, compared to the class 2 and 3 chutes, as well as movement of gravel lobes within the chute suggest that this class of chute has the higher boundary shear stresses (γRs) of the three main chute classes. Examples of class 1 chutes are shown on CI, BCU (Fig. 4.1) and on GPI (Fig. 4.2).

A scour hole appears immediately downchute of the last gravel lobe (BCU, Fig. 4.1; GPI, Fig. 4.2). The gravel lobes and scour hole may, and often do, occupy 50 per cent or more of the chute length.

The tail of the chute is filled with well sorted sands. These sands may be sand sheets or dunes depending on the flow velocities of the depositing floods. Details regarding gravel lobes and bars, scour holes and bed features are described in the sections following the chute hierarchy.

ii) *Class 2 Chute*

The class 2 chute has direct access to the main river . At the head of the chute a gravel bar is deposited rather than gravel lobes (Fig. 4.4). It was observed that the mouths of these chutes were usually oriented obliquely (greater than approximately 30°) to the main flow direction (Fig. 4.4). The lower water surface slope of a class 2 chute results in reduced boundary shear stresses compared to that of a class 1 chute.

Most of the chute is filled with sand which is rarely dune covered unless the chute is joined by another class 1 or class 2 chute (Fig. 4.2). The thickness of the sand unit increases down-chute from the gravel bar at the head of the chute.

iii) *Class 3 Chute*

The class 3 chute does not connect with the main river but is instead fed from an adjoining chute (Fig. 4.4). Since depth of flow is reduced as water flows from the main river to a class 1 or class 2 chute, there must be a reduction in hydraulic radius (R) and hence shear stress acting on the chute bed. A further reduction in boundary shear stress occurs when the water flows obliquely into the class 3 chute from its adjacent chute. The result is a bar of sand, as opposed to gravel, being built at the mouth of the chute (Figs 4.1, 4.4).

Only one clear example of the class 3 chute was found in the study area, located in the centre of Carey's Island (CI, Fig. 4.1, 4.5). Immediately downstream of the chute-head sand bar is a scour hole similar to those in all other chutes previously described. Sands deposited in these chutes are massive to ripple bedded. The chute tail contains a large amount of very fine sand and silt from the waning portion of the flood and from backwater entering the chute.

4.2.2 Chute head bars and lobes

Where a channel divides around an island, one channel will become dominant and carry most of the flow. A reduction in competence results in a lobe of gravel or a bar of gravel or sand being deposited in the mouth of the secondary channel during flood (Cheetham, 1979). The chute is cut off from low water flows and succeeding floods must move sediment over top of this pre-existing sediment if further deposition in the chute is to result. A similar process of chute cut-off has been described by Doeglas (1962) for the Durance River, Schumm and Lichty (1963) on the Cimarron River, Burkham (1972) during the Gila River project, and by Cheetham (1979) in the Spjeltfjelldal River in Norway.

Where chutes are oriented parallel or nearly parallel to the main river flow then gravel lobes move into the (class 1) chute in distinct units. It is believed that these lobes build in the mouth of the chute and are moved by flood waters down the chute. The surface slope of the lobe dips upstream. Each individual lobe therefore, offers a distinct surface for flood waters to act on and hence they move as individual units. Examples of these lobes are shown

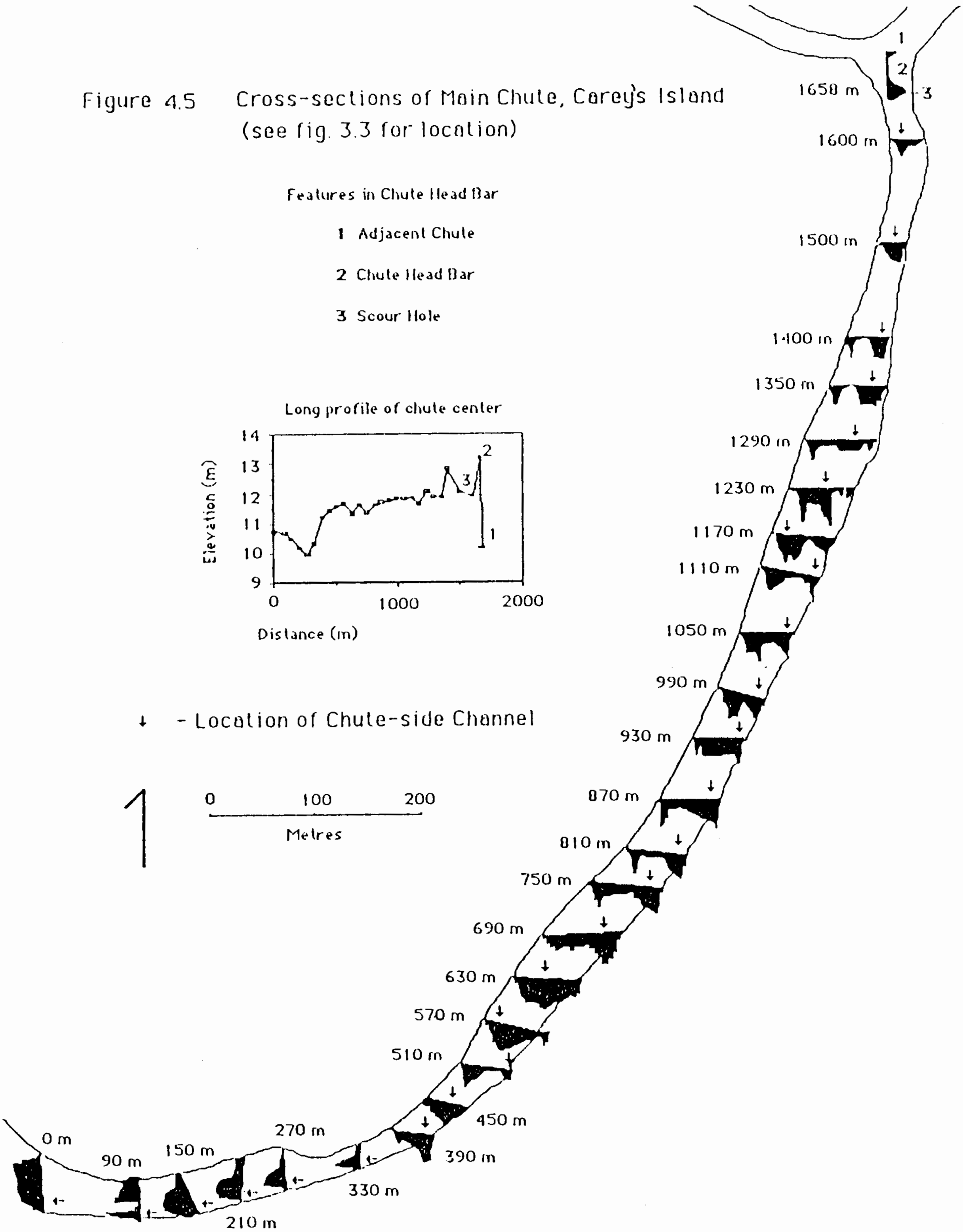


Figure 4.5 Cross-sections of Main Chute, Carey's Island (see fig. 3.3 for location)

for BCU and GPI in Figures 4.6A and B respectively and for CI (Fig. 4.1) and Is22 (Fig. 4.2).

Gravel bars are deposited across the mouth of a chute where it is oriented obliquely to the main river flow. All chute-head gravel bars observed were constructed from the downstream side of the channel entrance toward the upstream side (ie. bar growth is upstream). An example of a growing bar is shown in Figure 4.7A. Main river flow is from right to left. Once the bar has sealed the channel, the channel becomes a chute and is elevated above all but flood stages as is shown in Figure 4.7B. Other gravel bars are shown on CI, MI (Fig. 4.1) and GPI (Fig. 4.2).

Where water access to a chute is from another chute rather than the main river (class 3 chute), shear stress is lowered and the chute-head bar is composed of sand rather than gravel. The only example of a sand chute-head bar in the study area is found on Carey's Island (CI) and is shown in Figures 4.1 and 4.8.

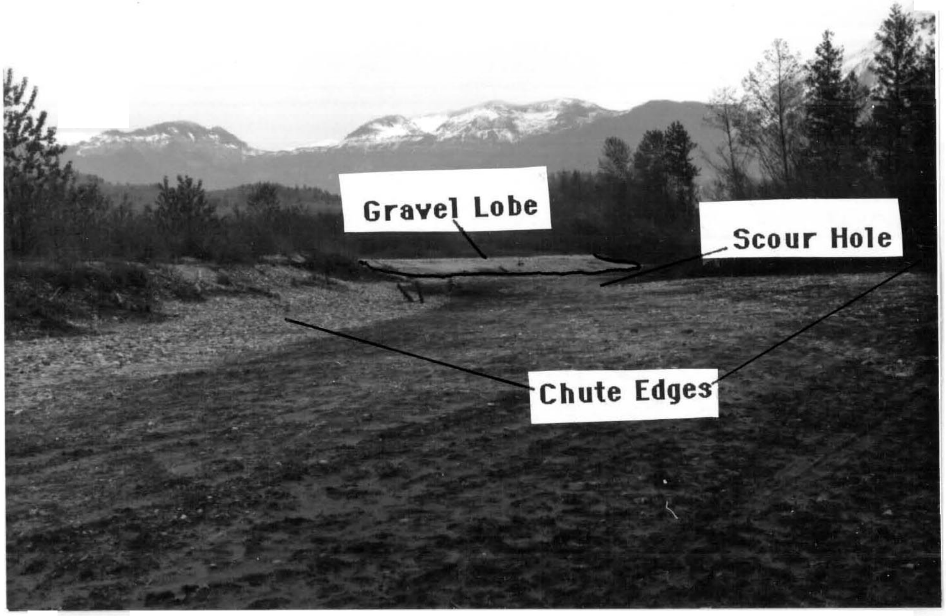
The process of chute-head accretion is also responsible for creating a chute slope which is much steeper than that of the main river. The results of a survey carried out on the Main Chute of Carey's Island (Fig. 4.1) are shown in Figure 4.5. The long profile of the chute centre shows that, excluding the chute-head bar and scour hole, the chute has a relatively steep slope of approximately 0.00091. This slope is considerably steeper than the general river slope for this area of 0.00047 (McLean and Mannerstrom, 1985).

4.2.3 Scour Hole

Immediately downstream of the chute-head bar or lobe is a scoured out depression in the sediment. This feature is shown in Figures 4.1 (MI, CI, BCU), 4.2 (GPI), 4.7B and 4.8. McLean and Mannerstrom (1985) report finding these scour holes in the main channel of the Fraser River immediately downstream of gravel bars. Church and Jones (1982) note that pools are often associated in sequence with bars and usually follow a riffle. Lisle (1986) suggests that obstructions create large scale secondary currents in the flow resulting in scour holes.

Figure 4.6 Chute-head Gravel Lobes. (A) BCU, (B) GPI
See Figure 3.2 and 3.3 for Locations

A



B

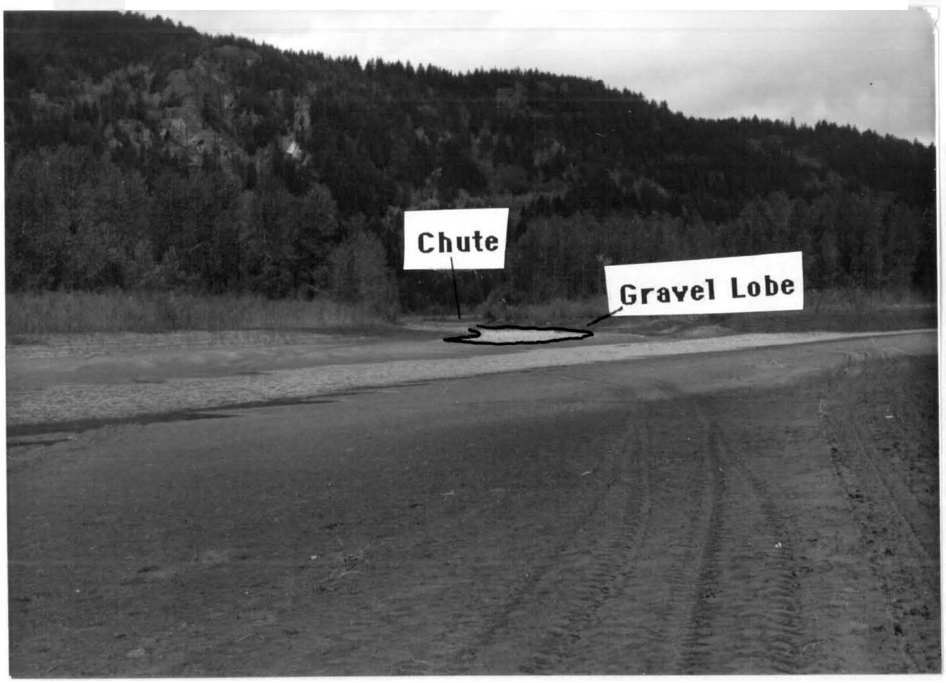


Figure 4.7 Chute-Head Gravel Bars. (A) Main Channel Building a Bar from Small Island on Left Toward Island 22 on Right, (B) GPI. Notice Person Standing in Scour Hole, Lack of Sand in Chute Head and Bank Bench at Left of Chute.

A

B

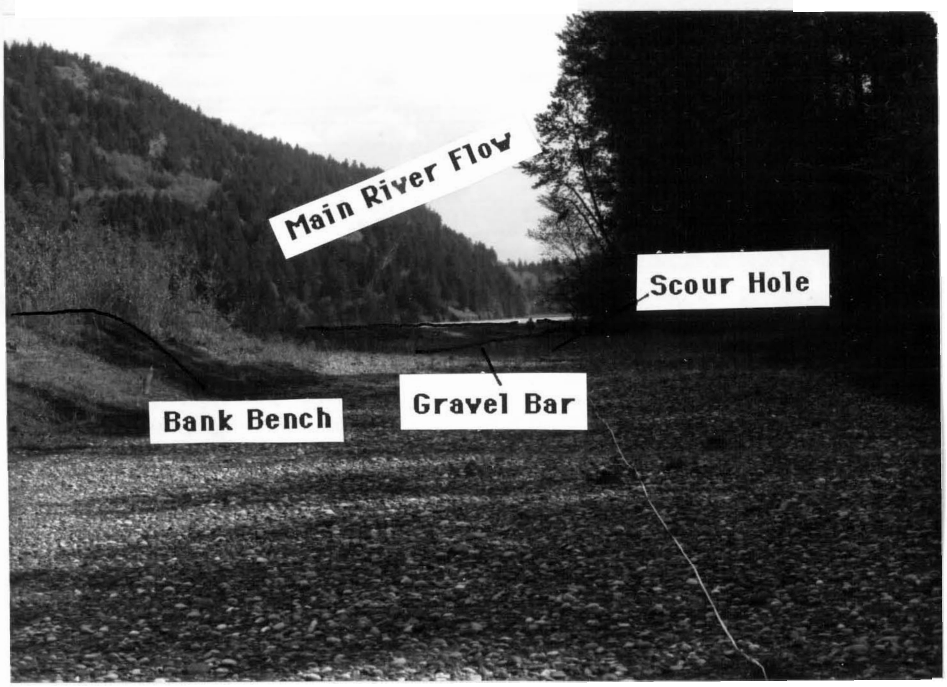
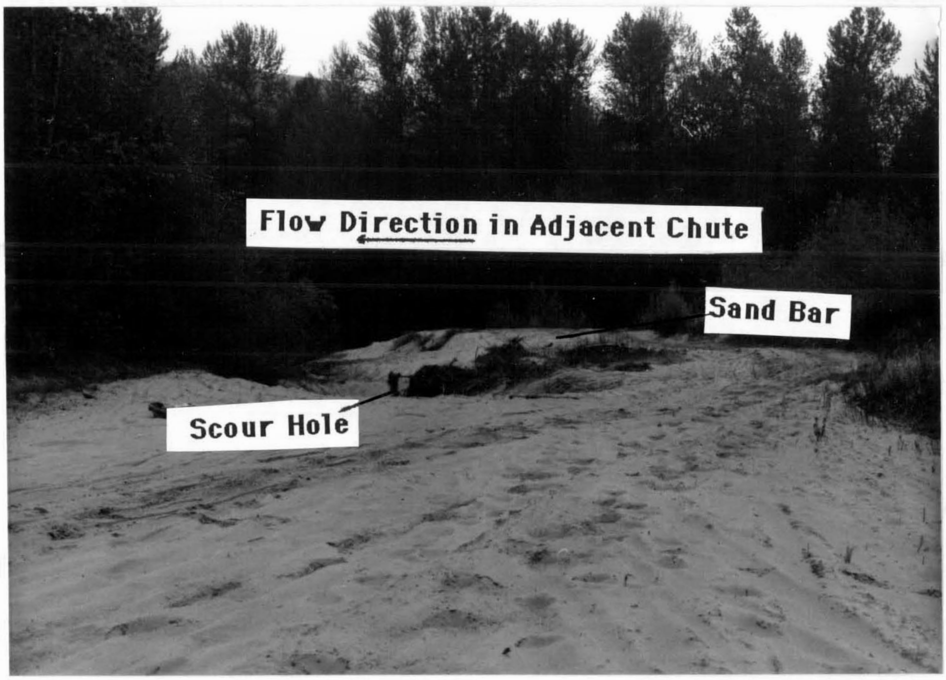


Figure 4.8 Chute-Head Sand Bar on Carey's Island. Note Access is from Chute Behind Bar and a Scour Hole is Immediately Downstream of the Bar



It was noted that all chutes observed had scour holes immediately downstream of the chute-head bar or lobe (see Figs. 4.1, 4.2). A scenario for the origin of scour holes has been proposed by Lisle (1986). Flood waters, after overtopping the chute-head bar, encounter backwater moving up the chute from its downstream end. The flow entering the chute at the head pushes the slow moving backwater ahead of it and creates large scale secondary currents. These secondary currents may be responsible for scouring a depression in the chute immediately downstream of the bar.

4.2.4 Chute Bed Features

There were two important aspects observed in the sediments of chute beds. The first is the fining of sediments down-chute and the second is the occurrence of sand sheets, dunes and ripples.

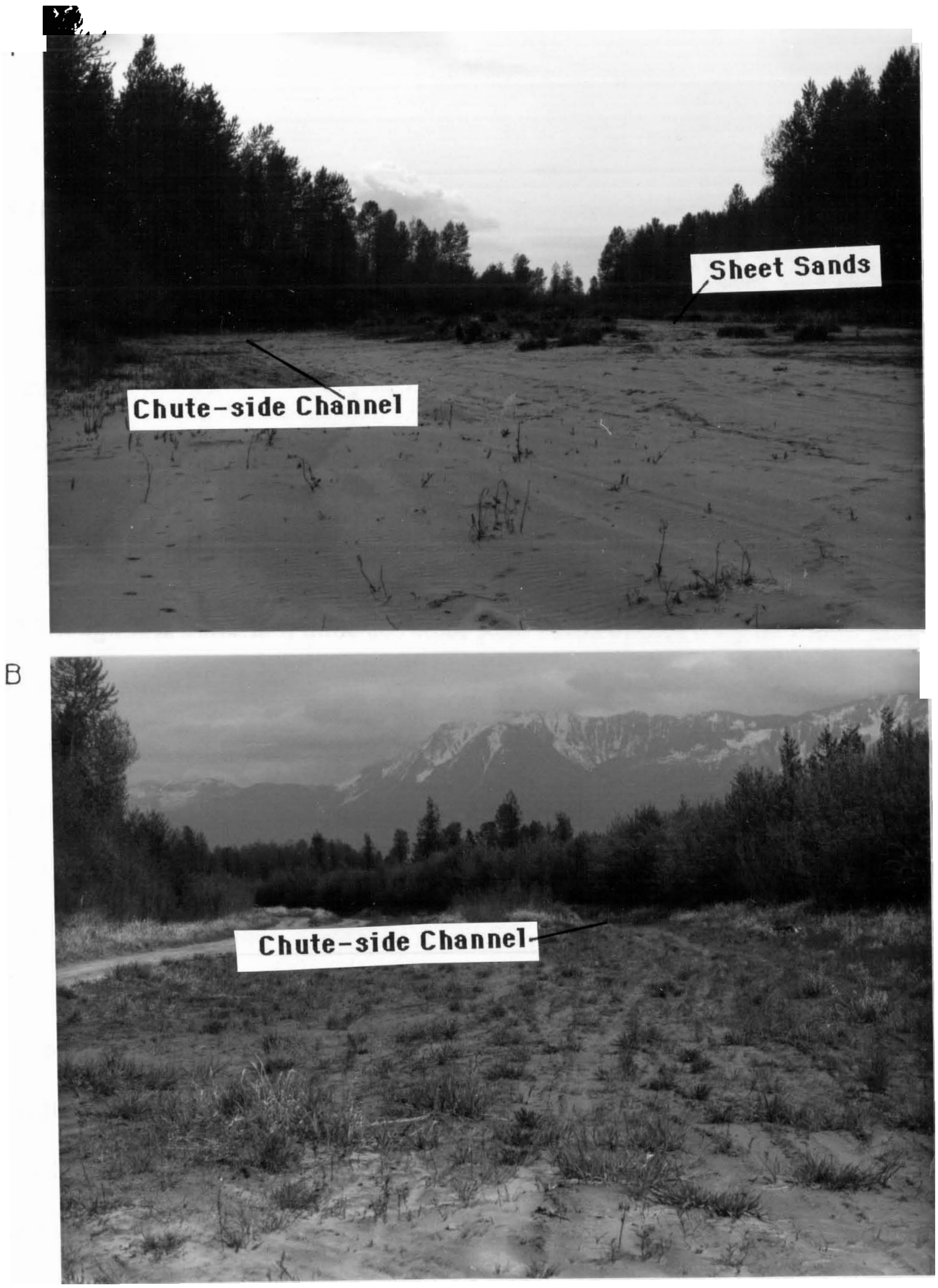
i) *Downstream Fining of Sediment*

Figures 4.8 and 4.9 show the fining of sediment down-chute in the Main Chute of Carey's Island. Figure 4.8 shows the head of the chute; Figure 4.9A shows the sandy mid section while Figure 4.9B shows the silty tail of the chute. The down-chute fining of sediments is a function of two factors: a) a reduction of stream power in the chute and b) backwater siltation.

a) Where the chute is oriented obliquely to the flow of the main river, the water surface slope in the chute must be less than that in the main river channel. The lower water surface slope results from backwater moving up the chute with the rise in flood stage. At the upstream end of the chute, the flood water overtops the chute-head bar and flows into the rising backwater. There is a rapid increase in depth down-chute as a result of the reduced water surface slope and the steep slope of the chute-bed. To maintain continuity, the flow velocity drops and there is a resultant drop in stream power. The coarser sediments are therefore deposited first as water flows down the chute.

b) During intermediate river stages, the chute tail is underwater while the head is blocked from main river flow by the chute-head bar. Under such quiet backwater conditions,

Figure 4.9 Carey's Island Main Chute. (A) Looking Downstream in the Sandy Middle Section of the Chute, (B) Looking upstream in the Silty Tail of the Chute. Note the Chute-side Channel on the Left Side in the Middle Section (A) and on the Right Side in the Tail (B)



fine silty material is able to settle out of suspension and results in the chute tail being much finer than the head or midsection (Fig 4.8, 4.9).

ii) *Sandsheets, Dunes and Ripples*

Since the sediments of high energy, multichannel rivers often display cross bedding of various types (see for example Miall, 1977,1978; Rust, 1978; Cant, 1978; Cant and Walker, 1978) it was expected that such features as ripples, dunes, and sand waves would be commonly found on chute bed surfaces.

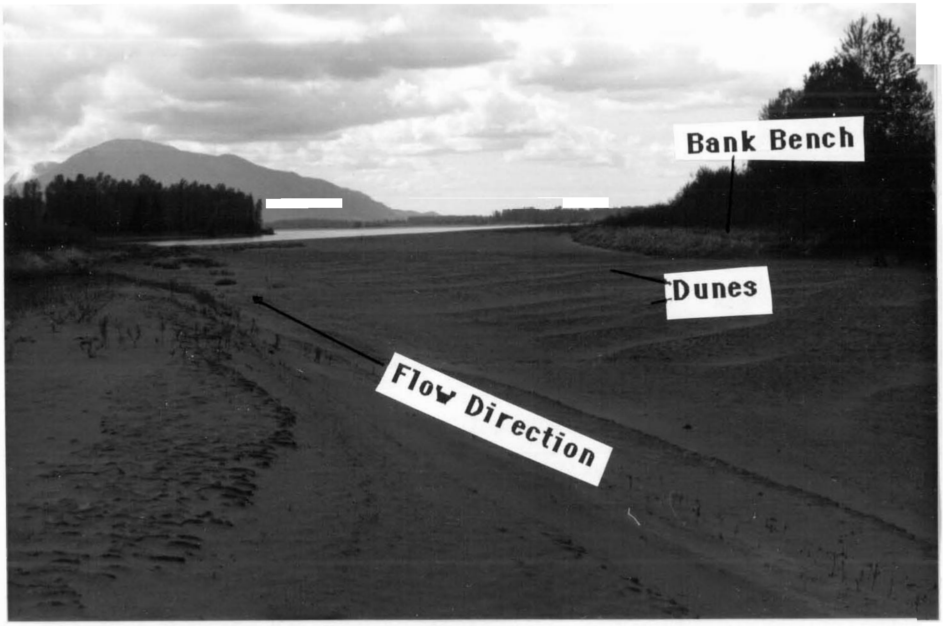
Chute infill, however, most commonly tends to be in the form of laterally extensive, massive sand sheets (Fig. 4.9A). As these sand sheets aggrade vertically, a horizontal, thickly bedded sand facies results (facies Sh). The deposition of sand sheets is comparable with the sedimentary findings of Desloges and Church (1987) for the wandering Bella Coola River. These authors found that facies Sh was most common in stable reaches and could result from upper or lower regime flow. The sedimentary structure of these sand sheets will receive more attention in a later chapter (chapter five).

Although less common, dune covered, sand filled chutes may be found downstream of where two chutes merge together (GPI, Fig. 4.2), particularly where one chute is oriented parallel to the river flow (CI, Fig. 4.1). Dunes were found in only two locations in the study area. A sinuous crested dune field was found in the western most chute on GPI (see Fig. 4.2 for location) and is shown in Figure 4.10A. Dunes were also found in a chute-side channel on Carey's Island (see CI, Fig. 4.1 for location) and are shown in Figure 4.10B. The GPI dunes (Fig. 4.10A) are located immediately downstream of the confluence of two chutes. The CI dunes (Fig. 4.10B) are located in a chute oriented near parallel to main river flow.

Ripples (Fig. 4.9A) are occasionally found on the beds of the chutes. These ripples, however, are rarely preserved. The ripples appear to be a feature developed at the end of the flood or are destroyed as soon as they are formed since they are found only on the surface of the sand sheet. During the next flood, the sand ripples are quickly eroded away so that no ripple bedding (facies Sr) is preserved. Sedimentary evidence for this and the few occasions

Figure 4.10 Dunes. (A) GPI (B) In Chute-side Channel on CI: Note Bank Bench to Right

A



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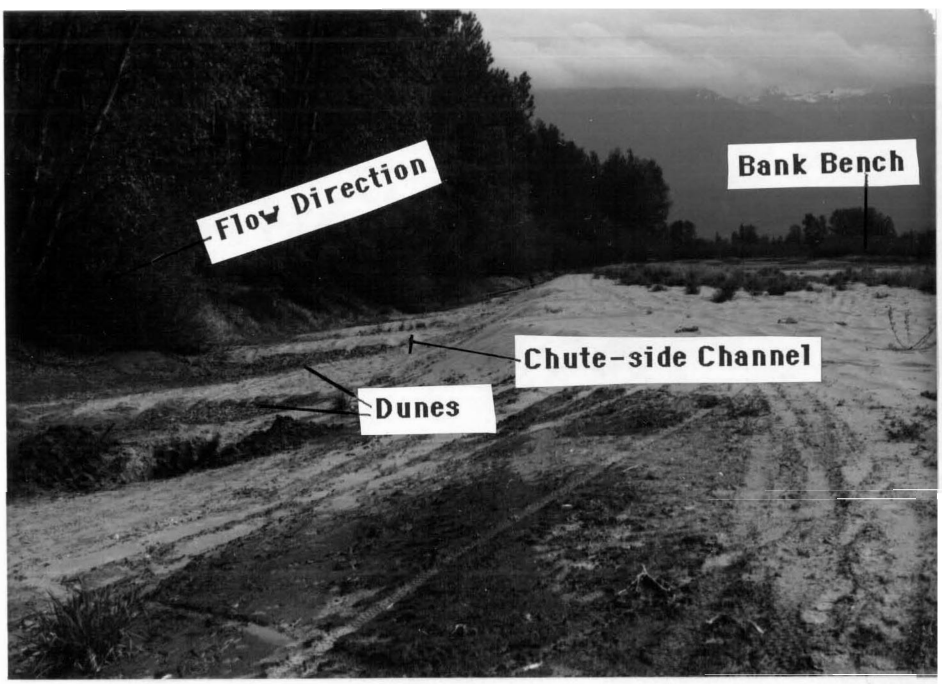
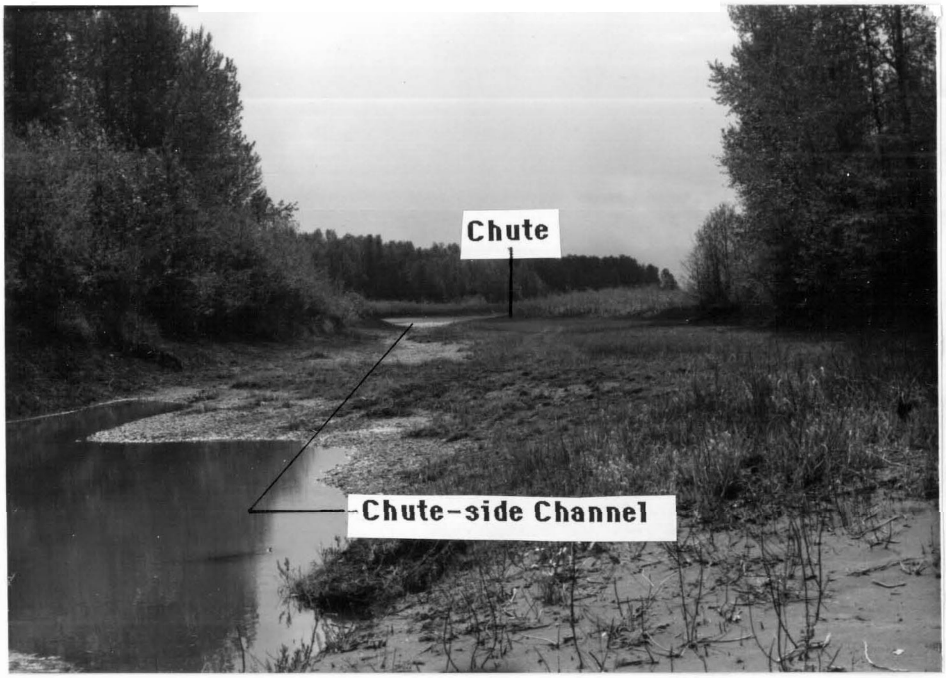


Figure4.11Chute-side Channels. (A) GPI (B) Is22B. Chute-side Channel is to the Left of the Chute in Both Photos

A



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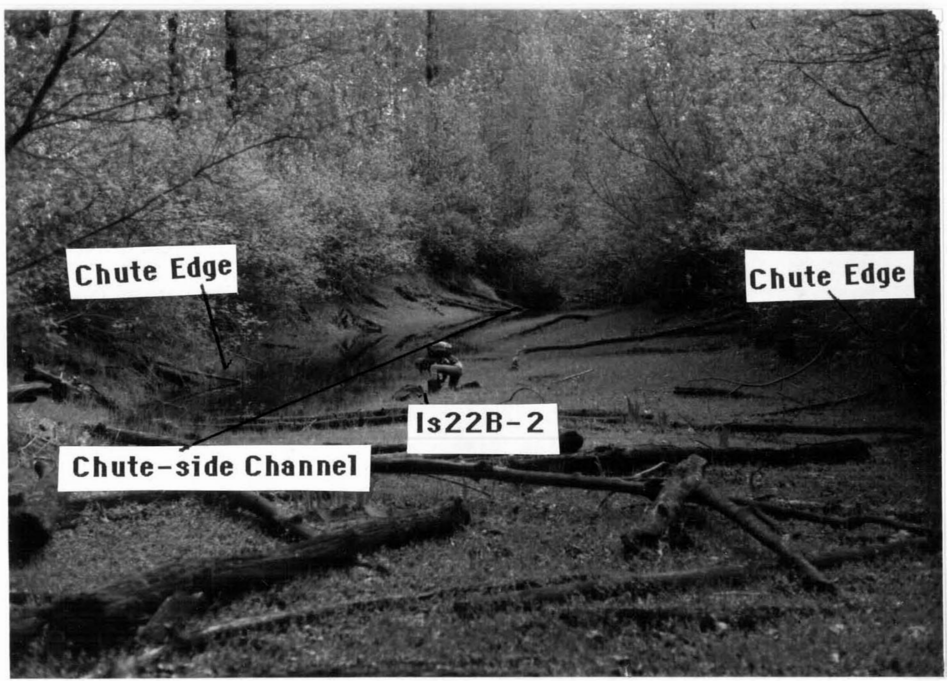


where ripple bedding is preserved is presented in the following chapter (chapter five).

4.2.5 Chute-side channel

The chute-side channel is typically a small channel which originates from a scour hole and winds its way down the side of the chute. Chute-side channels were found in all chutes observed in the study area (eg. Figs. 4.9, 4.10B and 4.11). These chute-side channels typically follow one side of the chute although they were occasionally observed to cross the chute or follow the centre.

The survey carried out in the Main Chute of Carey's Island (Fig. 4.5) shows an example of the chute-side channel. In 21 of the 26 (81%) cross-sections, the chute-side channel occurs on the right hand side (east) of the chute. It crosses to the left hand side (west) at stations 0, 570, 1170 and 1600 and lies in the centre at station 1230.

The chute-side channel is believed to carry most of the flow when flood water moves down the chute. Chute-side channels are not commonly reported in the literature but Allen (1965, p.120) observed that 'Many of the scours took the form of channels within channels.' The chute-side channel has important sedimentological implications which will be discussed in the following chapter.

CHAPTER FIVE

SEDIMENTOLOGY OF THE ACTIVE CHANNEL ZONE

This chapter will describe in detail the sedimentology of chutes within the active channel zone (section 5.1). This will be followed by a discussion of the processes of chute infill and the presentation of a depositional model (section 5.2). The geomorphology and sedimentology of the paleochutes (swales) of the floodplain will be described in chapter six as will a comparison of the sedimentology of the active channel and the floodplain.

5.1 Sedimentology of the Island Chutes within the Active Channel Zone

This section presents the results of excavations of 28 pits in chutes on seven islands in the active channel zone.

5.1.1 Carey's Island

Figures 5.1 a-d show the sedimentary profiles of the 12 pits excavated in the main Carey's Island chute. This is a Class 3 chute with a sand bar sealing the head of the channel. The following discussion will describe the sediments of : i) the chute-head bar, ii) the chute head, iii) the central portion along the chute and iv) the chute tail.

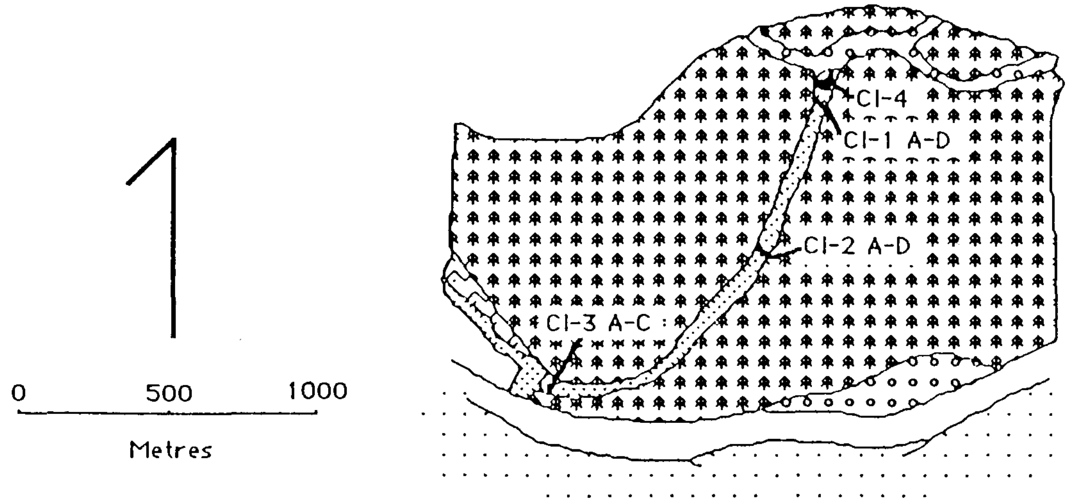
i) *The Chute-head Bar*

CI-4 (Fig. 5.1a) shows the sediments of a trench excavated perpendicular to and into the chute-head bar. The surface of the bar was featureless and the upper bed, averaging over one metre in thickness, displayed planar cross-bedding over a pre-existing bar. The three units found below were massive sands and although distinct textural units, the contacts between these beds were gradational (Fig. 5.1a).

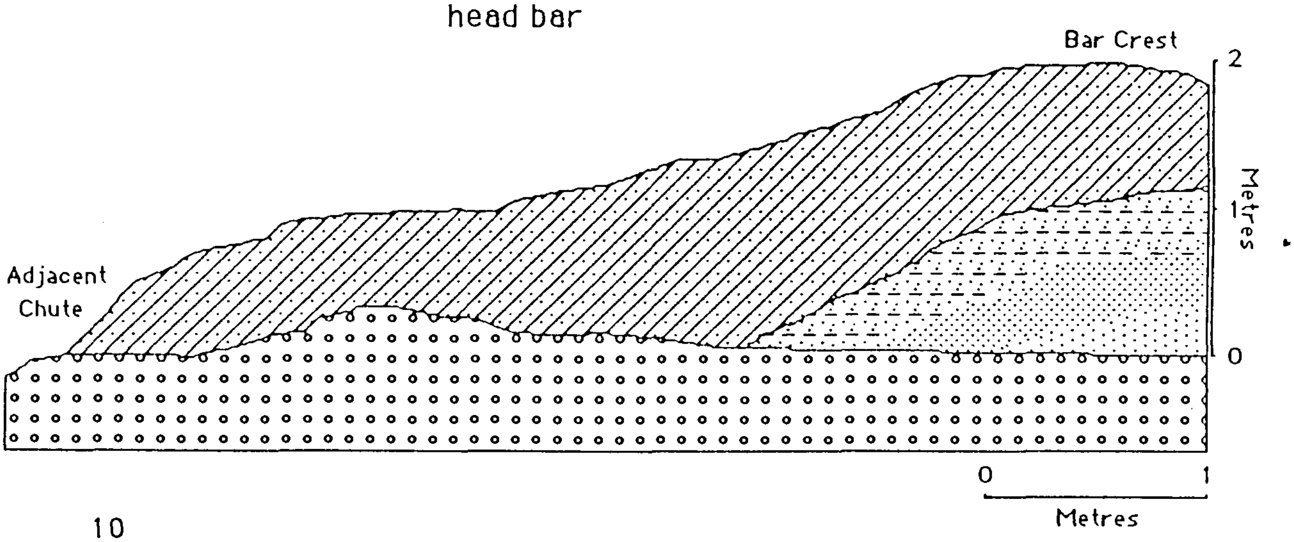
It is believed that the uppermost bed was deposited in the flood of June, 1986. No appreciable growth in the size of the chute-head bar was noticed afterward so that it is assumed that much of the pre-existing bar was eroded before the present bar was deposited.

The pre-existing bar fines upwards from medium to fine sand to very fine sand and silt. The cohesion of the fine upper bed may be one reason why the entire bar was not eroded.

Figure 5.1a Sedimentology of the Chute-Head Bar



CI-4 - Trench perpendicular to chute head bar



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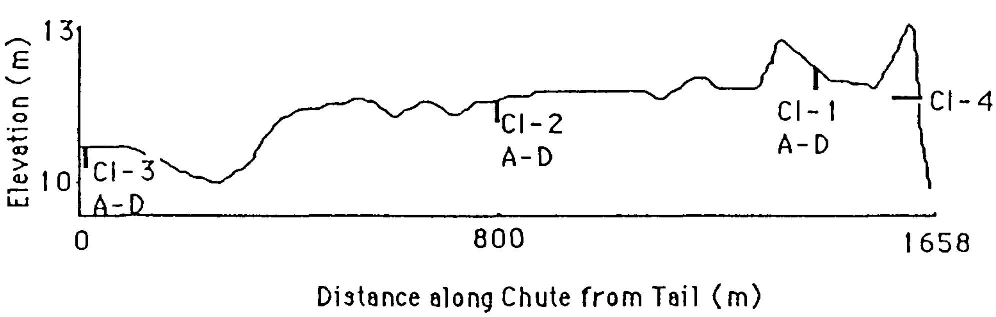
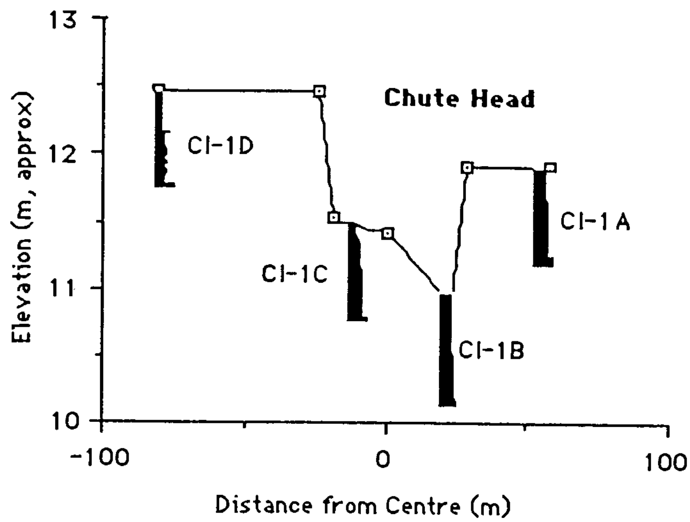


Figure 5.1b Sedimentology of the Upstream Section of the Main Chute, Carey's Island



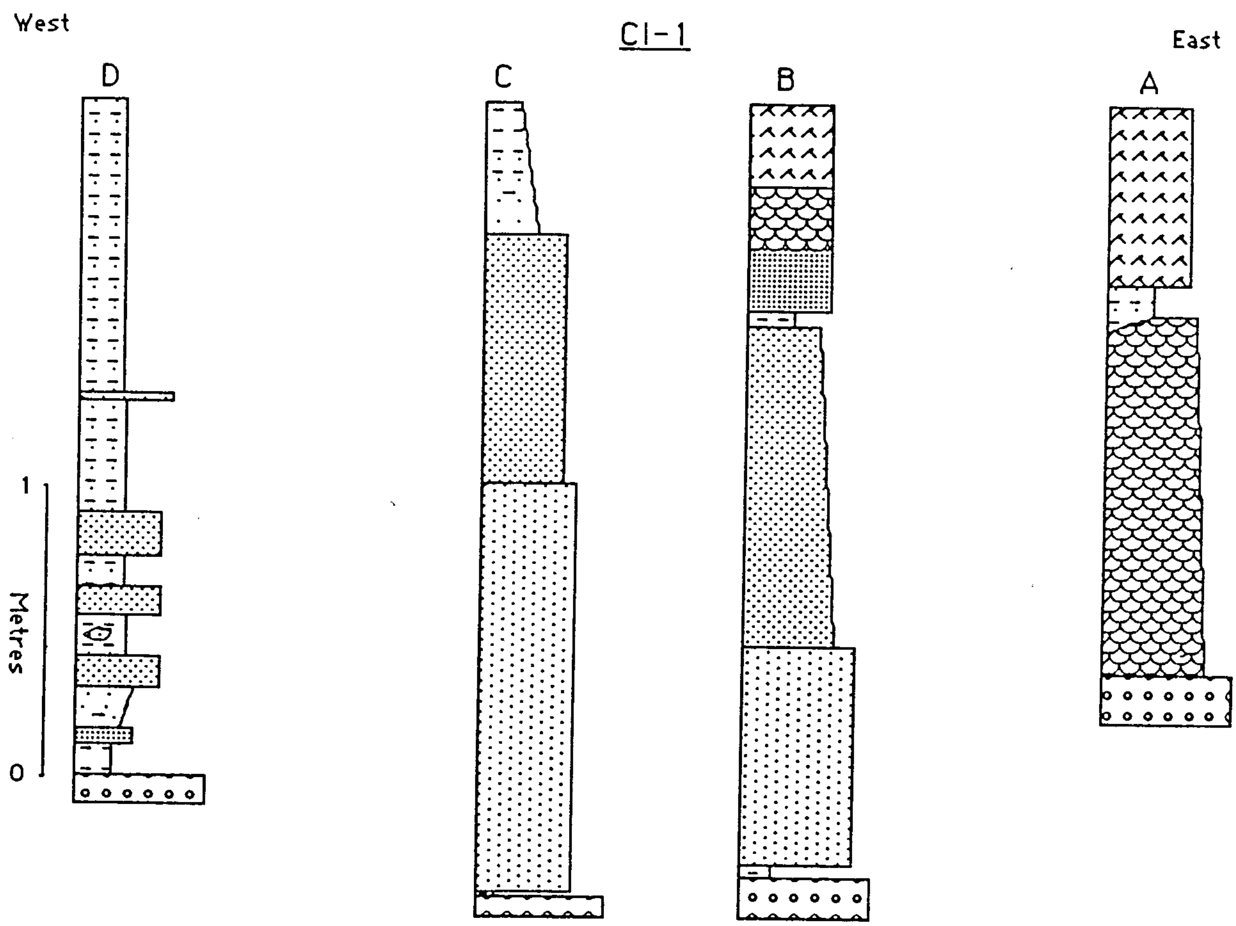


Figure 5.1c Sedimentology of the Middle of the Main Chute, Carey's Island

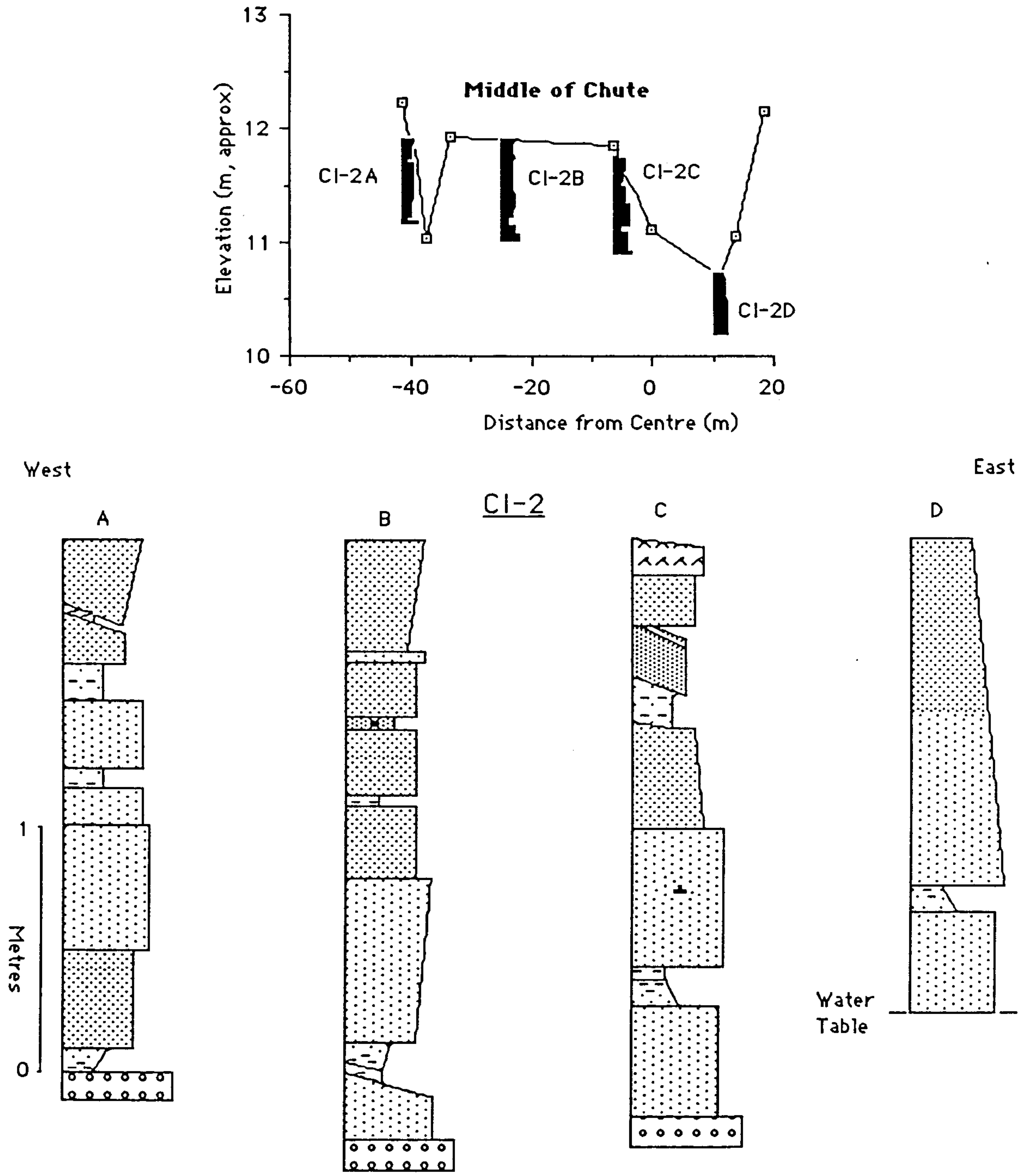
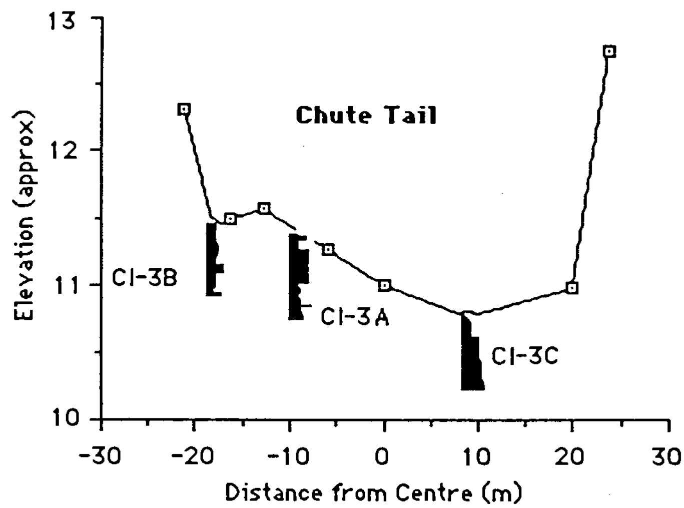
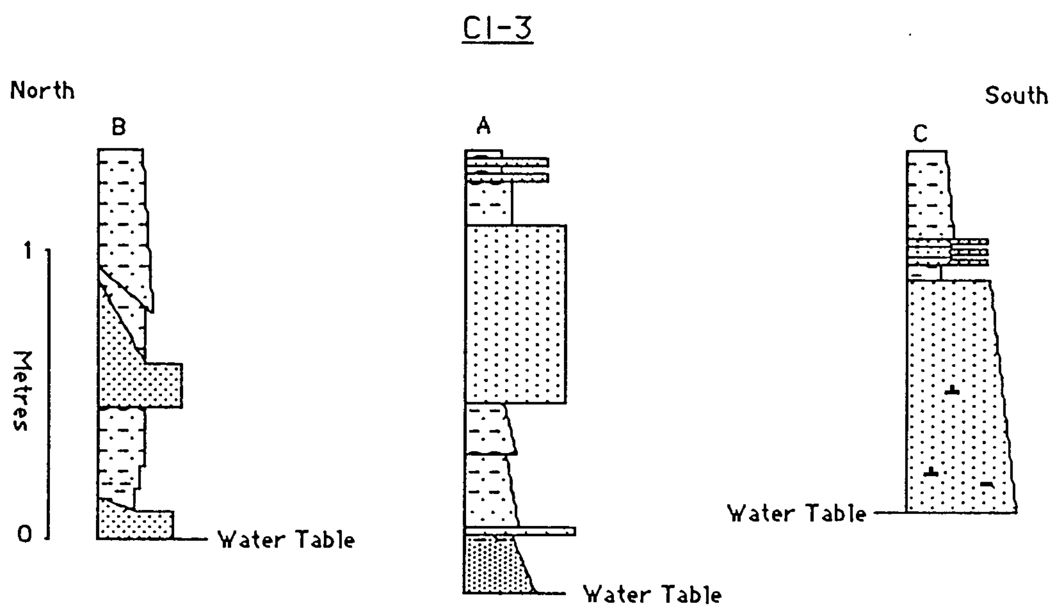


Figure 5.1d Sedimentology of the Tail of the Main Chute, Carey's Island.





ii) *The Chute Head*

CI-1 A-D (Fig. 5.1b) are profiles from pits excavated 58 metres downstream of the chute-head bar. CI-1A and CI-1D were excavated into the island west and east of the chute boundaries. CI-1B and CI-1C were excavated within the chute (Fig. 5.1b). It is believed that CI-1A and CI-1D are not comparable to the chute infill profiles of CI-1B and CI-1C since they are island platform deposits and therefore must have been in place prior to the deposition of sediments in the latter two pits. The location of CI-1A seems to match a portion of an older class 1 or 2 chute observed on 1929 air photography. If this were the case then the high shear stresses associated with the class 1 chute may explain the existence of trough (dunes) and ripple cross-bedding in CI-1A (Fig. 5.1b). These facies are rare, however, in both the island (Roberts, pers. comm.) and the chute deposits (Fig. 5.1 b-d).

The basal gravels shown in CI-1B and CI-1C are clast supported, rounded and range from 0.5 to 7.0 cm along the a axis. It was often found that channel head basal gravels tend to be clast supported with only minor amounts of coarse sand in the matrix while chute tail gravels tend to have a higher concentration of coarse sand or may be matrix supported.

The head of the chute also displays sequences of thickly bedded medium and fine, well sorted sands above the gravels with very few interbeds of silty material. Contacts between most of the beds are erosional. The sediments of both pits (CI-1B, CI-1C) also show a generally fining upwards sequence. Of note, however, is that upwards transitions of grain size in the beds are not consistent. The bedding above the basal gravel may alternate between coarse and fine sediment or there may be a coarsening or fining upwards between beds.

The variation in discharge and hence stage from year to year means there is great variation in stream power or energy of the water entering the chutes. This variation of energy is reflected in the size of the sediment deposited.

iii) *Central Portion Along the Chute*

CI-2 A-D (Fig. 5.1c) were excavated midway along the chute 800 metres south of the chute-head bar. Again of note is the general fining upwards and the inconsistent upwards grain size transitions of the beds. Again the basal gravels are clast supported.

There are three additional points of importance in this central profile, however; i) the interbedding of backwater silts between sand sheets, ii) the dip of some of the bedding toward the chute and chute-side channel, and iii) the sedimentology of the chute-side channel.

Interbedded Silts

Separating many of the sand beds, particularly in profiles CI-2 A-C are thin beds of massive silts and/or very fine sand. These sediments are often organic rich. It is believed that these fines are the result of backwater which enters the chute from the downstream end before the floodwaters can overtop the chute-head bar. Doeglas (1962), working on the Durance river, noticed that slow vertical eddies in backwater environments bring fine suspended sediment into the downstream ends of sealed channels. Doeglas also recorded the alternation of fines from backwater deposition and sand deposits from down-channel flow (his Figs. 15, 16, 17); a feature shown in Figures 5.1 c and d.

Dip of Beds

The contacts of the uppermost beds on the pits at the edge of the chute (CI-2A) and the chute-side channel (CI-2C) dip toward their respective channel (Fig. 5.1c). The dip of the upper beds are the greatest (~30^{o}) and become progressively more horizontal further down in the profile. This suggests that the sediments were draped over a pre-existing surface. The chute (and chute-side channel) was therefore already in place when these upper sediments were deposited.

Chute-side channel

The pit excavated in the chute-side channel (CI-2D) shows a thick (130 cm) massive, fining upwards bed not found in the other pits (CI-2A-C). The bed of the chute-side channel at CI-2D is approximately 1.0 m lower than the bed of the main chute at CI-2A-C. The chute-side channel appears to have infilled to some degree (Fig. 4.9A).

A preliminary survey pit was dug very close to the location of CI-2D within the chute-side channel before the 1986 flood. The survey pit was excavated to gravel at a depth of 35 cm. The sediment in this survey pit was sand with a thin silt cap (see lower units of CI-2D, Fig. 5.1c). It seems therefore, that the 130 cm fining upwards deposit is the result of one flood. It is also apparent from Figure 5.1c that the chute-side channel does not infill in the same manner as the rest of the chute cross-section.

The process of chute infill may take many years; the CI chute presently discussed is at least 60 years old (it was present on 1929 aerial photography), so that chute infill was not observed directly. The mechanism of chute infill may be speculated however, for the CI-2A-D cross-sections in the following manner:

i) the chute-side channel is kept clear of sediment by the concentration of flood waters (section 4.2.5) while the rest of the chute infills with thickly bedded sand sheets (CI-2A-C).

ii) Eventually, the chute-head bar aggrades to approximately island top elevation and the chute slope becomes reduced through aggradation; especially of backwater fines in the chute tail.

iii) The chute-side channel is no longer able to carry the sediment supplied to it and so infills rapidly with one thick bed which fines upwards from an erosional base (Fig. 5.1c, CI-2D).

iv) *Chute Tail*

The pits represented by CI-3 A-C (Fig. 5.1d) were excavated at the chute tail, 1640 m south and west of the chute-head bar. CI-3B was excavated at the west edge of the chute, CI-3A at the chute centre and CI-3C at the east edge of the chute; this pit is also believed to be within the chute-side channel.

In addition to points noted above (thickly bedded sheet sands, angular contacts at chute edge, fining upwards - especially the chute-side channel) there is one other point of note. The silty interbeds shown in CI-2 (Fig. 5.1c) are much thicker in these sections and in fact in two of the pits the fine sediment dominates the sequence (ie. CI-3B - 68% very fine sand and/or silt, CI-3A - 57% very fine sand and/or silt, CI-3C - 27% very fine sand and/or silt). All three sequences are capped with very fine sand and silt.

Deposition in a backwater environment results in the increasing thickness of fines in the lower end of the chute. The chute-head bar seals the chute off from all but flood stage flows. During more moderate river stages water enters the chute from the downstream end depositing silts and very fine sands as described earlier and outlined by Doeglas (1962). Since there is a slope to the chute, the backwater thins up-chute as do the sediments it deposits. Comparisons of the thicknesses of silt deposits in CI-1,2 and 3 are evidence of this down-chute thickening of fines.

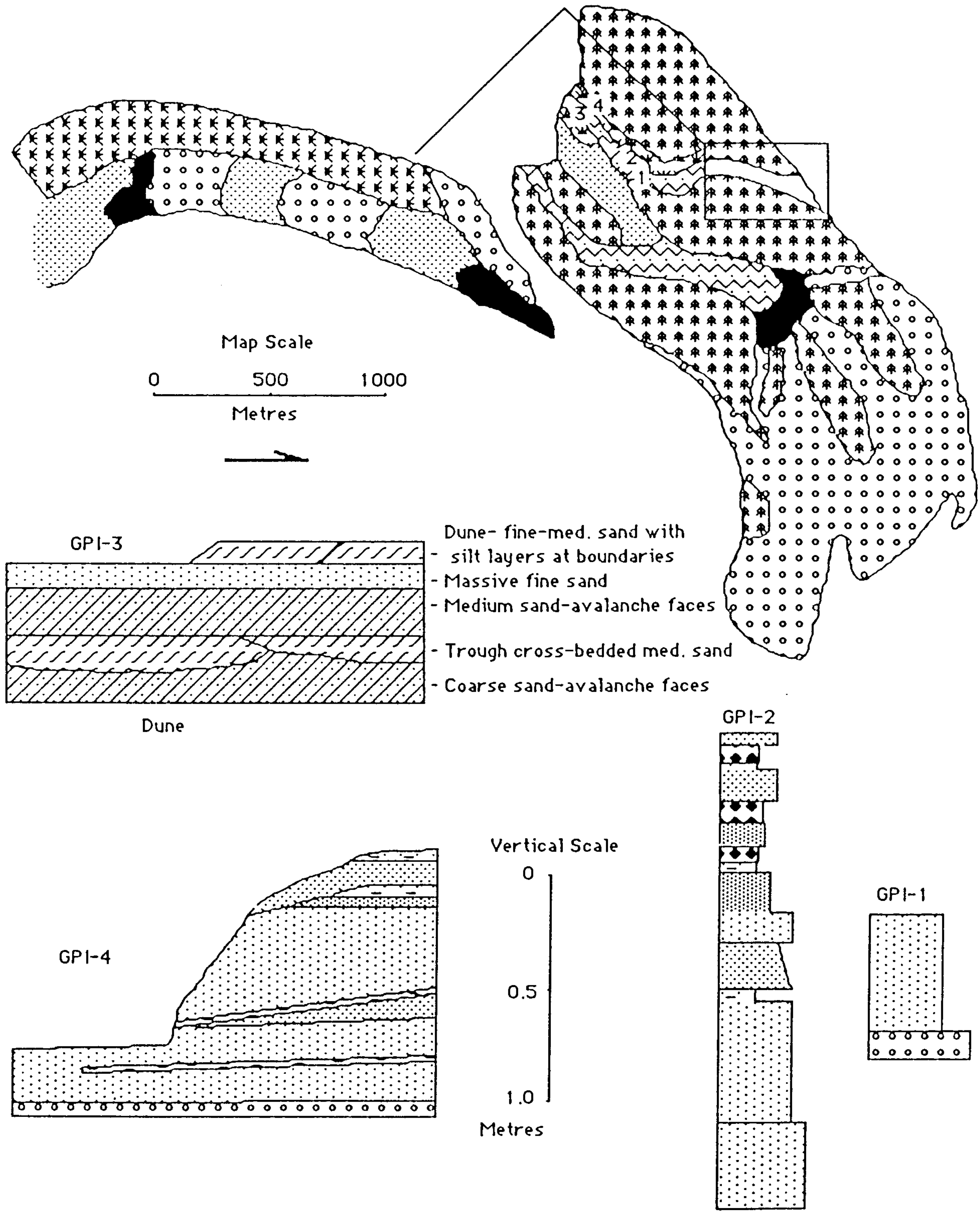
5.1.2 Gravel Pit Island (GPI)

The chutes on Gravel Pit Island (GPI) are all class 1 or 2 chutes (Figs. 4.4, 5.2). These chutes, in comparison to the Careys Island chute, have not yet developed the thick sequences of sediment. Sands within the chutes are seldom greater than one metre deep except on bank benches and in chute tails. The heads of all chutes on GPI have gravel exposed at the surface (see for example Figs. 4.6B, 4.7B, 5.2).

Figure 5.2 displays two distinctive sedimentologic features in the GPI chutes: i) bank benches and ii) dunes. The class 2 chute on the northwest portion of GPI was chosen to represent these features. The upstream portion of this chute is enlarged in Figure 5.2 and shows the geomorphic and surface sediment features of the upstream portion.

Sealing the chute is a gravel bar. Downstream of the gravel bar is a scour hole which is positioned to the east side of the chute. In addition to the gravel bar are two gravel lobes which are each lower in elevation at the upstream end than the downstream end. The resultant upstream depressions have been covered with sand (Fig. 5.2, enlarged portion). Downstream of the last gravel lobe is another scour hole which also preceeds the sand infill.

Figure 5.2 The Sedimentology of Gravel Pit Island (GPI)



i) *Bank Benches*

On the west side of the chute (Fig. 5.2) is a bank bench which parallels the chute from head to tail. The development of bank benches was described geomorphically in the previous chapter (section 4.1.3i). To the north of GPI-2 (Fig. 5.2) the ground surface rises and then flattens out to the island surface (Fig. 4.7B). The bench on which GPI-2 (Fig. 5.2) was excavated is approximately 20 metres in width and has a flat surface. To the south of GPI-2 is the lower lying chute (GPI-1). The chute in which GPI-1 was excavated is approximately 1.5 metres lower in elevation than the bank bench.

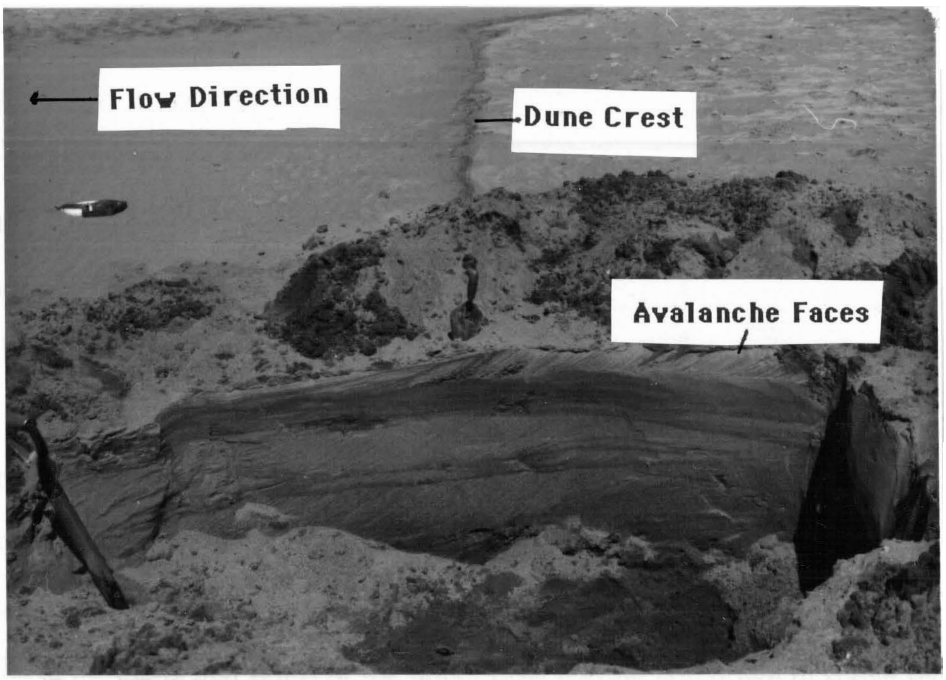
GPI-2 shows the thickly bedded deposits of the bank bench. The individual beds are massive to thinly laminated and the sequence generally fines upwards. GPI-4 shows a two-dimensional profile of a pit dug into the side of the bank bench. The important point of note in these two pits is the horizontal bedding indicating deposition as laterally extensive sand sheets. An idealized version of the geomorphic development and sedimentology of bank benches is shown in Figure 4.3.

The deposition of these plane bed sand sheets and formation of bank benches may result in the narrowing of the chute. For example, prior to development of the bank bench, the chute in the northwest portion of GPI (Fig. 5.2) must have been 35 metres in width. The narrower (15m) chute has resulted from the deposition and growth of the 20m wide bank bench.

ii) *Dunes*

The second point of note on GPI (Fig. 5.2) is the sedimentary structure of the dune covered portion of the chute (GPI-3). Figures 5.2 (GPI-3) and 5.3 show an excavated pit across a relict dune. Four separate beds resulting in planar cross-stratification (ie avalanche faces) are shown, as well as the presence of a massive bed of medium sand below the surface dune. The massive and horizontally bedded sand is by far the most common sedimentary structure found in the active channel zone. Dunes exist infrequently and often only for short distances where two chutes merge or where a class 1 chute changes from

Figure 5.3 Planar Cross-bedding Produced by the Avalanche Faces of a Migrating Dune. Cross-section Through Dune Located in Chute of Gravel Pit Island (GPI-3, see Figures 3.8A, 4.3).



gravel to sand. Trough cross-bedding which originates from these dune structures and ripple cross-bedding (see Fig. 5.1a,b) are relatively rare in the channel zone and not found at all in the floodplain cores.

The occurence of massive sands arranged in thickly bedded, horizontal units, as opposed to planar or trough cross-stratification, seems to be a key difference between wandering and braided rivers. Cross-bedding of many types are a trait of braided rivers (Miall, 1977, 1978; Rust, 1978b). Facies Sh however, is much more common and in fact appears to be favoured in the wandering style of river.

Rust (1972) found bedding of sand wedges on the margins of bars in the Donjek River to contain high angle cross-stratification. These wedges however, differ from the sand sheets of the Fraser River in that the sand sheets originate from in-channel sedimentation while the sand wedges of Rust (1972) originate from deposition from water passing over the bar surface laterally into the channel. Similar planar cross-stratified sand sheets are reported by Bluck (1979) as downfilling or sidefilling inner channels or chutes. Bluck (1980) reports the origin of planar cross-stratified coarse members in braided cycles of the Old Red Sandstone in Scotland to be the result of lateral migration of bars. These authors report on chute infilling in a braided river environment.

The difference between bedding structure in the braided environment and that of the wandering river environment is due to the relative stability of the wandering river planform (Desloges and Church, 1987). Desloges and Church (1987) report channel fill deposits of horizontally bedded fine to coarse sands (facies Sh). These authors cite the origin of these deposits to be 'plane bed sands of the upper flow regime laid down in stable sections ...' and ' In other instances, such as along back channel margins, it is probable these sediments aggrade as lower regime plane-bed sands.' (p.105).

For the wandering Bella Coola River, Desloges and Church (1987, p.107) suggest that 'Progressive lateral accretion and the vertical stability of the river appear to favour the simpler facies sequence (Gm/Sh/Fsc)...'. In the Fraser, the lateral stability of the islands prevent rapid migration and hence planar cross-stratification as described by Bluck (1979, 1980) and Rust (1972) is rarely found. The apparently low shear stresses in most of the chutes results in a paucity of dunes and hence trough cross-stratification is uncommon. Although ripples occur occasionally, they are rarely preserved in the sediments. It seems therefore, that the dominance of massive, horizontally bedded sands, is due mainly to sediment raining out of suspension under lower flow regime. This deposition of suspended sediment results from a reduction of stream power in the chute (section 4.2.4).

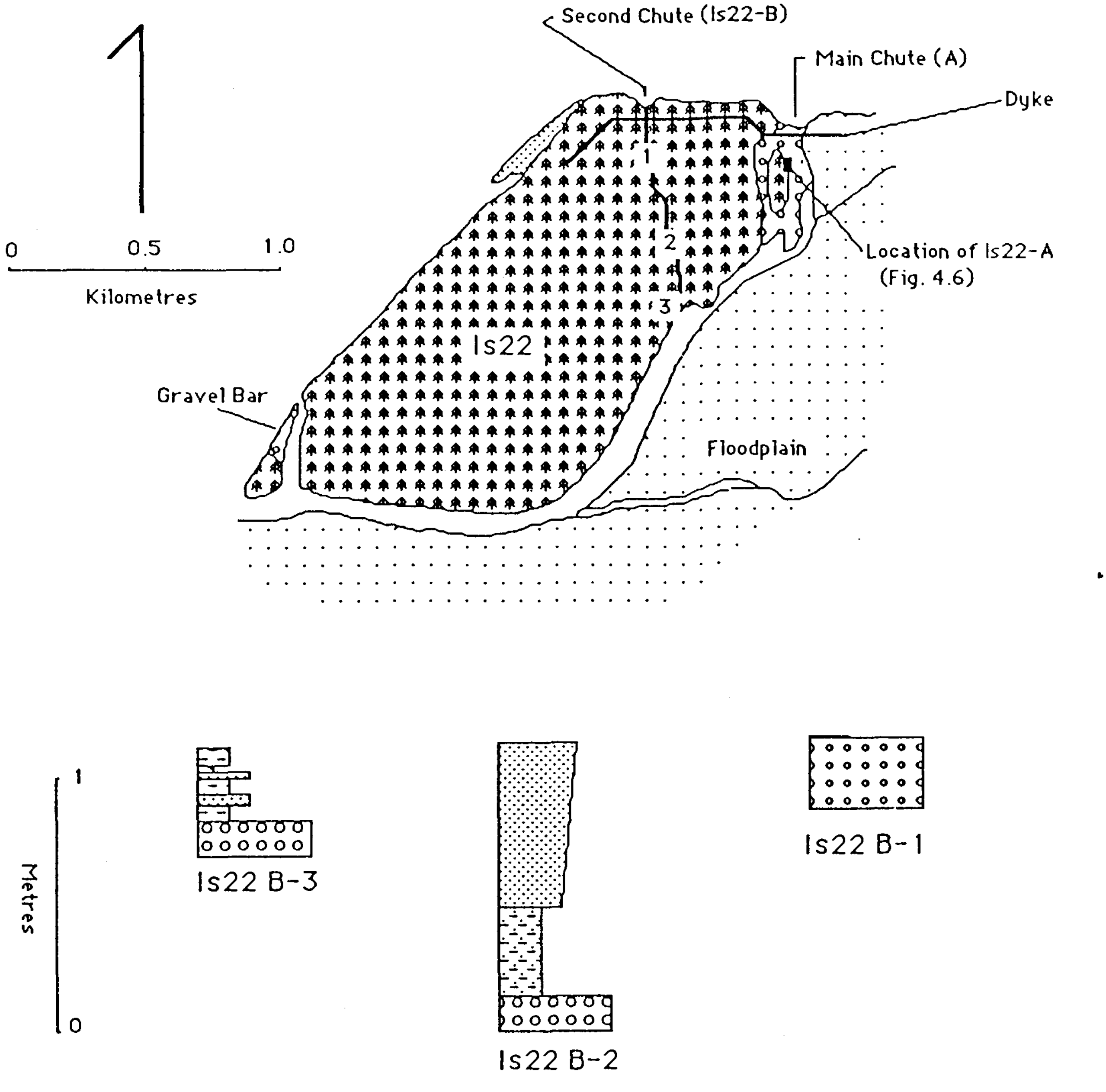
5.1.3 Island 22

The sedimentary structure of Is22 chutes is somewhat anomalous to many other chutes reported in this study. A dyke was constructed along the north edge of the island artificially closing off two chutes (Figure 5.4) and the island was joined to the floodplain. This situation has presented a modification to natural sedimentation patterns and provided an opportunity to study chute sedimentation in what may be regarded as an experimental setting.

The lithology of pits excavated in the second chute (Is22-B) is shown in Figure 5.4. The dyke which has sealed the upstream end of the chute has prevented sand from entering the system and covering the gravel. Sedimentation in this chute almost exclusively consists of backwater silts over gravel (Is22-B1,3). The origin of a wedge of sand in the middle of the chute (see Is22-B2) is unknown although it possibly results from a recent, large flood which overflowed the dyke and deposited sediment locally.

The excavated face shown in Figure 5.5 displays a large variability in sediment bedding. This section is in sharp contrast to previous discussions of deposition of sediment occuring in large sheets. This section was excavated in the main chute and along the side of an island which occured in the middle of the chute as observed on 1943 aerial photography. Again, the sediments in the profile may be somewhat anomalous as the dyke placed across the chute head was constructed in the late 1940s and probably has altered natural sedimentation patterns considerably. The variability in sediments however is an important departure from other observed sedimentation patterns.

Figure 5.4 Sedimentology of Second Chute, Island 22 (Is22-B)



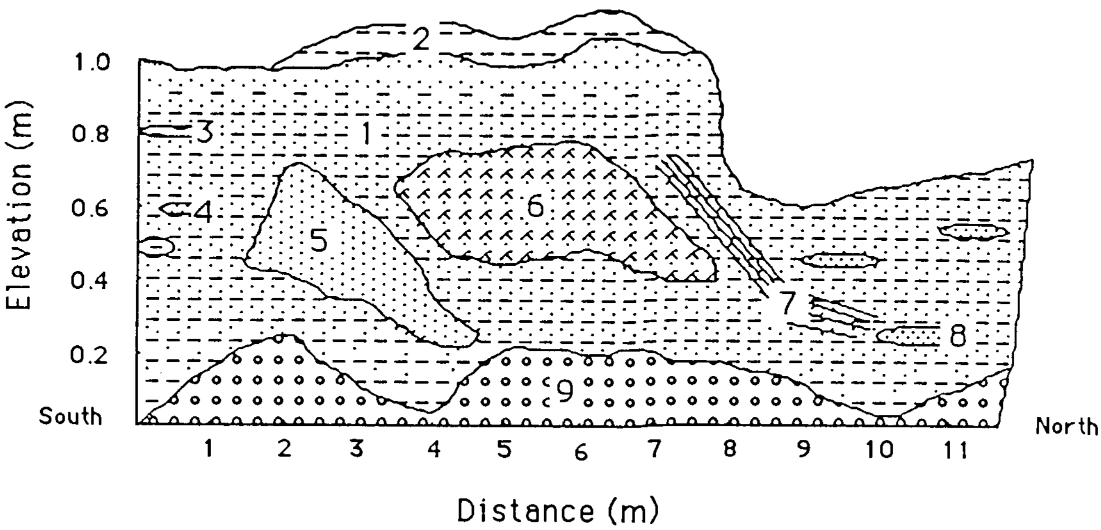


Figure 5.5 Sedimentology of Island in Main Chute, Island 22
(For Site Location see Figure 5.5)

Key to excavated face

1. Silt and very fine sand- generally fines upward

2. Clay overbank deposits

3. Lenses of clay and silt

4. Lenses of fine to medium sand

5. Massive medium sand

6. Ripple cross-bedded medium sand

7. Silt laminae

8. Lenses of fine-medium sand

9. Matrix supported gravel

When working with borehole or other one dimensional data it is often difficult to make connections or interpretations between cores (data points). This exercise is further complicated by the existence of beds which pinch out at various locations between the point sources. This point is demonstrated in the exposure shown in Figure 5.5. Despite the existence of these discontinuous lenses, however, there is considerable continuity in the bedding, shown by the extent of the fine sand and silt unit in which many of the sand lenses lie.

5.1.4 Other Islands

The sedimentology of chutes on other islands in the study area are shown in Figures 5.6 (BCC 1-4), 5.7 (BCU 1-4) and 5.8 (MI 1-3). To be noted in each figure are the sedimentary changes down-chute: fining of sediment, increasing thickness of backwater fines and increasing thickness of sediment over gravel. Except for one bed in BCU-2 (Fig. 5.7) which shows trough cross-bedding, all beds are massive or thinly laminated. It may be speculated that since BCU-2 is in a similar location as the chute shown in Figure 4.10B, the trough cross-bedding (Fig. 5.7) originated from dunes in the chute-side channel. Fining upwards sequences of chute-side channels are shown in Figures 5.6 (BCC-1a) and 5.7 (BCU-2).

The features described above are similar to the findings in the Main Chute of Careys Island (section 5.1.1). However, in contrast to the Careys Island chute these are not class 3 chutes. In BCC (Fig. 5.6) there is gravel very near the surface and capped by a thin bed of silt and sand for greater that 50 per cent of the channel length. Only near the tail were the sand sheets and slackwater silts found. This bears marked resemblance to the class 1 chute described earlier.

BCU (Fig. 5.7) and MI (Fig. 5.8) have gravel at or very near the surface in the head of the chute. The gravel surface however rapidly drops and is covered with sand and silt sequences of increasing thickness. MI is still an active chute although the head has been somewhat infilled with gravel by local contractors. Both of these chutes fit the description of

Figure 5.6 Sedimentology of the Infilled Chute on Back of Carey's Island, Center (BCC)

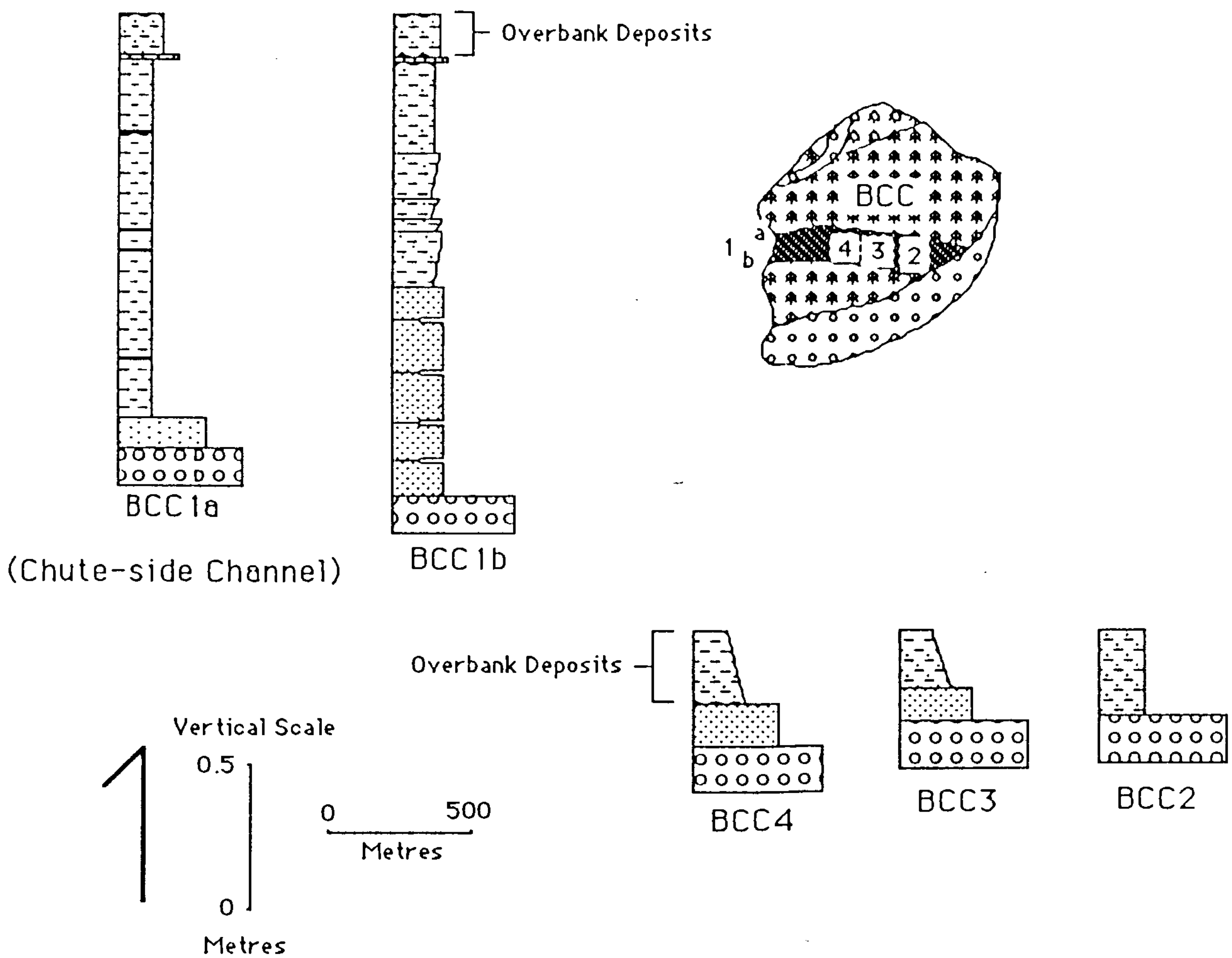


Figure 5.7 Sedimentology of Infilled Chute on Back of Carey's Island, Upper (BCU)

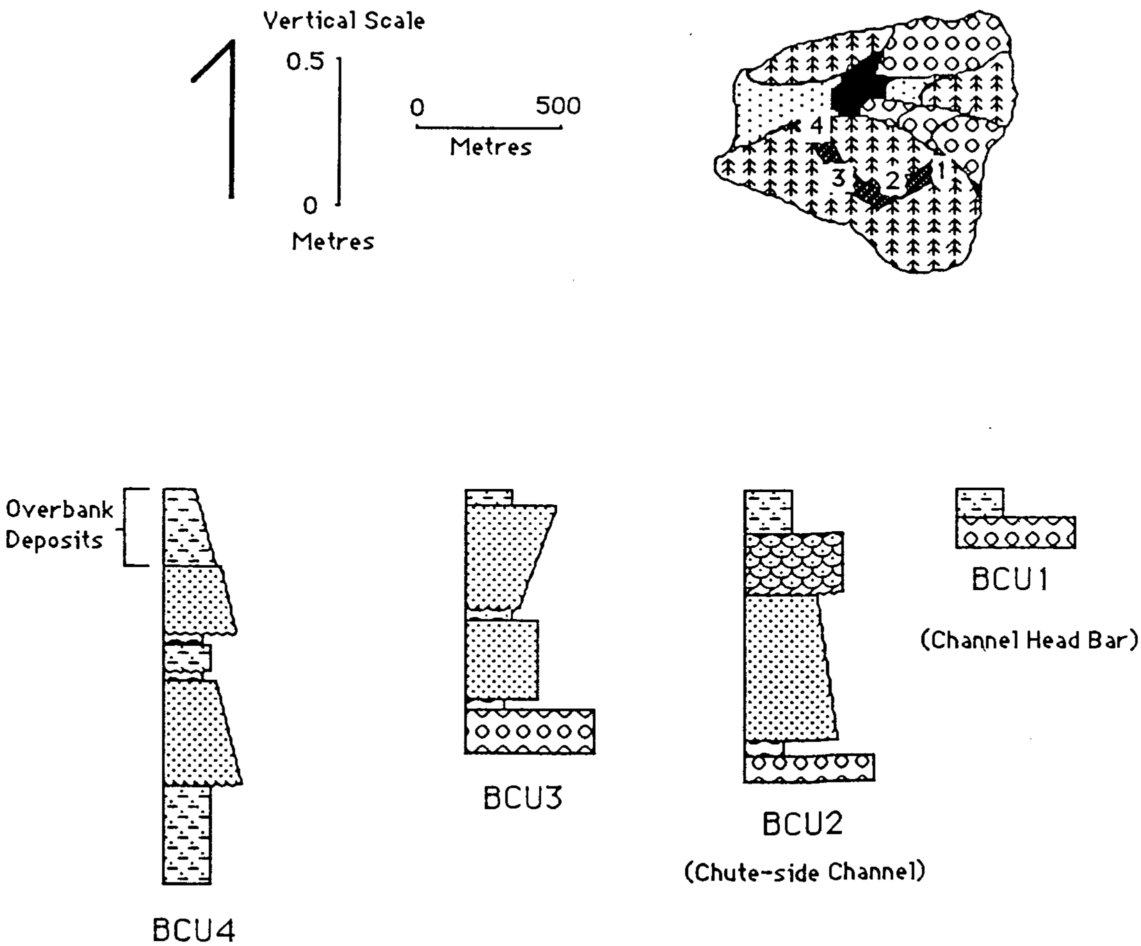
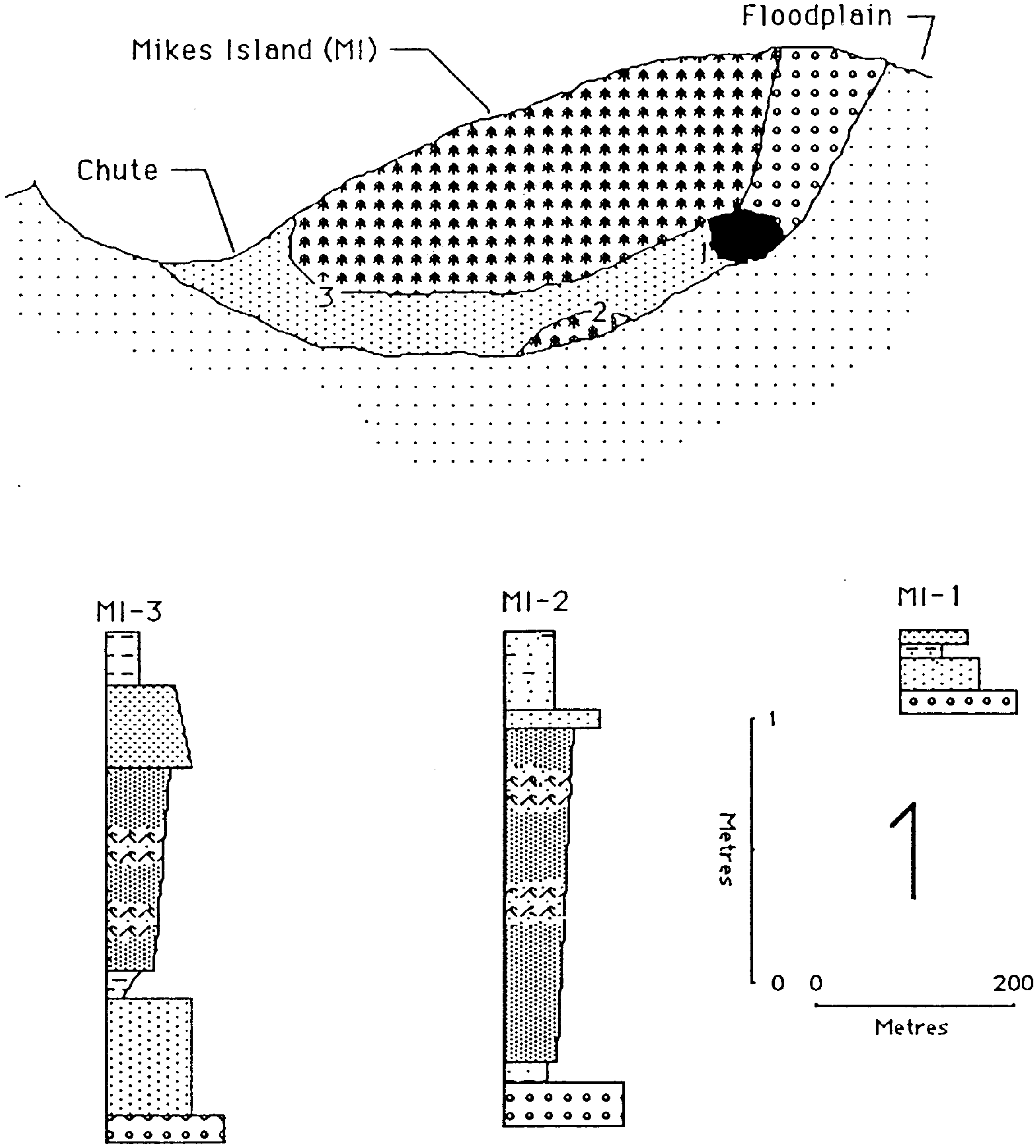


Figure 5.8 Sedimentology of the Infilling Chute Adjoining Mike's Island (MI)



the class 2 chute. Note that the chute on BCU (Fig. 5.7) is now connected to an adjoining chute although when it was active it must have had its head with access to the main river.

It seems, therefore, that once a chute is created, the infill mechanism is not dependent on the class of chute.

The cap of overbank fines in each infilled chute (BCC, Fig. 5.6, BCU, Fig. 5.7) was a significant finding. Only these two chutes of all those studied in the active channel zone were found to be at this advanced stage of infilling. The silt cap covering the chutes of BCC and BCU are the first indication of vertical accretion (overbank) deposits.

Although the beds of sediment discussed thus far are deposited vertically upon one another, the effect is to infill a chute and accrete an island to the floodplain laterally. The deposits could therefore be arguably described as lateral accretion deposits. Thus, in this type of environment the terms lateral and vertical accretion deposits may be redundant. Overbank deposits however, may be a useful term and can be defined as silt and very fine sand deposits laid down when the river overtops the banks of islands and floodplain. These deposits are defined for practical purposes as the units of silt and/or very fine sand from the surface of the chute, island or floodplain down to the first sand bed in the vertical sequence.

Desloges and Church (1987) found overbank deposits further back on the floodplain of the wandering Bella Coola River in sequences up to 1.5 metres thick. On the Fraser, silt and fine sand beds cap older islands and infilled chutes. The deposition of 30-50 cm of thinly laminated silt with minor amounts of very fine sand in the infilled chute is the final stage in the accretion of two islands or an island to the floodplain (Figs. 5.6, 5.7). On the floodplain overbank fines are found to accumulate to depths of greater than 150 cm.

Once the overbank fines begin accumulating the chute is normally invaded by vegetation and is abandoned. A swale, often from 50-150 cm in depth is left to provide evidence of the paleochannel.

5.2 Discussion and Depositional Model of Chute Infill

The sedimentary infill of seven chutes were investigated by the excavation of 28 pits. These pits, as well as the geomorphological findings (section 4.2) will be used in the following discussion of the infill of chutes in the active channel zone. Following this discussion a model for chute infill is proposed.

5.2.1 Discussion of Chute Infill

As water flows from a primary channel into a chute there is a reduction in competence and a bar (gravel or sand) is deposited at the head of the chute. Once the bar is initiated, subsequent flows must overtop the bar to deposit sands in the chute. Each flood event, if it is large enough to overtop the chute-head bar, may partly erode the bar prior to depositing more sediment (Fig. 5.1a). Therefore, with net sedimentation, the chute-head bar builds vertically to island surface level and seals off water from entering the chute except in times of very high flood.

Flood waters overtopping the bar will deposit material in the chute itself. The sands in the chute usually occur as laterally continuous sand sheets which are massive to thinly laminated and are horizontally bedded (facies Sh). Occasionally, in a class 1 chute or where two chutes merge (Figs. 4.1, 5.2), dunes may be formed (Fig. 4.10). The resultant planar (Figs. 5.2, 5.3) or trough (Figs. 5.1b, 5.7) cross-bedded sands (facies Sp, St) are occasionally preserved. Ripples are also found on the beds of these chutes but are rarely preserved. Although facies St, Sp and Sr are found in the sediments of active and abandoned chutes, facies Sh is by far the most common.

The material deposited in the chute normally consists of medium to coarse sand in the lower part of the sequence and then fines upwards to a fine sand. Although there is no consistent upward transition in grain size from bed to bed, there is a general fining upwards of the sediments. Sediments also tend to fine in the down-chute direction although to a large extent this is due to deposition of backwater fines (Figs 5.2b, c, d).

During periods of moderate flood, water is blocked from entering the chute by the chute-head bar. Since the tail of the chute is much lower than the head, water is able to enter the chute from the downstream end. This water however, is a backwater with very low energy. The backwater moves up the chute to an elevation controlled by the river stage. This low energy backwater deposits laminae of silt and/or very fine sand. Since the flood waters may overtop the chute-head bar only each 2 years on average (level of bankfull stage for young islands, McLean and Mannerstrom, 1985), thinly deposited laminae have the opportunity to build, with thicker sequences at the chute tail, thinning toward the chute centre and pinching out before the chute head. The virtual nonexistance of silt beds at the head of the chute shown in Figure 5.1b and the thickening of the silt beds toward the tail (Fig. 5.1d) display this point clearly.

Once flood water passes over the chute-head bar, secondary currents generated by accelerating water create a scour hole (Figs. 4.1, 4.2, 5.2, 5.7, 5.8). From this scour hole a narrow chute-side channel carries most of the flow and is kept clear of sediment by the water it carries while the rest of the chute infills. When the chute-side channel finally fills in, it does so with a thick fining upwards bed of sand (Fig. 5.1c) probably as a result of one flood event.

When the chute has infilled to near island top elevation, the sequence is capped with a bed of overbank silts and very fine sands (Figs. 5.6, 5.7). These fines are often thinly laminated and are quickly vegetated. The chute is then abandoned and a swale is left as evidence of the paleochute.

5.2.2 A Model of Chute Infill

Figure 5.9 shows a model of the infilling of chute channels in a simplified form. The main diagnostic features are as follows:

1) Stages 1 and 2 : A bar develops at the head of the chute which seals the chute from all but floodwater flows. This bar may be composed of sand (class 3 chute), gravel (class 2 chute) or gravel lobes occupying 50 per cent or more of the channel (class 1 chute).

Figure 5.9 Infilling of Chutes and Channels in the Wandering Reach of the Fraser River, Near Chilliwack, B.C.

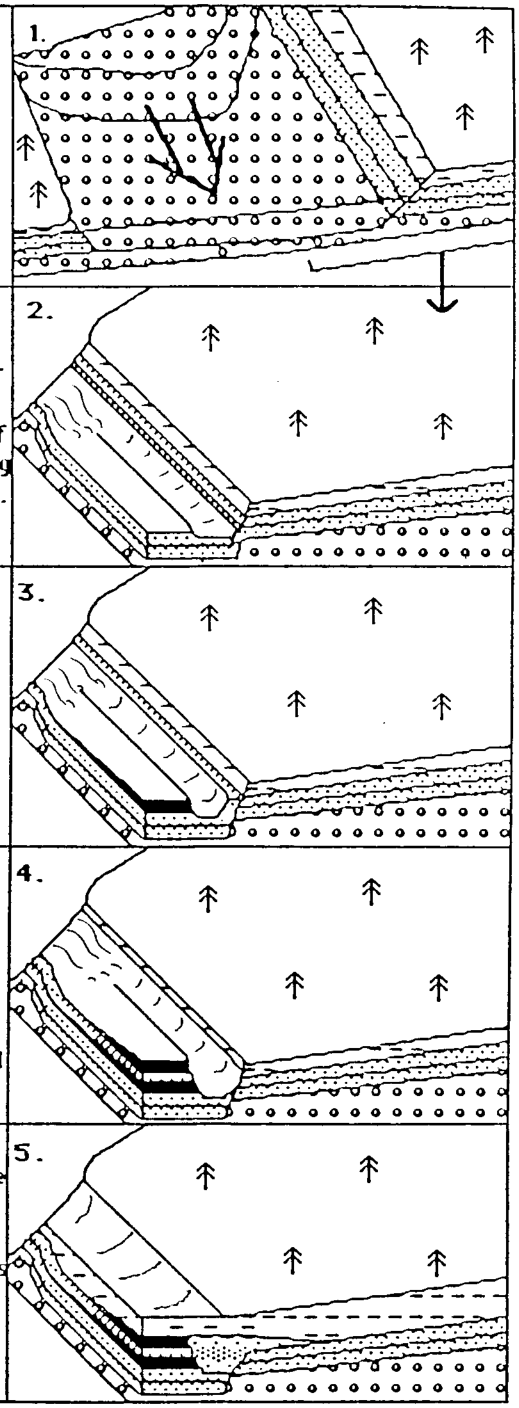
1. Diffuse gravel sheets (lobes) move down the channel between two islands or between island and the floodplain during flood creating a shallow chute.

2. A sand or gravel bar or slugs of gravel plug the head of the chute and allow only floodwater to enter the chute. The chute head bar aggrades and sheets of sand carried over the bar during flood are deposited in the chute.

3. The lower portion of the chute is covered with beds of silt between major floods. These beds are deposited by backwater during floods which are unable to over top the chute head bar.

4. Beds of flood sands and backwater silts continue to aggrade in the chute. The majority of the flood flow and all of the rising and falling flood water in the chute is carried by a chute-side channel which is kept clear of sediment

5. The chute-side channel fills in with a fining up sequence and the entire chute is capped with overbank deposits of very fine sand and/or silt. The two islands have at this point accreted together or the island has accreted to the floodplain.



2) Sediments at the head of the chute are composed of relatively thick sequences of coarse material (fine-coarse sand) overlying gravel and with few interbeds of silt.

3) Stages 3 and 4 : Sediments down the chute become finer as floodwaters deposit sand in large sheets. Separating many of these sand sheets are wedges of fine material (silt and/or very fine sand) which are deposited from backwater entering the chute from the lower end. These wedges are thicker at the chute tail and pinch out up chute.

4) In cross-section, the sand and silt units pinch out at the side of the channel against the edge of the island. Island deposits dip toward the channel.

5) Stages 4 and 5 : A chute-side channel is kept clear of sediment by floodwaters until the chute has infilled with sand and then fills in with a single fining up sequence or occasionally with a silt plug (BCC1a, Fig. 5.6). The edge of the chute-side channel is typified by beds of the chute dipping toward the chute-side channel.

6) Stage 5 : Once the chute has infilled, the sequence is capped with a bed of overbank fines (very fine sand and silt) and becomes abandoned.

Investigations of all seven chutes support the development of this model and observations in other newly developing chutes also appear to agree with chute development in this manner.

CHAPTER SIX

GEOMORPHOLOGY AND SEDIMENTOLOGY OF THE FLOODPLAIN

6.1 Introduction

Chapters four and five have presented the chute infill processes in the active channel zone. It has been demonstrated that the infill of these chutes is an important mechanism for the attachment of islands to the floodplain. It was hypothesised that the floodplain has been constructed of islands which have accreted to the floodplain by accretionary processes which are similar to those processes presently occuring in the active channel zone (section 1.1).

Kellerhals and Church (in press) state that 'Particularly in cases where there are significant areas of genetic floodplain, one normally is justified in assuming that the appearance of the channel and floodplain reflect presently active processes.' The floodplain in the study area (Fig. 1.2) may be classed as an active or genetic floodplain (Williams, 1978).

In the active channel zone, once a chute has infilled and the island is attached to the floodplain, there is a small depression where the former chute flowed. This paleochute does not appear to completely fill in during subsequent flooding events but leaves a ridge and swale topography that outlines past chute locations. Desloges and Church (1987) also found abandoned channels across the floodplain of the wandering Bella Coola River.

Nanson (1980) found that ridge and swale topography, in a meandering environment, was not only preserved but that there was as much deposition on ridges as in swales over time. This is contrary to some other floodplain research. For example, Alexander and Prior (1971), Kesel et al (1974) and Roberts (pers. comm.) have demonstrated that swales tend to fill in more rapidly with vertical accretion deposits than do ridges so that floodplain relief tends to diminish away from the active channel.

This chapter will present the geomorphic and sedimentologic results of this study for the floodplain. The geomorphology of the floodplain is first discussed (section 6.2) and emphasizes: i) variations in the relief of the floodplain surface (section 6.2.1) and ii) the cross-valley profile of the floodplain (section 6.2.2). A second section describing the sedimentology of the floodplain (section 6.3) is then discussed and deals with: i) the sedimentology of each of the three (Fig.1.2) floodplain zones (sections 6.3.1-6.3.3) and ii) summarizes and make comparisons between zones (section 6.3.4). Next, the floodplain is treated as a whole by considering the direction of floodplain construction (section 6.4). The final section (6.5) will compare the geomorphology (section 6.5.1) and the sedimentology (section 6.5.2) of the floodplain with the active channel.

6.2 Geomorphology of the Floodplain

6.2.1 Floodplain Relief

Inspection of any topographic or large scale planimetric map of the Fraser River floodplain in the Chilliwack area will show features that hint at floodplain construction by channel and chute infill and lateral accretion of islands. The proximal zone of the floodplain (zone 2, Fig. 1.2) is crossed by many sloughs. Some of these sloughs join the river channel at both ends while some are connected to the river only at their downstream end. These sloughs appear to delineate large islands so that it could be postulated that the river channel extends to the southern most slough and that the interstitial lands are islands in the channel. Indeed, many of the sections of land between the sloughs are given island designation by the National Topographic System (Fig. 6.1).

The two longest and southern most, discontinuous sloughs (Fig. 6.1) may still be continuous (ie. connect to the river at both ends) were it not for human interference.The Hope and Camp sloughs have both been sealed off for flood control purposes (District of Chilliwack Engineering- pers. comm.; Sinclair, 1961; McLean and Mannerstrom, 1985). The Camp slough is regulated by a control gate at its upstream end so that flood waters can be prevented from entering the slough.

Inspection of NTS topographic sheets 92H/4d,e,f and 92G/1h reveal contouring suggestive of ridge and swale topography, possibly outlining other previous islands across the floodplain. The availability of large scale (1:5000) floodplain mapping made detailed topographic surveys for the study area possible. From these orthophotos a floodplain geomorphology map showing the swales and paleochannels was created and is presented in Figure 6.1.

The map of floodplain geomorphology has two important components. The first component is the curvelinear appearance of many of these swales. If the swales were extended, they could possibly outline previous islands.

Secondly, when the swale topography outlined in Figure 6.1 is compared with the zones previously shown in Figure 1.2 the zonation is clearly defined geomorphically. Zone 1 (Fig. 1.2) is clearly the active channel displayed in Figure 6.1. Zone 2 (Fig.1.2) is defined by the existence of active sloughs and a high density of swales (Fig. 6.1). Zone 3 (Fig. 1.2) is defined by the lack of active sloughs and the presence of a high density of swales (Fig. 6.1). This zone is also fortuitously bounded on the south by the Trans-Canada highway. Zone 4 (Fig. 1.2) is defined by the lack of active sloughs and the presence of a low density of swales (Fig. 6.1).

Related to the distinction between floodplain zones discussed above, is the differences in surface relief between the ridges and swales in each zone. Zone 2 (proximal floodplain) averages approximately 13.2 metres above sea level (masl) along the ridges and 11.8 masl in the swales. Average relief differences between ridge and swale is 1.4 m. In zone 3, the mid portion of the floodplain, ridges average 12.5 masl and swales average 11.6 masl with a relief difference average of 0.9 m between ridge and swale. In zone 4, the distal portion of the floodplain, ridges average 10.6 masl and swales 9.9 masl. Average relief difference between ridge and swale is 0.7 m. These data reveal a reduction in floodplain relief with distance from the active channel. Also clear from these data is a reduction in elevation from the proximal floodplain zone (11.8-13.2m) to the distal floodplain zone (9.9-10.6m).

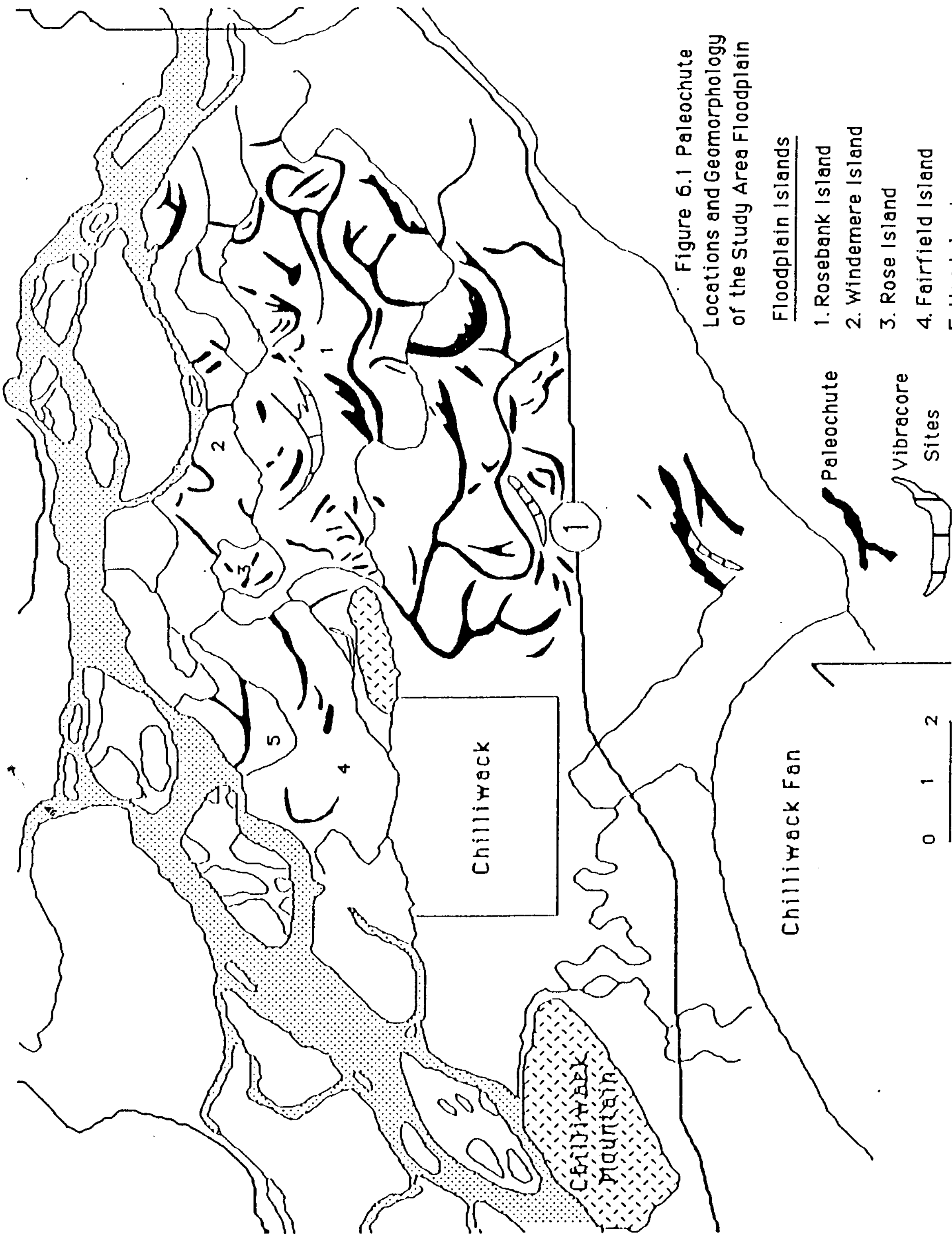


Figure 6.1 Paleochute Locations and Geomorphology of the Study Area Floodplain

6.2.2 Cross Floodplain Profile

Stable alluvial floodplains are considered to be nearly horizontal or slightly tilted toward the channel. This factor is rarely stated but is implicit in all lateral aggradation models (Allen, 1965). Schumm (1968, 1985) and Leopold and Bull (1979) suggest that a stable channel is one that shows no vertical aggradation (ie., is horizontal) and does not change slope, dimensions or shape. None of these conditions, however, preclude lateral migration, a point that Schumm (1985) states explicitly.

In order to determine the cross floodplain differences in elevation, the bottom of the swales selected for the vibracore sites (Fig. 6.1) were chosen for comparison. Swale bottoms were chosen so that similar geomorphic positions in each zone would be compared.

The Fraser River follows an average course of 249° azimuth from Hope to Hatzic Lake. For purposes of this study, it is assumed that the floodplain has grown orthogonally to the average river course (249°) over time. This assumption, however, is not strictly accurate. The piecemeal manner in which islands are attached to the floodplain and the wandering of the river thalweg over time means that a constant orientation of floodplain growth probably does not exist. An average orientation for floodplain growth (249°) is therefore the best available estimate. Cross-floodplain slopes are measured orthogonally to the direction of river orientation (249°) while floodplain slope is measured downstream along this orientation.

McLean and Mannerstrom (1985) found that the Rosedale Reach of the river presently has a slope of 0.00047 while the Chilliwack Reach has a lower slope of 0.00018. From the available orthophotography it was found that the slope of the middle of the floodplain between the proximal zone sites and the mid floodplain zone sites along the 249° orientation is 0.00047.

Since the vibracore sites (Fig. 6.1) were not located along the same orthogonal to the slope of the floodplain (249°), some deviation from the same elevation would be expected across a horizontal floodplain. The expected differences in elevation between the sites due to the slope of the floodplain are shown in Table 6.1. Variation from expected elevation as well as the differences found for the centre of the chute as averaged for each site are also shown in Table 6.1. The variation from expected elevation was calculated by subtracting the expected difference from the difference in elevation found between each site.

The swale bottoms of the distal site average 1.2 metres elevation lower than expected in comparison with the swale bottoms of the proximal site. The swale bottoms of the mid floodplain site are 0.8 metres higher than expected compared to the distal site and 0.4 metres lower than expected compared to the proximal site. This reaffirms the assertion that the floodplain is tilted away from the river and suggests that aggradation has taken place as the channel has shifted northward.

6.3 Sedimentology of the Floodplain

Zones 2, 3 and 4 (Fig. 1.2) represent the study area floodplain. A discussion of their geomorphic boundaries was presented in section 6.2.1. A study of sediments across the floodplain was designed so that one swale in each of these zones would be sampled (vibracore sites, Fig. 6.1). The following discussion deals with the sedimentology of the sampled swales in the proximal, mid portion and distal zones of the floodplain.

6.3.1 Zone 2 - Proximal Floodplain

Figures 6.2, 6.3 and 6.4 show the results of the vibracore boreholes in the proximal floodplain zone. A general fining upwards sequence is evident in each of the cores. The lower portion of each core consists of massive beds of fine to medium sands occasionally interbedded with massive to thinly laminated, very fine sand and silt. There is no systematic upwards transition in sediment size from bed to bed but the overall trend is to fine upwards. Bed contacts are most commonly erosional. In each core the sand sequences are capped with one to three metres of overbank silts and very fine sand.

The interbedded silts and very fine sand are found more often and occur in thicker units in the VeF cores (Fig. 6.4) than in the MF cores (Fig. 6.3) which are in turn more predominant than in the VF cores (Fig. 6.2). The presence of peat units in MF-3 and VeF-3

Table 6.1 Floodplain Swale Elevations for Study Location (Vibracore) Centrelines.

Site	Centre Elevation (masl)		Sediment Thickness
	Gravel (est.)	Surface(meas)	
VF-3	9.6	12.5	2.9
MF-3	8.8	11.9	3.1
VeF-3	9.0	12.0	3.0
Prox. Av.	9.1	12.1	3.0
BFA-3	7.7	11.2	3.5
BFB-3	7.9	11.0	3.1
BFC-3	8.1	11.3	3.2
Mid. Av.	7.9	11.2	3.3
KFC-3	6.6	9.2	2.6
KFA-3	5.2	9.3	4.1
KFB-3	5.7	9.4	3.7
Dist. Av.	5.8	9.3	3.5
	Difference in Av. Elevation(m)		Expected Diff .00047 Slope
Prox-Mid	1.2	0.9	0.48
Mid-Dist	2.1	1.9	1.08
Prox-Dist	3.3	2.8	1.56
	Variation from Expected (m)		
Prox-Mid	+0.7	+0.4	
Mid-Dist	+1.0	+0.8	
Prox-Dist	+1.7	+1.2	

Figure 6.2 A Profile Across a Swale in the Proximal Floodplain Zone. Vaughan Farm Vibracore Boreholes - VF 1-5.

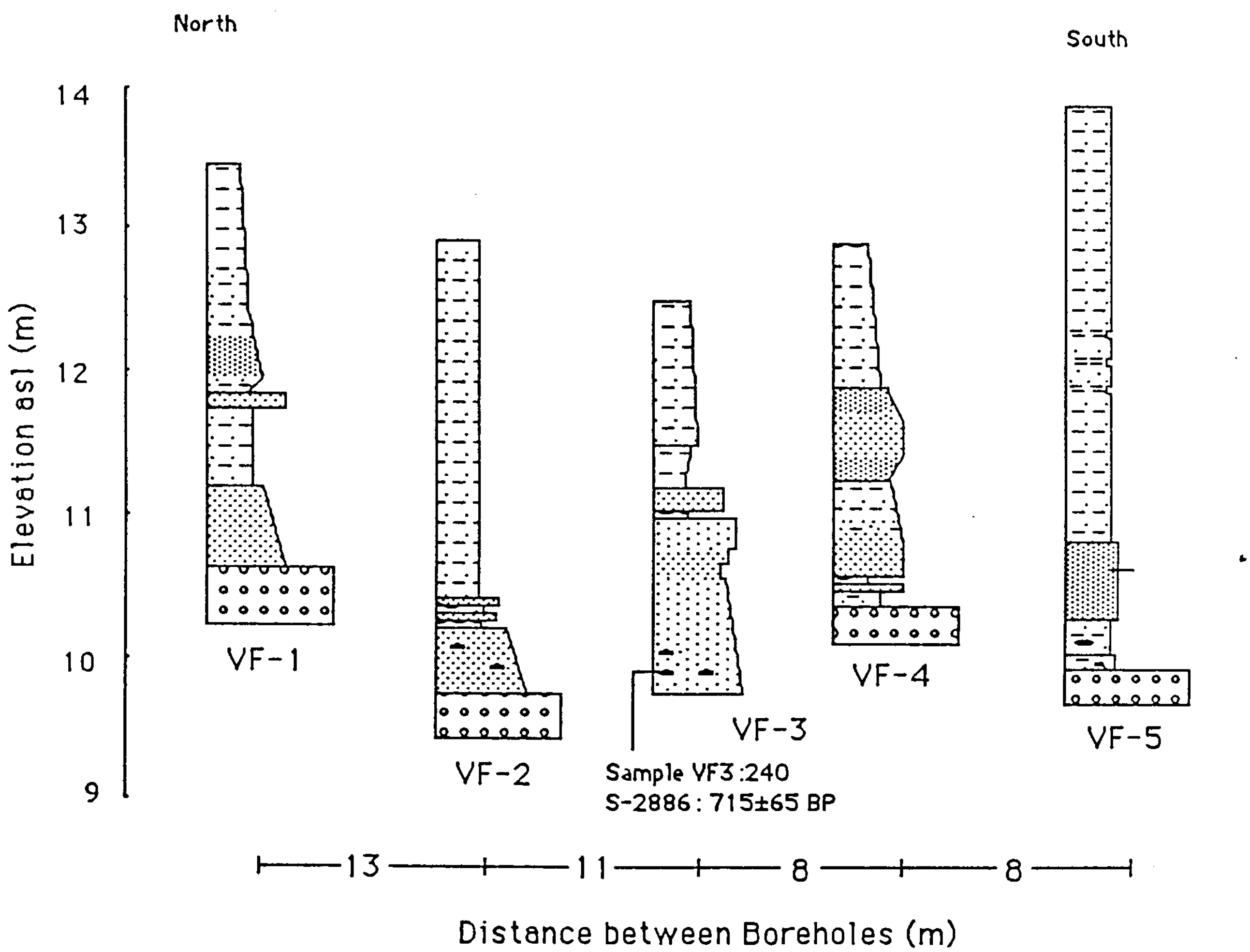


Figure 6.2a Vaughan Farm: The Stratigraphic Cross-section: Interpretation Based on Vibracore Boreholes (Fig. 6.2).

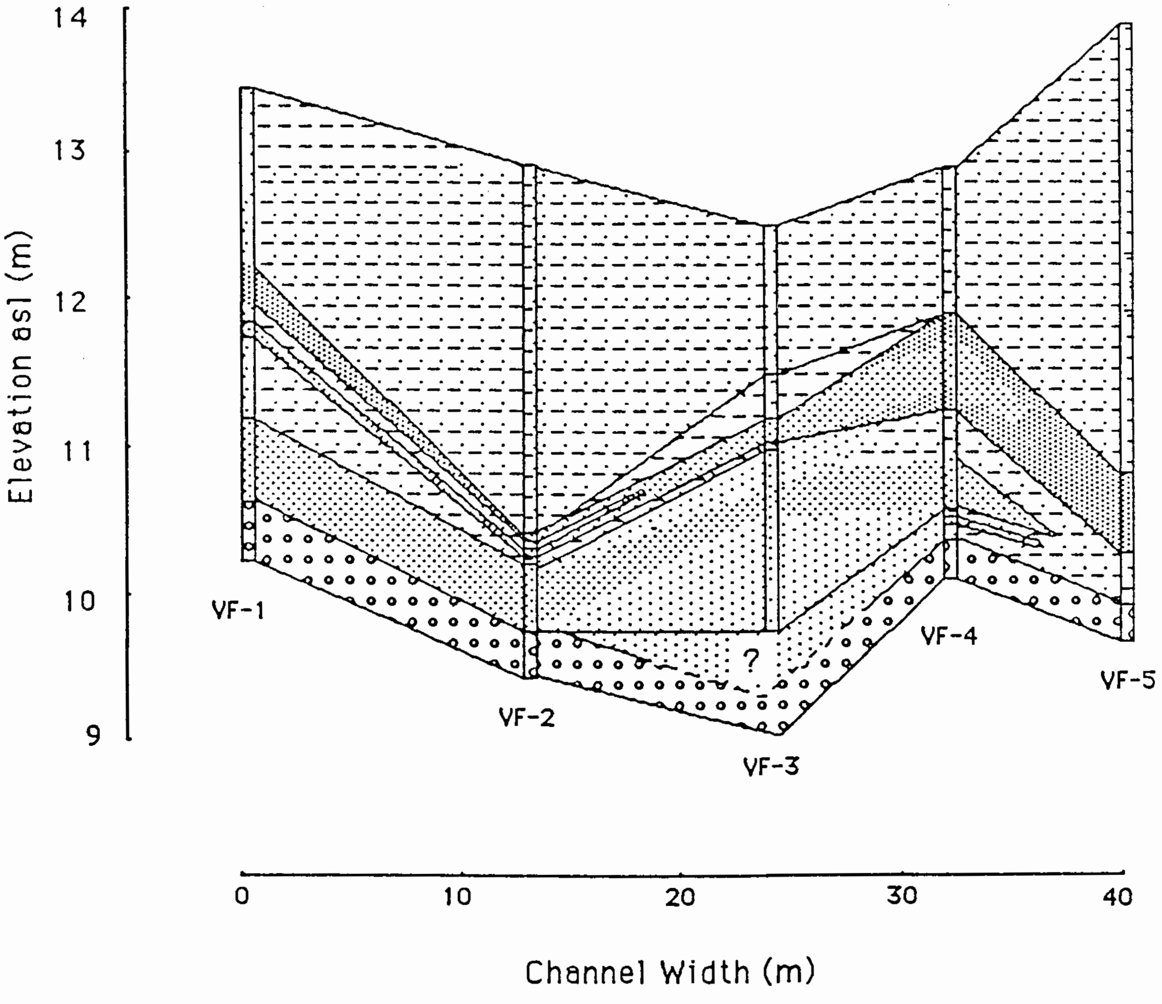


Figure 6.3 A profile Across a Swale in the Proximal Floodplain (Zone 2). Muxlow Farm Vibracore Boreholes MF 1-5.

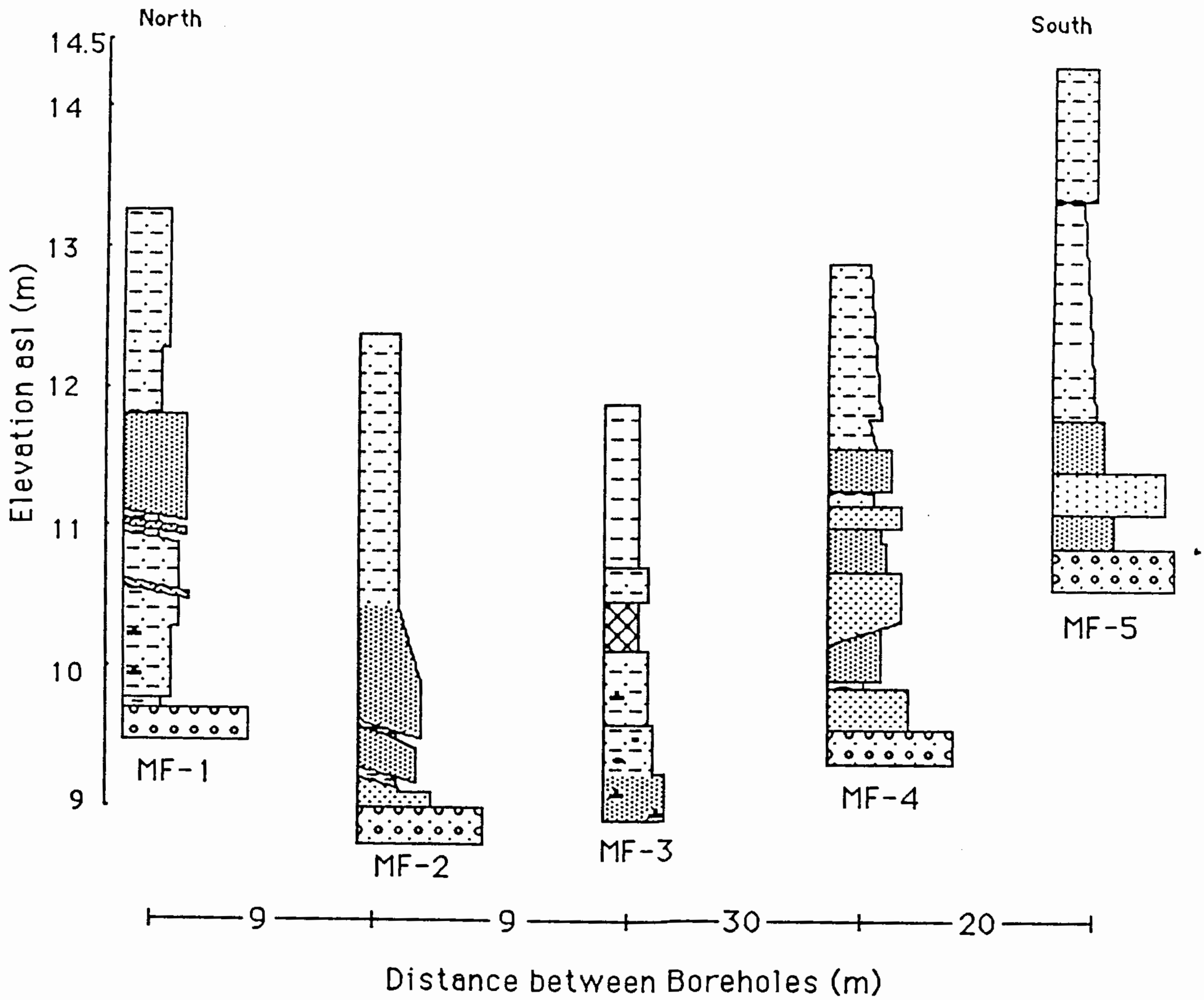


Figure 6.3a The Stratigraphic Cross-section at Muxlow Farm: Interpretation Based on Vibracore Boreholes (Fig. 6.3).

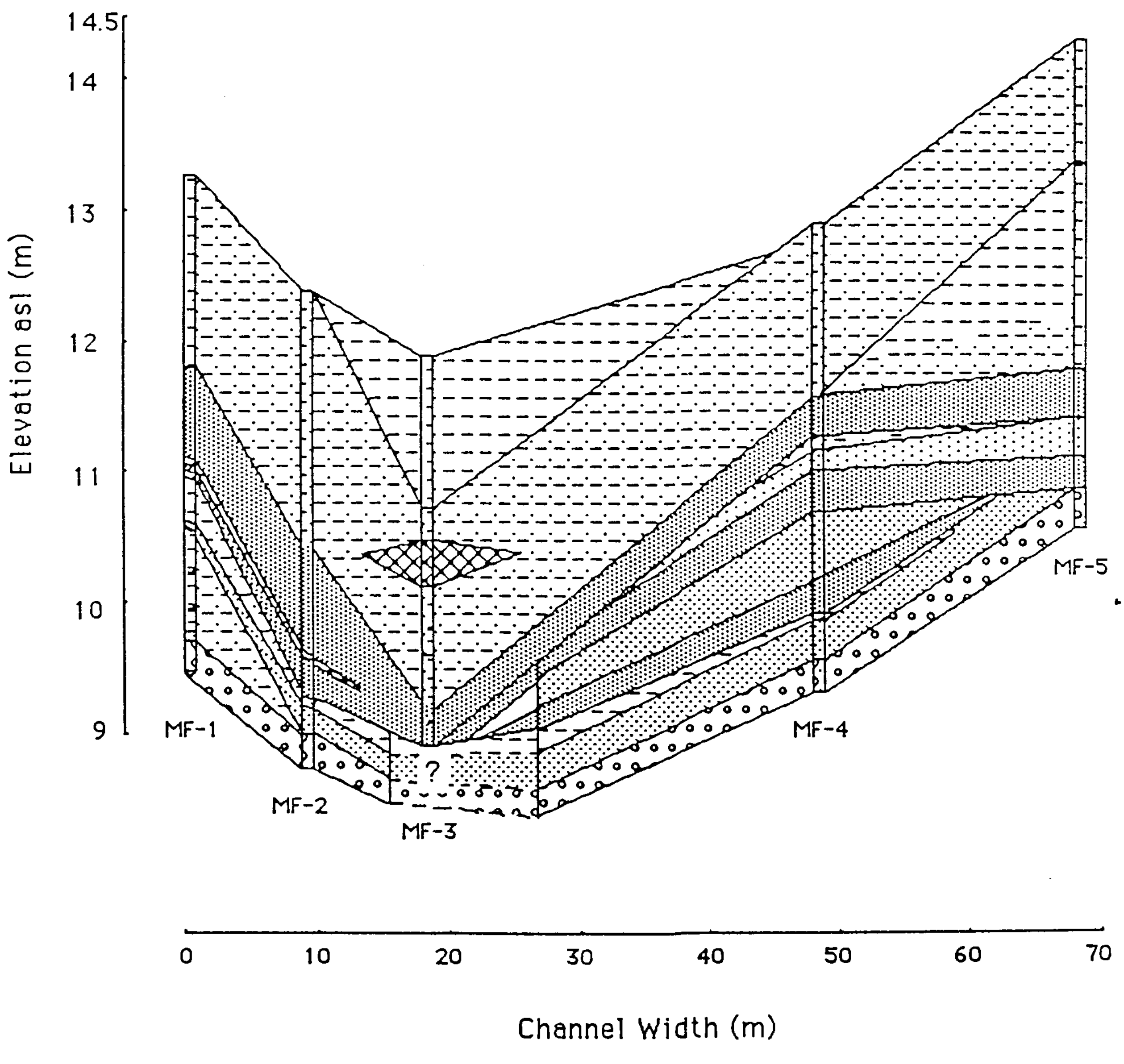


Figure 6.4 A profile Across a Swale in the Proximal Floodplain (Zone 2). Verschuur Farm Vibracore Boreholes VeF 1-5.

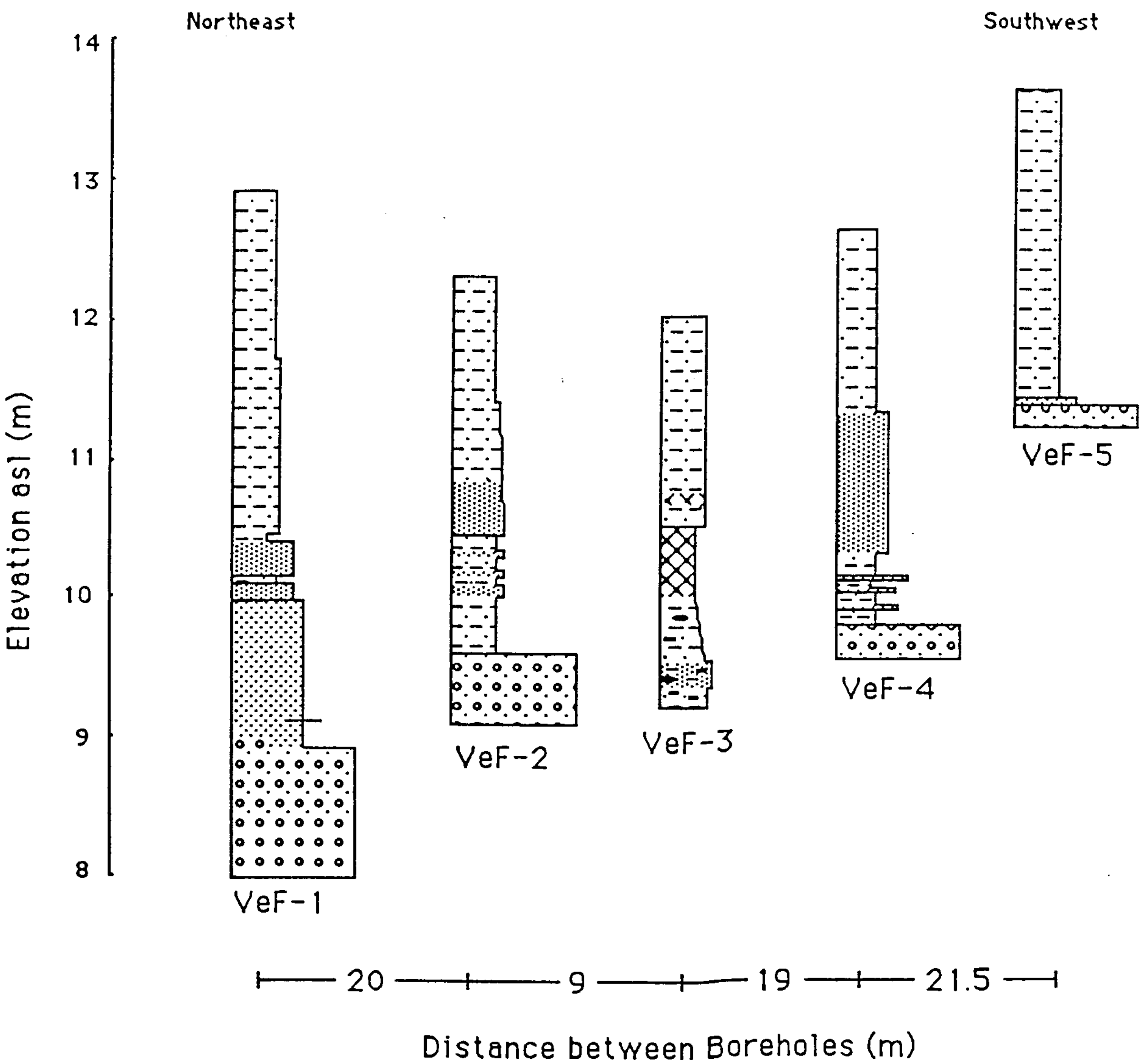


Figure 6.4a The Stratigraphic Cross-section at Verschuur Farm: Interpretation Based on Vibracore Boreholes (Fig. 6.4).

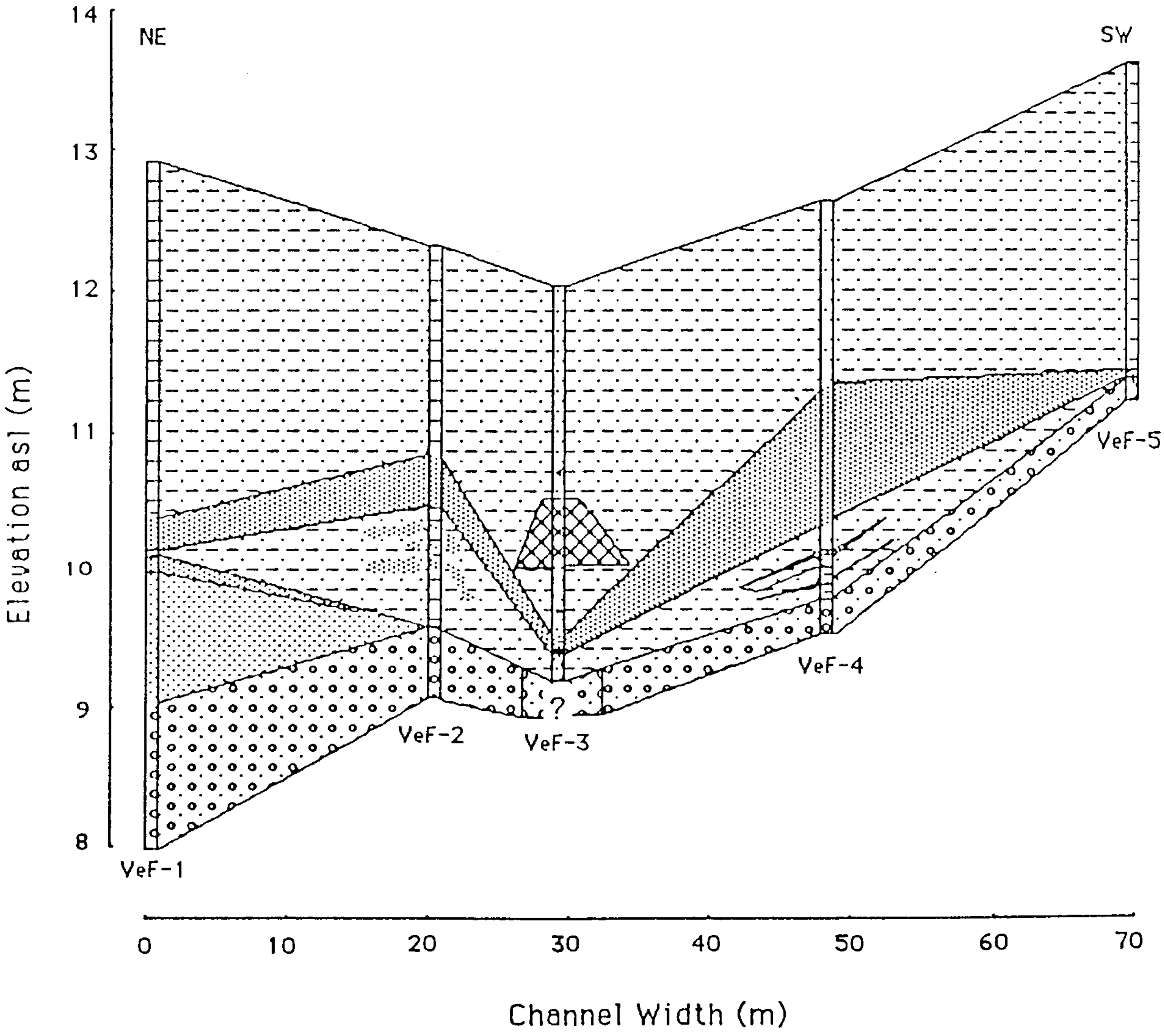
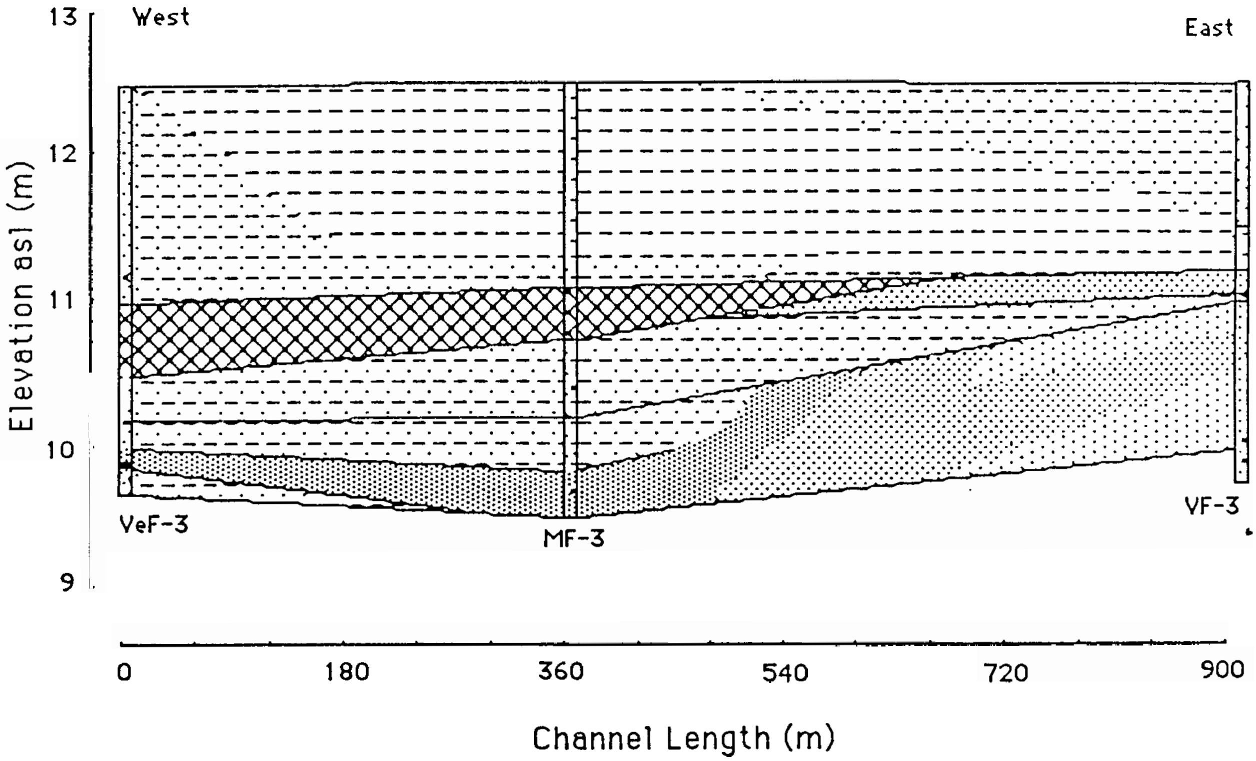


Figure 6.5 A Cross-section Along the Chute Centre, Proximal Floodplain Zone (2): Based on Interpretation of Cores VF-3, MF-3, VeF-3.



are indicative of a surface depression in the downstream portion of this paleochute which must have existed after abandonment and prior to being capped with overbank fines.

Excepting VeF-1, all VeF cores (Fig. 6.4) appear to consist of units of silt and very fine sand with thinner units of coarser sand interbedded while the VF cores (Fig. 6.2), excepting VF-5, appear to consist of units of coarser sand with thinner units of very fine sand and silt interbedded. The MF cores (Fig. 6.3) lie in between these two extremes with a tendency to be more like the VF cores. These observations show that there is a tendency for sediment to fine down-chute from VF to VeF.

Interpretation of the core data was made by connecting beds felt to be laterally continuous. These interpretations are shown in Figures 6.2a, 6.3a, 6.4a and an interpretation along the chute centre is displayed in Figure 6.5. Care should be exercised in using these interpreted data since the shape and extent of individual beds may not be as shown.

Bearing this in mind, there are a number of issues that can be illlustrated by Figures 6.2a, 6.3a, 6.4a and 6.5. Cores VF-2 (Fig. 6.2a), MF-3 (Fig. 6.3a) and VeF-3 (Fig. 6.4a) show the location of an infilled chute-side channel. In the cross-section (Figure 6.2a), the surface expression does not mirror the subsurface topography below the overbank fines so that without the cores, the chute-side channel would not be apparent. The past existence of the chute-side channel is shown in MF-3 and VeF-3 by the presence of the water derived peats. The dipping of the MF-2 beds toward MF-3 provides a further clue to the presence of a chute-side channel (Fig. 6.3).

Another feature of these cross-sections is the wedging out of various beds. The VF and MF cross-sections show at least one bed of silt in each pinching out at the chute edge. The VF, MF and VeF cross-sections show sandy beds at the chute edges pinching out toward the chute-side channel. This thinning or pinching out of silt and sand beds shows the edge of the chute (silt beds) and chute-side channels (sand beds).

The slope of the chute and the fining down-chute of sediment is illustrated in Figure 6.5. In this chute centre profile is shown the abundance of silt and very fine sand and especially the overbank fine portion of the sequence. Although the gravel base was not found in these cores, there is reason to believe that it is within a half a metre at each site. If this is the case, then the above gravel profile is dominated by the overbank fraction.

6.3.2 Zone 3 - Mid-floodplain

The results of the vibracoring program in the midfloodplain zone are shown in Figures 6.6, 6.7 and 6.8. In these profiles, the following features have similarities with the proximal zone and therefore will not be explained in detail here :

i) Each core generally fines upwards from massive coarser sands, to massive to thinly laminated finer sand and silt although there is no consistent upward transition of sediment size from bed to bed. Contacts between the beds are generally erosional.

ii) Each sequence is capped with overbank fines ranging in thickness from 30 to 130 cm;

iii) Interbedded silts and very fine sands are found more often and in thicker units in the BFC (Fig. 6.8) cores than in the BFB (Fig. 6.7) cores which in turn are more predominant than in the BFA (Fig. 6.6) cores;

iv) There is a tendency for sediments to fine down-chute from the BFA cores to the BFC cores with the BFB cores lying in between with a tendency to be more like the BFC cores.

Cross-swale sections are displayed in Figures 6.6a, 6.7a, 6.8a and 6.9. Again, caution is advised in the literal use of these diagrams . The following features are similar to the proximal floodplain zone. The details of these features have been explained previously and need not be discussed again in detail: i) The chute-side channel is shown at BFA-4, BFB-4 and BFC-4 (Figures 6.6a, 6.7a and 6.8a). In all of these cases the surface expression does not mirror the subsurface depression; ii) As in the proximal zone, some of the lenses pinch out toward the side of the chute and some of the coarse sand beds pinch out toward the channel and chute-side channel (eg. BFB-4 - BFB-2, BFB-4 - BFB-5). Again, further evidence for these chute and chute-side channel edges are shown in BFB-1 and BFB-2 (Fig. 6.7) and BFC-5 (Fig. 6.8) where some of the beds dip toward the chute.

Figure 6.6 A profile Across a Swale in the Mid Floodplain (Zone 3). Birkholz Farm, East Site (A) Vibracore Boreholes - BFA 1-5.

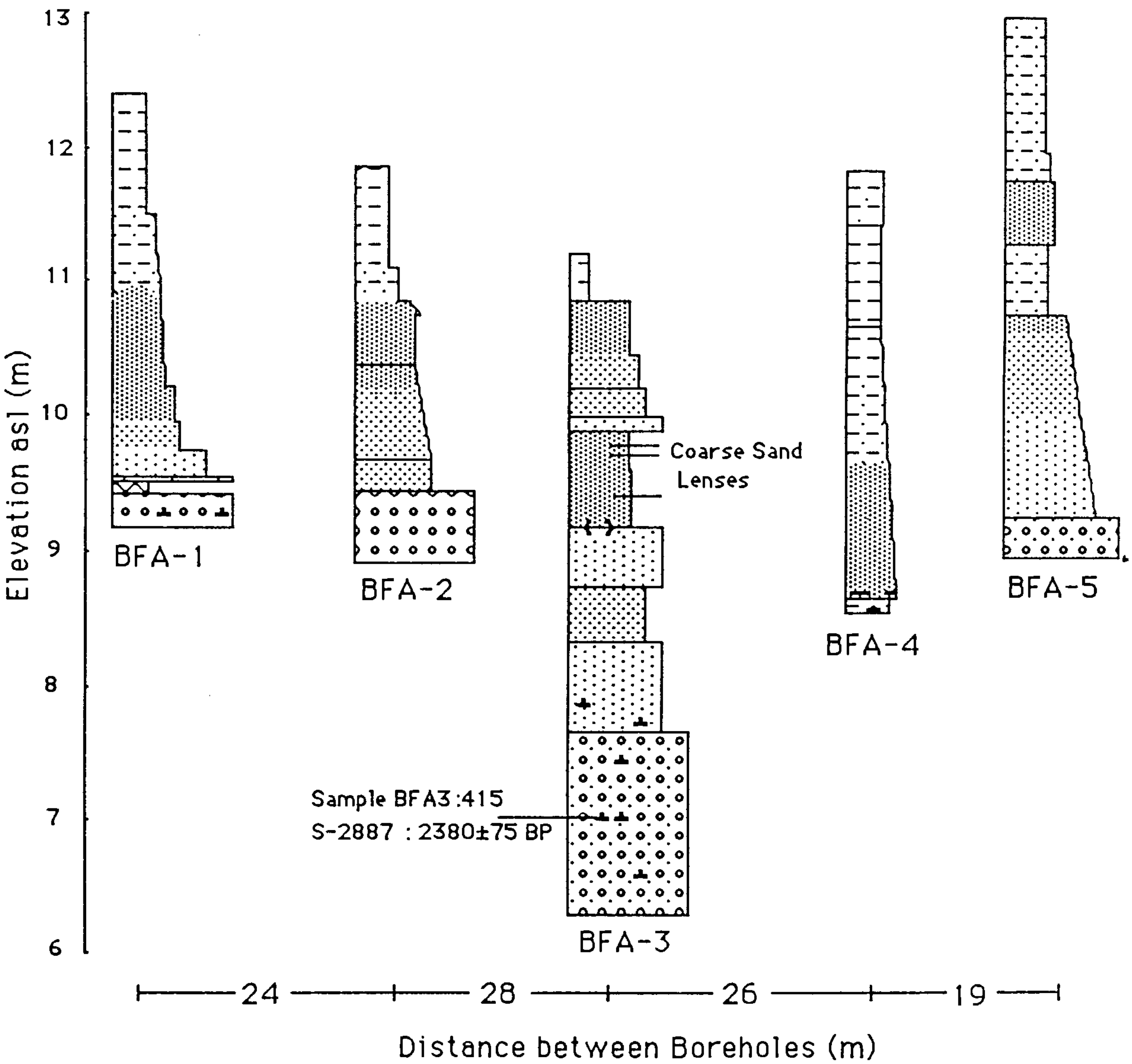


Figure 6.6a A Stratigraphic Cross-section at Birkholz Farm, Site A: Interpretation Based on Vibracore Boreholes (Fig. 6.5).

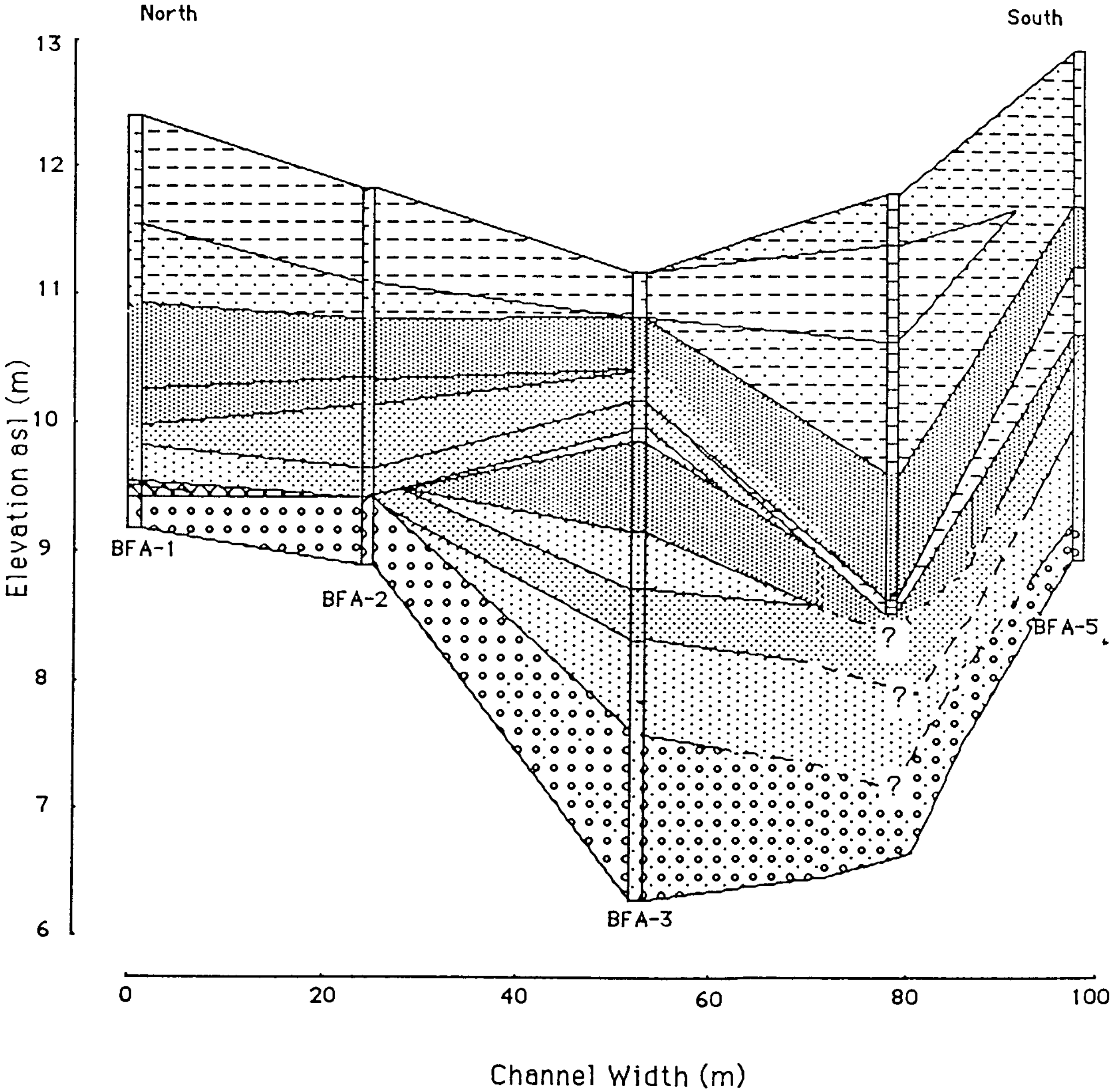


Figure 6.7 A Profile Across a Swale in the Mid Floodplain (Zone 3). Birkholz Farm, Middle Site (B), Vibracore Boreholes - BFB 1-5.

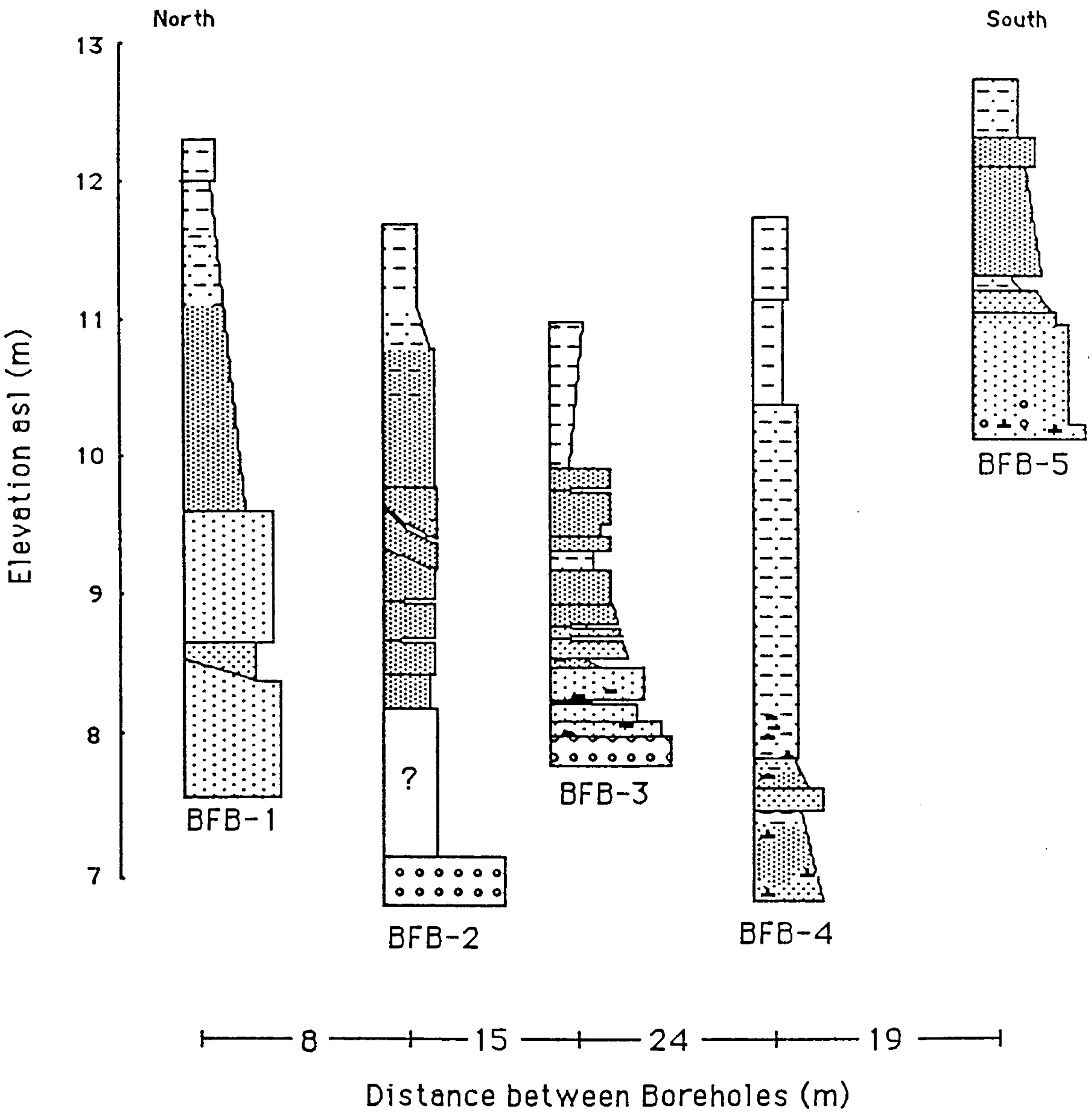


Figure 6.7a A Stratigraphic Cross-section at Birkholz Farm, Middle Site (B): Interpretation Based on Vibracore Boreholes (Fig. 6.7).

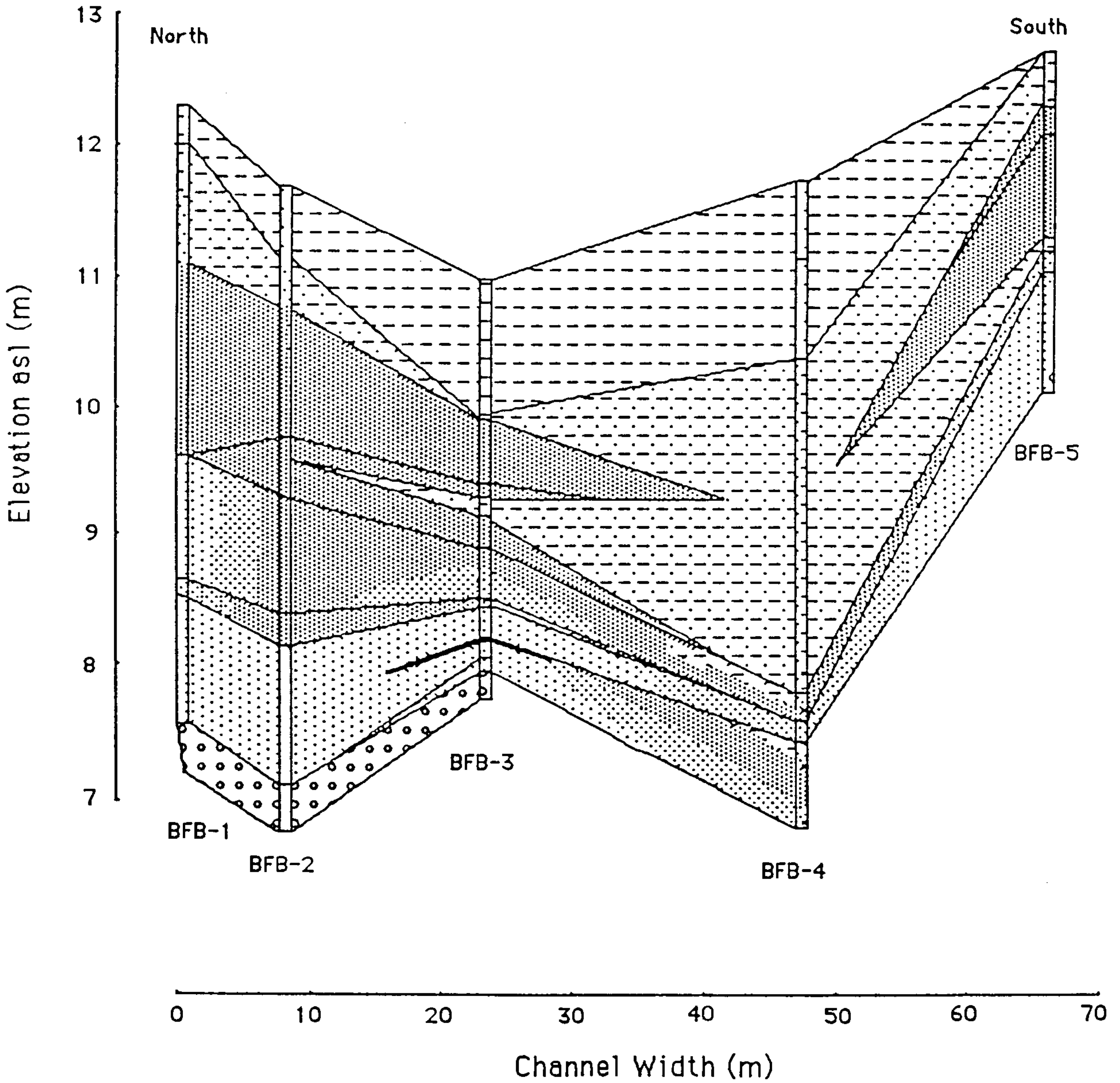


Figure 6.8 A Profile Across a Swale in the Mid Floodplain (Zone 3). Birkholz Farm, West Site (C), Vibracore Boreholes - BFC 1-5.

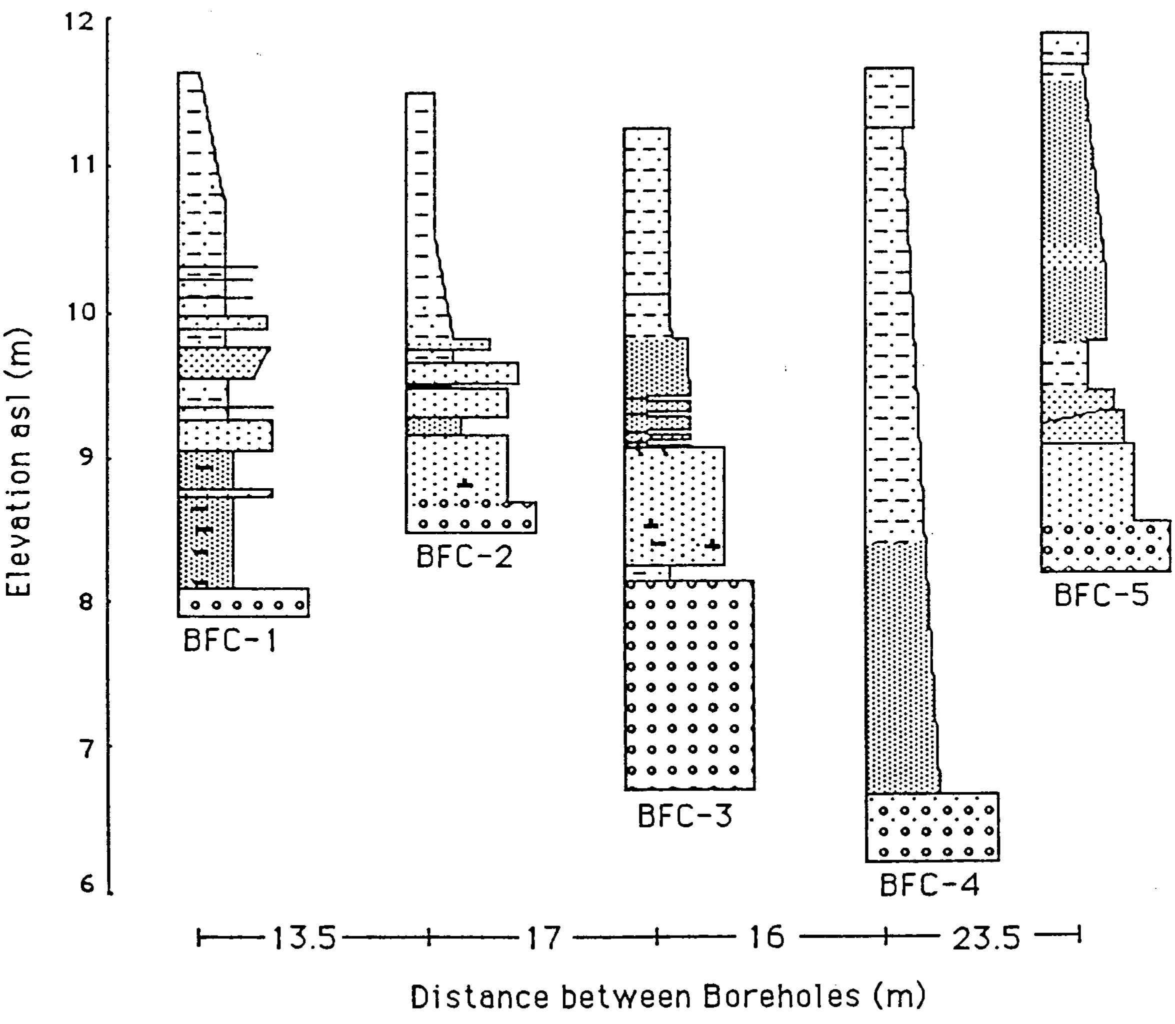


Figure 6.8a The Stratigraphic Cross-section at Birkholz Farm, West Site (C), Interpretation Based on Vibracore Boreholes (Fig. 6.8).

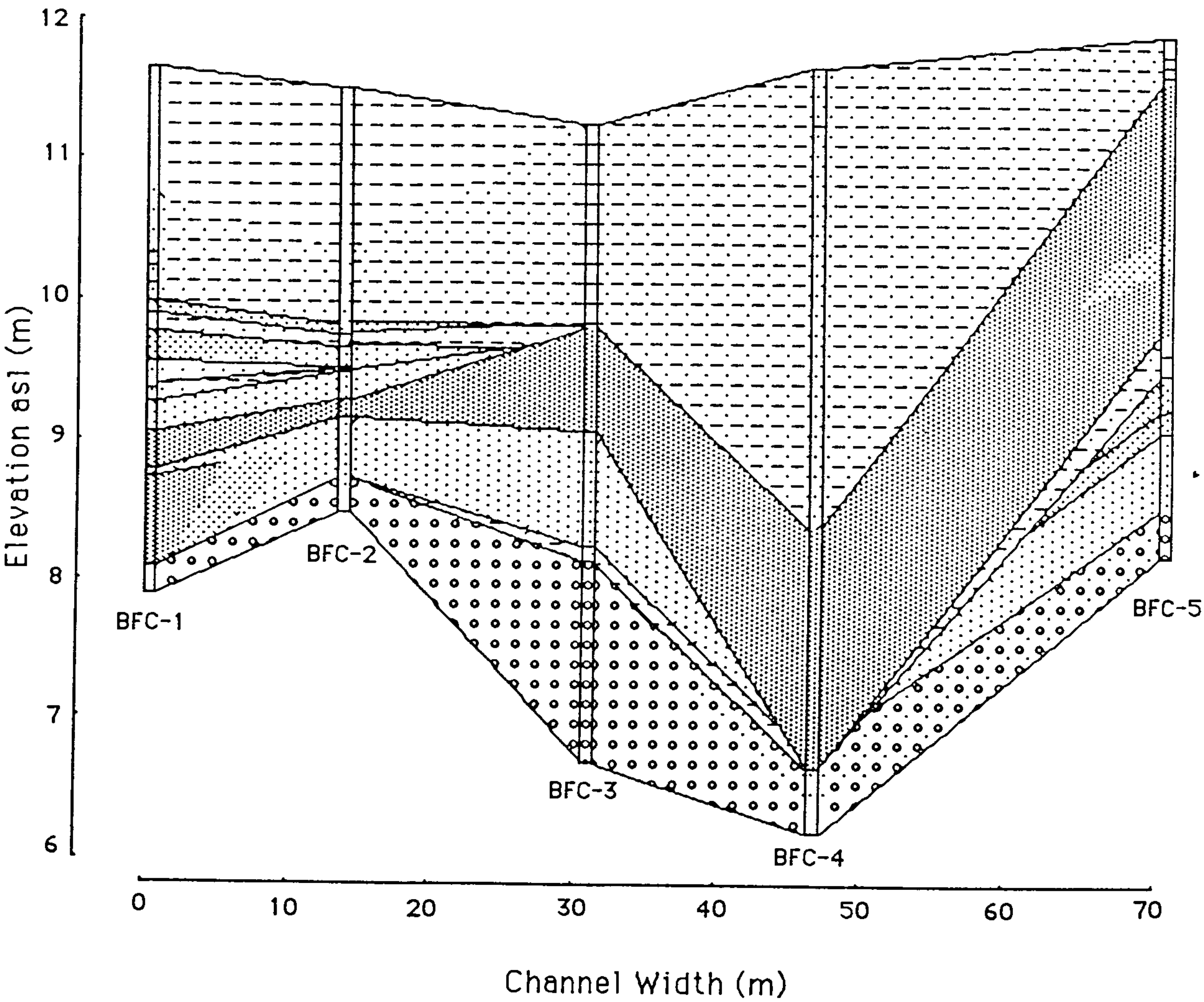
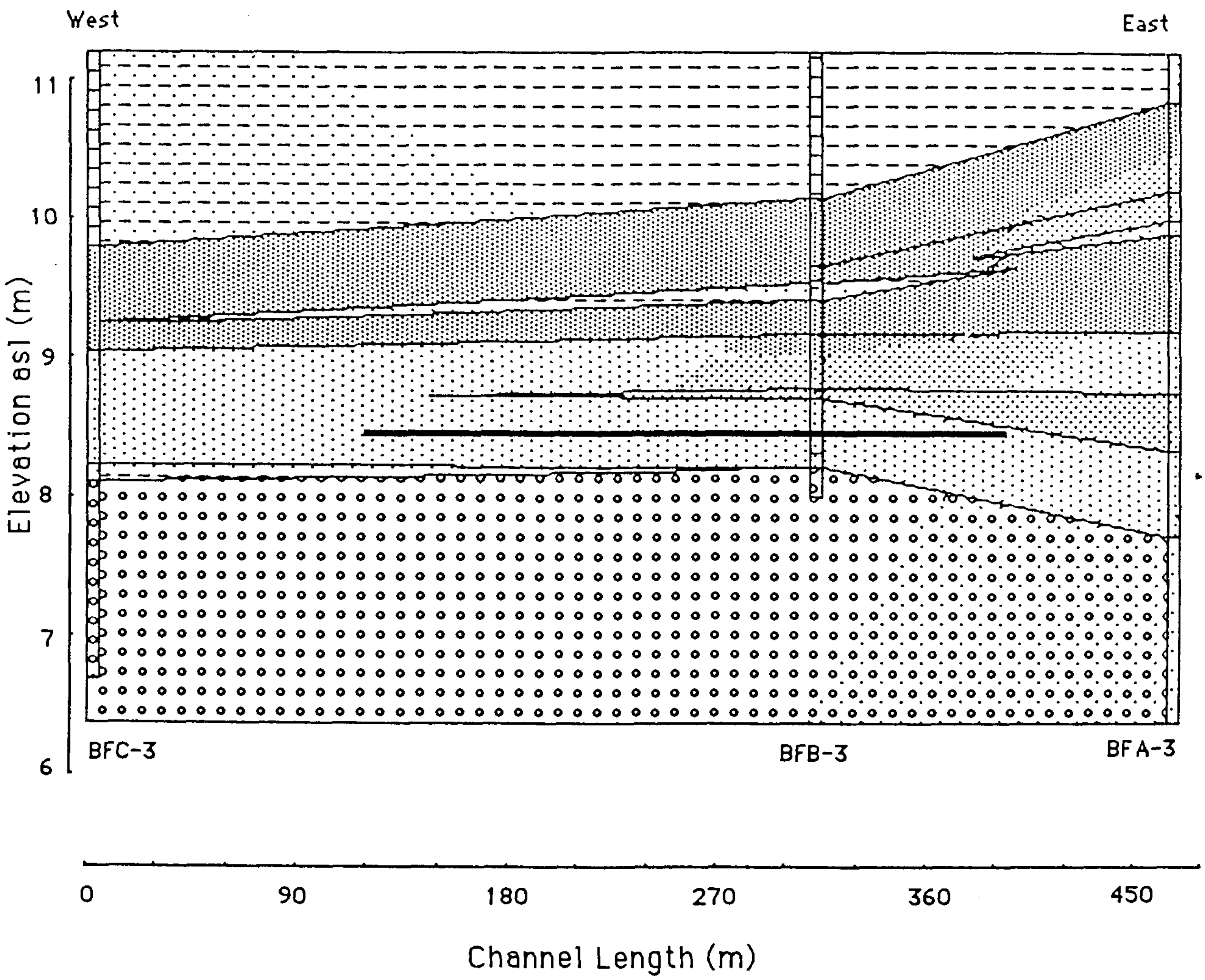


Figure 6.9 A Cross-section Along the Chute Centre, Middle Zone of Floodplain (3): Based on Interpretation of Vibracore Cores BFA-3, BFB-3, BFC-3.



The cores corresponding with the chute-side channel described above (BFA-4, BFB-4, BFC-4) all display a single, large fining upward sequence. This fining upwards sequence is remarkably similar to the sedimentology of the chute-side channel in the active channel zone (Fig. 5.1c, section 5.1.1iii).

Figure 6.9 shows the long profile of the chute centre as interpreted from cores BFA-3 (Fig. 6.6), BFB-3 (Fig. 6.7) and BFC-3 (Fig. 6.8). Again there is a slope shown dipping down-chute as well as a general fining in sediments although neither is as pronounced as in the proximal zone chute. There is a thinning and pinching out of two sand beds downstream from BFA-3 and the pinching out of two silt wedges upstream from BFC-3 shown in Figure 6.9. This shows the fining of the sands and the increasing thickness of the backwater silts in the down chute direction. The overbank fines shown in Figure 6.9 constitute less than 50 per cent of the sediments above gravel at this site as opposed to their predominance at the proximal floodplain site.

6.3.3 Zone 4 - Distal Floodplain

Distinctive features in the core results of the distal zone of the floodplain are as follows:

i) Each core (Figs. 6.10, 6.11, 6.12) generally fines upward from massive coarser sands to massive to thinly laminated finer sand and silt although there is no consistent upward transition of grain size from bed to bed. Contacts between the beds are commonly erosional.

ii) Each sequence is capped by 30 to 150 cm of overbank silts or very fine sand and silt. The only exception to this is core KFA-3 which has approximately 2.5 metres of peat at the surface.

iii) Interbedded fine materials are more common and in thicker units in KFB cores (downstream, Fig. 6.11) than in KFA cores (middle, Fig. 6.10) which in turn is more predominant that in the KFC cores (upstream, Fig. 6.12). It should be noted however that the interbeds of fine material are not as predominant at this site as at the other two

Figure 6.10 A Profile Across a Swale in the Distal Floodplain (Zone 4). Kessler Farm, Middle Site (A), Vibracore Boreholes- KFA - 1-5.

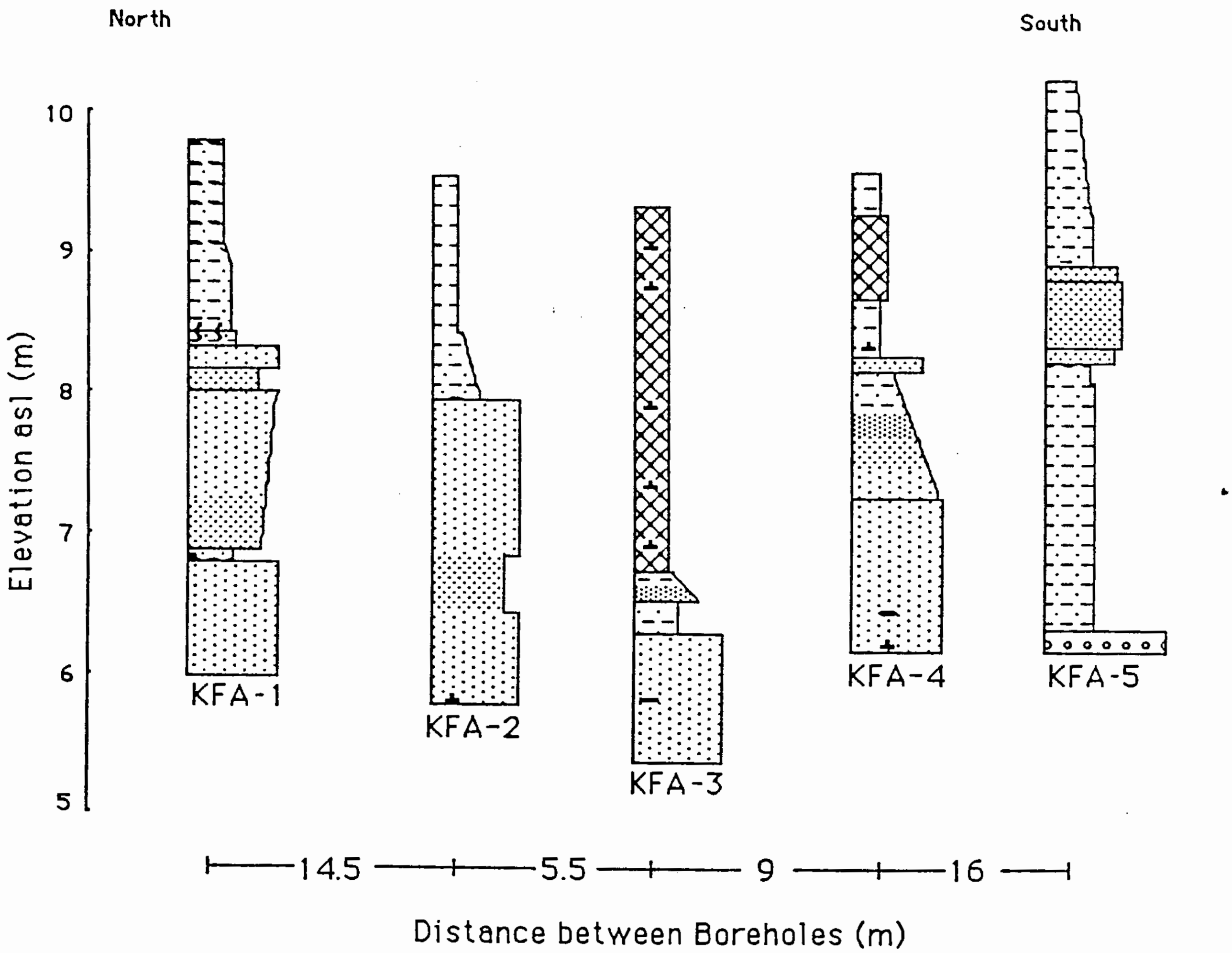


Figure 6.10a The Stratigraphic Cross-section at Kessler Farm, Middle Site (A), Interpretation Based on Vibracore Boreholes (Fig. 6.10).

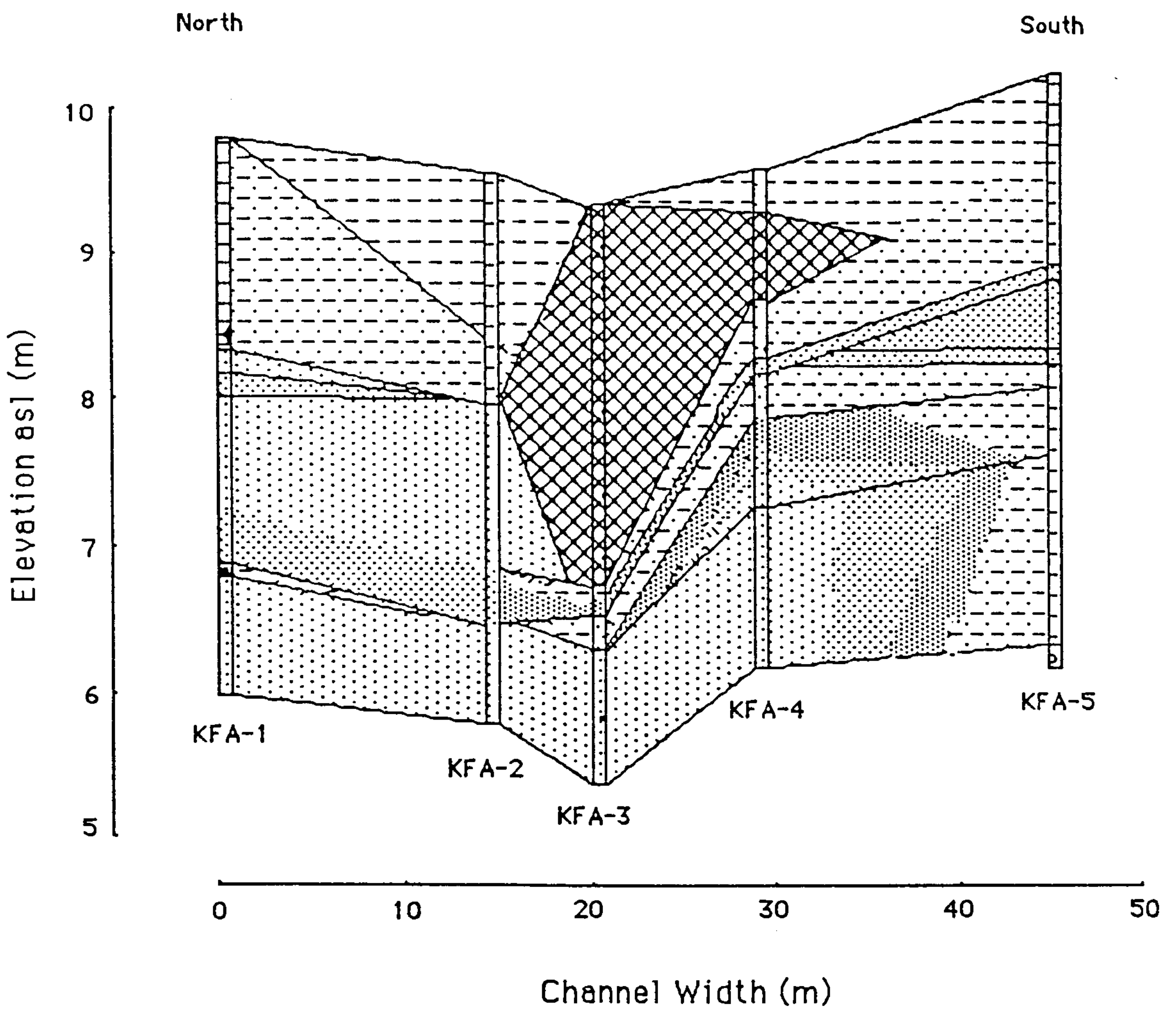


Figure 6.11 A Profile Across a Swale in the Distal Floodplain (Zone 4). Kessler Farm, West Site (B), Vibracore Boreholes - KFB 1-5.

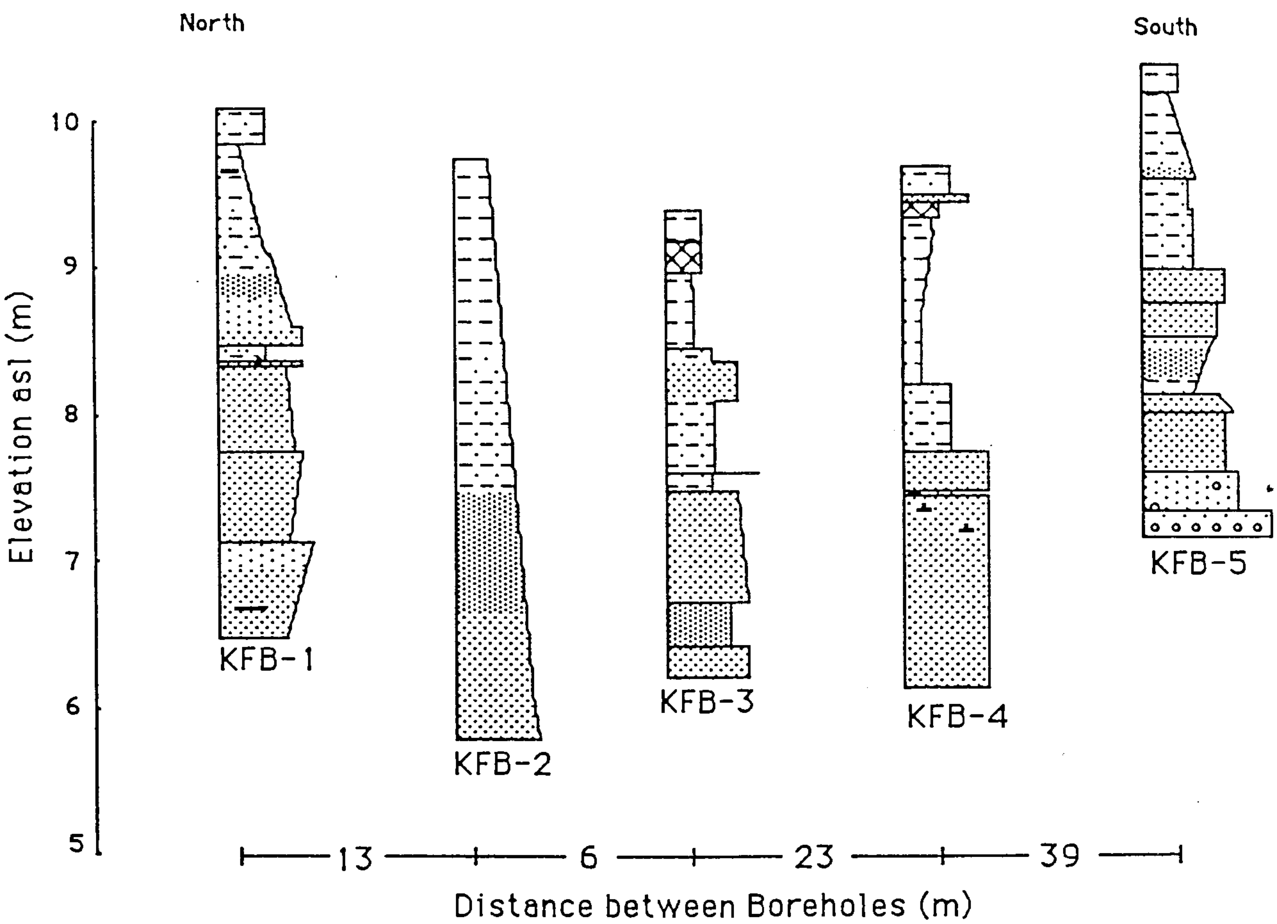


Figure 6.11a The Stratigraphic Cross-section at Kessler Farm, West Site (B), Interpretation Based on Vibracore Boreholes (Fig. 6.11).

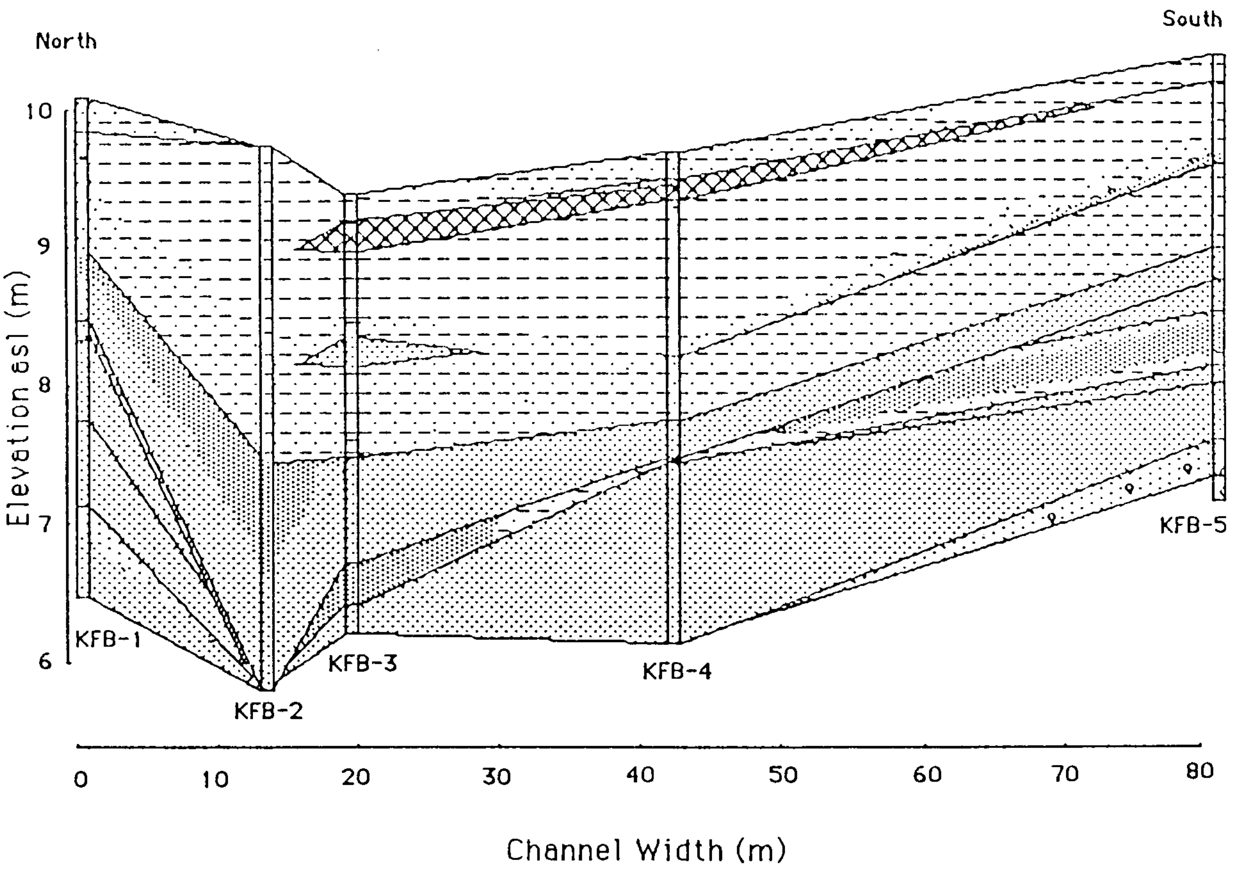


Figure 6.12 A Profile Across a Swale in the Distal Floodplain (Zone 4). Kessler Farm, East Site (C), Vibracore Boreholes - KFC 1-5.

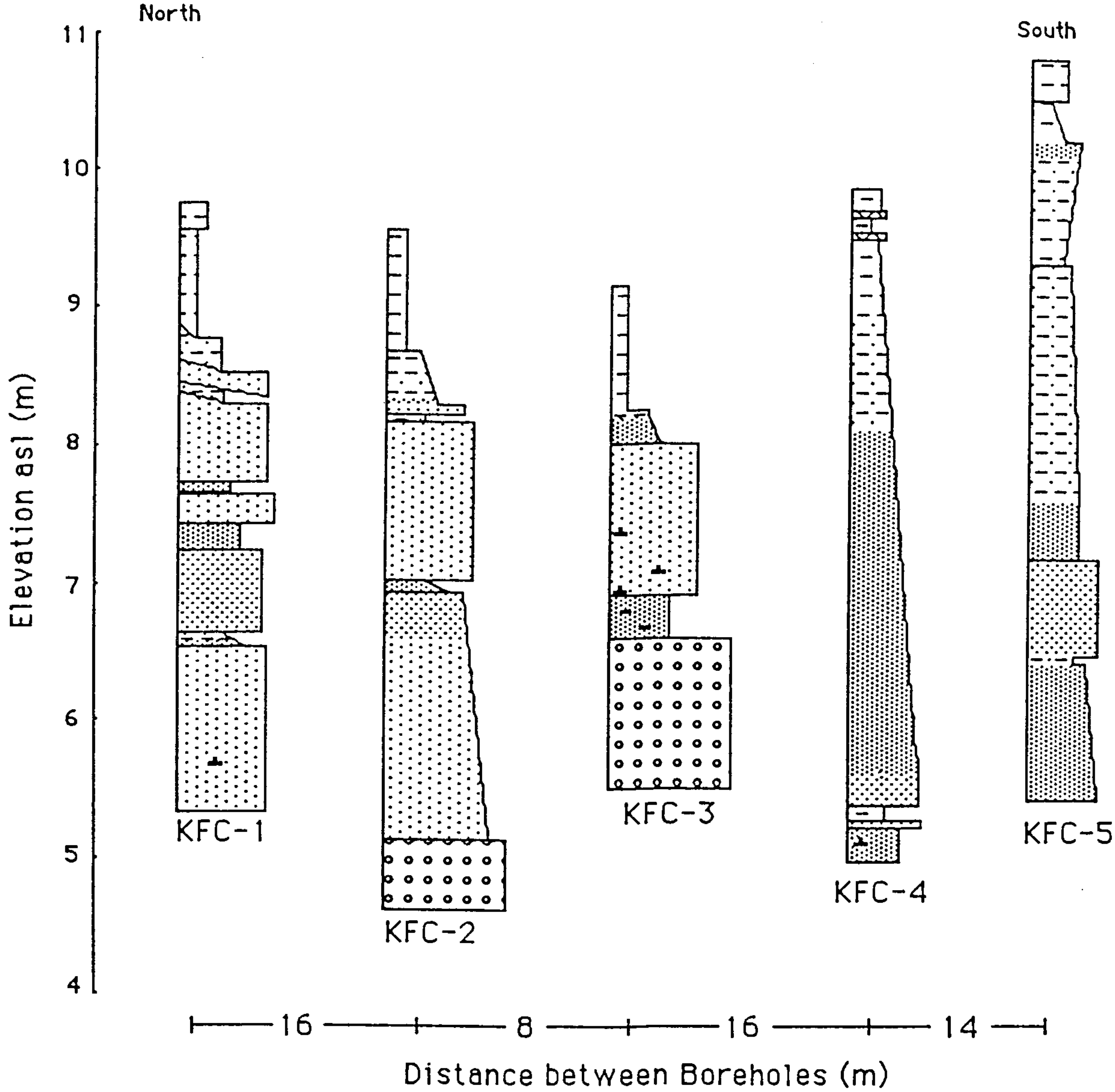


Figure 6.12a The Stratigraphic Cross-section at Kessler Farm, East Site (C): Interpretation Based on Vibracore Boreholes (Fig. 6.12).

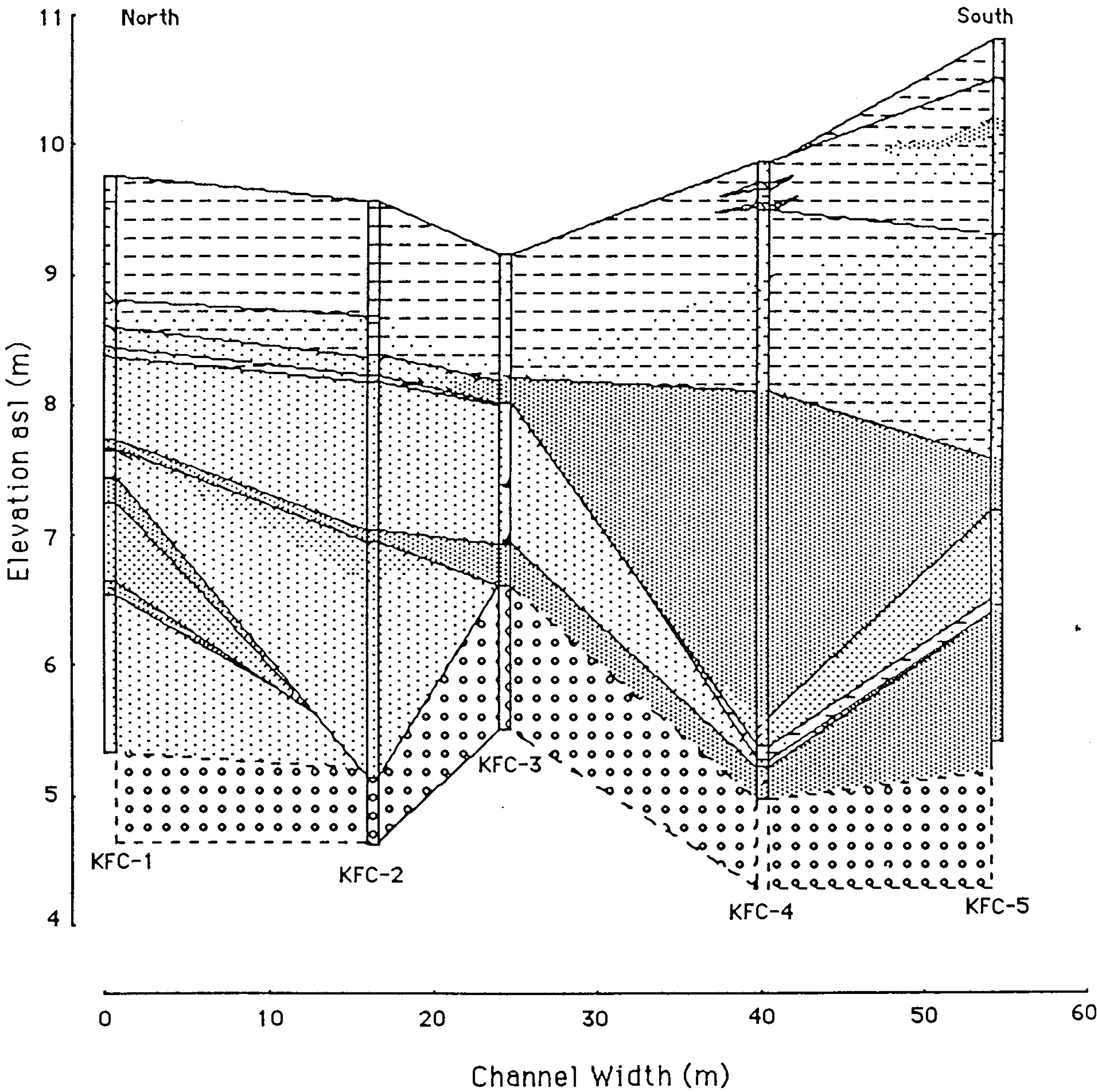
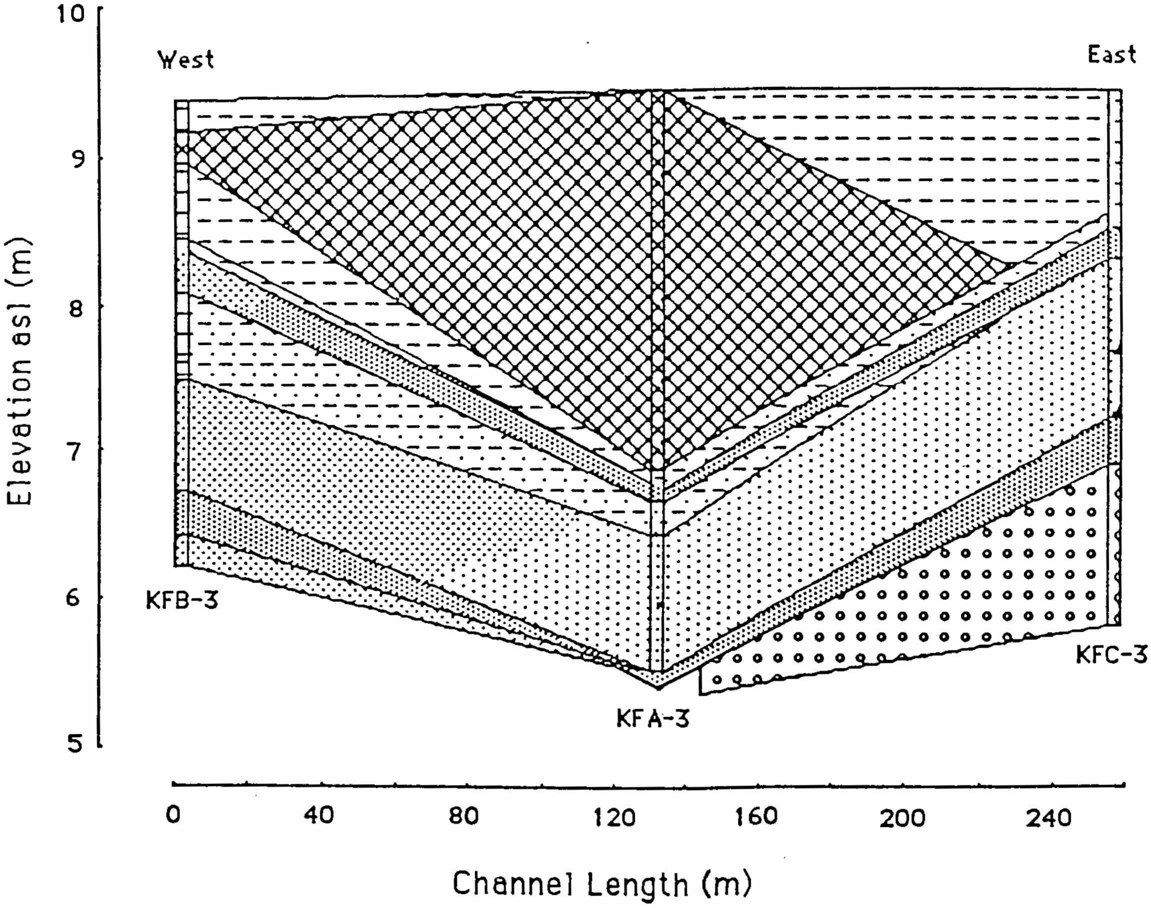


Figure 6.13 Cross-section Along the Chute Centre, Distal Floodplain Zone (4): Based on Interpretation of Vibracore Cores KFA-3, KFB-3, KFC-3.



sites (proximal, midfloodplain zones).

iv) There is a tendency for sediments to fine down-chute from the KFC cores to the KFA cores to the KFB cores.

v) KFC-4 represents the chute-side channel in the upstream location. The thick fining up sequence shown in Figure 6.12 (KFC-4) and the dip of the sand beds toward KFC-4 in Figure 6.12a are characteristic of the chute-side channel.

KFA-3 shows where the chute-side channel has shifted to the middle of the main chute. Although no fining upwards sequence is evident, the dip of the sand beds toward KFA-3 in Figure 6.10a and the thickness of the peat in Figure 6.10 shows that this chute was cut off from its sediment supply before completely infilling. This prevented the usual upwards fining sequence from developing. The resulting abandoned chute contained stagnant water which allowed peat to develop and complete the infill sequence.

KFB-2 represents the chute-side channel in the downstream location. Again, the large fining upwards sequence (Fig. 6.11) and dipping beds (Fig. 6.11a) are characteristic of this feature.

The above discussion shows that the chute-side channel switches sides from north (KFC) to middle (KFA) to south (KFB) in the chute. Of the three cross-sections the subsurface chute-side channel is mirrored by surface topography only in the centre location (KFA-3).

vi) Silt lenses pinch out toward the chute edges and some of the coarser sand beds pinch out toward the chute centre.

vii) The long profile (Fig. 6.13) shows the characteristic fining downstream. The down-chute slope however appears to steepen at mid chute and then reduce again at KFB-3. Since KFA-3 was thought to be a part of the chute-side channel, it would be reasonable that this location would be of lower elevation and that a characteristic chute centre cannot be traced due to the crossing of the chute by the chute-side channel.

viii) The overbank silts and peat form approximately 50 per cent of the above gravel sediments in the KF core profiles.

6.3.4 Sedimentary Comparison of Floodplain Zones

A number of sedimentary characteristics are common to all three of the zones on the floodplain:

i) Sediments generally fine down channel.

ii) The sedimentary sequence in cross-section reveals a general fining upwards from gravel through sand beds of various coarseness and capped with overbank silt and very fine sand. Sediments are deposited in distinct massive to thinly laminated beds with no consistent upward transition in grain size between beds. Contacts between beds are most commonly erosional.

iii) Down-chute cores contain more and thicker silt beds than up-chute cores. This is a reflection of the fact that coarse beds will fine and thin downstream while fine backwater deposits pinch out upstream.

iv) The thick fining up sequence characteristic of the chute-side channel was found in five of the nine swale cross-sections while all cross-sections revealed a dip in the sand beds not necessarily mirrored at the surface. Again these dips point to the location of the chute-side channels which were found in all chutes of the active channel zone. The sides of the paleochannel showed fine beds pinching out away from the channel and coarse beds pinching out toward the channel.

v) Overbank fines compose approximately 50 per cent of the above gravel sediments. Desloges and Church (1987) found that overbank sedimentation on the Bella Coola River was of minimal importance. They also show however, that the rate at which the active channel re-occupies a unit length of the 0.5 km wide floodplain is from 145-165 years. On the Fraser, the time for re-occupation is in excess of 2400 years (see section 6.4.1) thereby allowing for much thicker units of overbank fines to accumulate.

6.4 Direction of Floodplain Construction

It was earlier suggested that the geomorphology of the floodplain led to the hypothesis that the floodplain had been constructed progressively from south to north (section 4.4). The following discussion will address the subsurface evidence for this proposition in terms of i) radiocarbon dating (section 6.4.1) and ii) sedimentary evidence (section 6.4.2).

6.4.1 Radiocarbon Dating

As shown in Figures 6.1 - 6.12, many pieces of wood and organics were found in the cores. Two pieces of wood were selected for radiocarbon dating. Sample VF3:240 was a piece of Angiosperm wood, probably of the Willow (*Salix*) or Poplar (*Populus*) genus found at a depth of 2.40 metres (10.1 metres above sea level) in core VF-3 (Fig. 6.1). This sample was found in loose, well sorted medium sands. It is estimated that, based on surrounding cores (VF-2, VF-4), the sample was taken approximately 0.40 metres above the basal gravels. This sample was radiocarbon dated at 715 ± 65 BP (S-2886). The VF-3 core is located 1.6 km south of the active channel (Fig. 6.a).

Sample BFA3:415 was a piece of wood identified only as a Gymnosperm. The sample was found in core BFA-3 (Fig. 6.5) in clast supported gravel at a depth of 4.15 metres (7.1 metres above sea level). This sample was radiocarbon dated at 2380 ± 75 BP (S-2887). The BFA-3 core is located 5 km south of the active channel (Fig. 6.1).

These dates suggest that for at least the proximal half of the floodplain, deposition has been occuring from south to north in a progressive manner. The resulting rate of floodplain growth is 2.10 m/yr for the mid floodplain zone to the present river, and 2.80 m/yr for the proximal zone to the present river. These rates, however, should be treated with a great deal of caution. The episodic nature of island accretion and hence floodplain construction means that an expression of rate of floodplain construction may be meaningless. These radiocarbon dates do, however, show that more than half of the floodplain in the study area has been built within the past 2400 years.

Clague et al (1983) state that 'Rising seas triggered aggradation of the Fraser River floodplain .....'. Although these researchers studied the lower Fraser River and its delta, one might expect the sea level rise which occured from approximately 7500-5000 BP (Clague et al, 1983) to have some affect on the aggradation which has taken place across the floodplain in the study area (sections 6.2, 6.4.2). As the dates presented show, this is not the case. At least half of the floodplain has been constructed approximately 2600 years after sea level stablized.

The evidence for vertical aggradation within the dates presented is consistent with the findings of McLean and Church (1986). These researchers found that approximately five million tonnes of gravel have been deposited between Agassiz and Mission since 1950. If similar volumes of gravel have been deposited in the study area over the past 2400 years, the aggradation shown would not be unreasonable.

Another interesting point of speculation arising from the presented radiocarbon dates is that, assuming the southern portion of the floodplain was constructed over a similar time period (ie. entire floodplain is less than 5000 years old), then the sedimentary record for the Fraser River in this area, between the end of the Fraser glaciation and approximately 5000 BP, has not been preserved.

6.4.2 Sedimentary Evidence

The radiocarbon dating (section 6.4.2) and geomorphic (section 6.2) evidence indicates that the floodplain has been progressively constructed from south to north. In addition, it has been demonstrated that the proximal zone of the floodplain averages 1.2 metres higher than expected at the surface than the distal zone (Table 6.1 and section 6.2) revealing that vertical aggradation has occured.

In order to document the nature of vertical aggradation, the elevations of the subsurface gravel at the swale centres were determined (Table 6.1). Since only four of the nine swale centre cores were penetrated to gravel, the gravel/sand contact elevation had to be estimated for the remaining five cores. These estimates are believed to be accurate to within

0.3-0.4 metres; this variation is not believed to significantly affect the results.

As Table 6.1 clearly shows, the variation from expected elevation of gravel in these cores is even greater than for the variation in expected surface elevation. The gravel in the bottom of the KF paleochutes (distal portion of the floodplain) was found to be 1.7 metres lower, on average, than expected in comparison to the proximal floodplain zone.

A slight thinning of sediment (0.5 m) above the gravel from distal to proximal on the floodplain is shown.

These results demonstrate the degree of vertical aggradation that has occured. This aggradation however is restricted to the elevational rise of the basal gravels. The sand and silt overburden in the proximal zone has in fact thinned a minor amount as the gravel has risen.

The elevation of the basal gravels rises from approximately 5.8 metres above sea level in the channel centre of Zone 4 (KF) to approximately 9.1 metres above sea level in the channel centre of Zone 2 (proximal to river). This rise in elevation is accompanied by a similar increase in surface elevation (section 6.2.1) although not to the same extent.

The increase in elevation from south to north is believed to be due to aggradation of the basal gravels as the floodplain was constructed. The trend for aggradation from south to north also furthers the argument that the floodplain has built progressively in this direction.

6.5 Comparison of the Active Channel Zone and the Floodplain

6.5.1 Comparison Difficulties

When comparing the active channel to the floodplain, a number of difficulties arise. As briefly discussed in the floodplain geomorphology section (4.2), this portion of the Fraser Valley has been farmed for over 120 years. This has led to considerable infilling of swales and depressions which in turn makes the tracing of the full extent of the paleochutes near impossible. Since the full extent of the paleochute cannot be located, it is not possible to locate the true head of the paleochute (chute-head bar) or the true tail. A portion of the paleochute only could be found and the exact location on the chute is also unknown.

Not knowing the borehole location along the chute creates two problems. Firstly, the floodplain data fit only a portion of the chute infill model (Fig. 5.9). Precisely which portion between the two extremities is unknown. Secondly, by not knowing the nature of deposition at the head of the chute it cannot be determined which class of chute is being studied.

Another active channel zone feature which was undetectable in the floodplain is the bank bench. Since bank benches have similar sedimentary structure as chute infill deposits (facies Sh), it is not possible to recognise these features without geomorphic surface expression. The bank bench builds to island top level (Fig. 4.4) so that once the chute has infilled there is no surface expression of the bank bench.

Despite the reliance on one dimensional borehole data (3 inch core), it was expected that the angular contacts of planar cross-bedding or evidence of ripple bedding would be preserved since bedding contacts were well defined in the cores. No planar cross-bedding (facies Sp) or ripple bedding (facies Sr) was found however, in any of the floodplain cores.

6.5.2 Comparison of Active Channel Zone and Floodplain Geomorphology

The islands in the present Fraser River are defined by channels of actively flowing water. Crossing many of these islands are chutes of previously described characteristics which carry water only during flood. Some of the chutes have infilled resulting in the joining of two islands (BCC, BCU, Fig. 4.1). Other chutes separate islands from the floodplain. In these cases (MI, Fig. 4.1; Is22, Fig. 4.2) the island has accreted to the floodplain at its upstream end.

In examples such as the channels south of CI (Fig. 4.1) and GPI (Fig. 4.2) it is apparent that further sedimentation at the head of these channels could result in their attachment to the floodplain similar to MI and Is22.

The floodplain adjacent to the active channel zone is characterized by large islands which are separated by sloughs and are often crossed by swales which may represent infilled channels or chutes (Fig. 6.1). The midportion and distal zones of the floodplain have no active sloughs but do have the ridge and swale topography. The middle zone has a higher density of swales than the distal zone.

The above suggests that the floodplain was constructed by the infilling of chutes and channels similar to those in the active channel zone. Prior to becoming abandoned, the larger of these chutes and channels remain as sloughs which carry flood waters onto the floodplain, proximal to the river. The diminishing relief from the proximal floodplain zone to the distal floodplain zone as well as the reduction in the number of sloughs and density of swales suggests that the floodplain has built progressively by the infill of channels and accretion of islands from south to north.

The increase in average elevation of the floodplain from south to north supports the floodplain relief argument presented above and demonstrates that there has been vertical aggradation of sediment during the period of floodplain construction.

In summary, the geomorphic evidence suggests that the floodplain has been built progressively from south to north. This floodplain construction has occured with the accretion of midchannel islands to the floodplain by the infilling of intervening chute channels. There has also been aggradation from south to north as the floodplain grew.

6.5.3 Comparison of Active Channel Zone and Floodplain Sedimentology

Despite the problems created by not being able to locate the true head or tail of the paleochute (section 6.5.1) there were properties found in the cores on the floodplain that show the similarity between the floodplain and the active channel zone. The following features were found in the vibracore boreholes on the floodplain and have direct corollaries with infilled chutes in the active channel:

i) There is a general fining upwards although individual beds may vary in texture with no consistent upward transition in grain size between beds. Contacts between sand beds are usually erosional. These features were well demonstrated in the Carey's Island chute in the active channel zone (Fig. 5.1b-d) and on the floodplain in all of the swale cross-sections (Figs. 6.2-6.12).

ii) Massive or laminated, horizontal bedding (facies Sh, Fl) are the most common facies while St, Sp and Sr are found infrequently in the active channel zone chutes

(Figs. 5.1b, 5.2, 5.7, 5.8) but are not found in the floodplain swales (Figs. 6.2-6.12).

iii)Sediments in a chute become generally finer in the downstream direction. This is largely a function of the increase in thickness of the backwater silt units (compare Figs. 5.1 b-d, 5.7 with Figs. 6.5, 6.9).

iv) There is a subsurface dip in the (swale) sediment bedding which is not always mirrored at the surface of the floodplain (eg. Figs. 6.7a, 6.8a, 6.11a, 6.12a). This dip, interpreted as the chute-side channel (see profiles in Figs. 5.1 b-d), is filled with a one unit fining up sequence or a silt or peat plug (compare CI-2D, Fig. 5.1c; BCC1a, Fig. 5.6; BCU2, Fig. 5.7 with BFB-4, Fig. 6.7; KFB-4, Fig. 6.11; KFC-4, Fig. 6.12). This fining upward sequence is typical of the chute-side channel found in the active channel zone.

This list provides a summary of the basic similarities between the sedimentology of the active channel zone chutes and the sedimentology of the floodplain swales. Although sedimentary results were interpreted from one dimensional sources (ie. borehole data) it is felt that the combined geomorphic and sedimentologic similarities discussed above between present (active channel zone) chute infill and the floodplain swales leads to the conclusion that the depositional processes are the same for both locations. This gives further applicability of the model developed in Figure 5.9 to the floodplain in the study area. It is therefore concluded that the processes responsible for infilling chutes in the active channel zone today are similar to those which created the swales on the floodplain.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

7.1 Summary

The following discussion summarizes the findings of this study with respect to the objectives stated in section 1.2.

7.1.1 Objective i) Nature of Island Accretion

Vegetated islands are built on the surfaces of bar platforms by the vertical accretion of sand sheets and capped by a bed of sandy silt. There is an interdepencency of development of these islands between the invasion of vegetation and the stabilization of the vertically accreted sands. Mature forests on some of these islands create a semi-stable fluvial environment. These semi-stable, forested islands are a distinguishing feature of the wandering river planform.

The growth of lateral gravel benches and the development of sand bank benches on one side of an island narrows the second order channel between the island and the floodplain. Erosion on the other bank means the island may grow towards the floodplain. At some point the channel between the island and the floodplain fills with gravel above low water flows and a chute is created.

During flood, flow in the secondary (chute) channel is less competent than the primary (major) channel and deposition occurs in the head of the chute. The type of deposit is dependent on the class of chute. A class 1 chute will have a gravel lobe, a class 2 chute will have a gravel bar, and a class 3 chute will have a sand bar deposited in the chute head.

The chute-head bar grows vertically by the accretion of sand or gravel over pre-existing bars. The growth of the chute-head bar cuts off flow from entering the chute during all but flood discharges. As flood water overtops the chute-head bar, secondary circulation creates a scour hole immediately downstream of the bar.

Sand sheets are deposited in the chute during flood. There is no consistent upwards transition in grain size from bed to bed of these sand sheets but there is, nevertheless, a general fining upwards of sediment. The sand sheets are generally either massive or thinly laminated (facies Sh) and contacts between the beds are usually erosional. Dunes and ripples and their associated sedimentary facies (St, Sp, Sr) do occur but are rare in the active channel zone. These simpler facies (Sh, Fl) are a function of the deposition of sediment in sheets in a laterally semi-stable wandering river environment.

Chute sediments also tend to fine downstream. This is due to i) an increasing depth and decreasing velocity down-chute which results in a lower stream power (γQs) and ii) the increasing thickness and occurrence of backwater fines downstream from chute head to chute tail.

A chute-side channel leads from the scour hole, down-chute to the tail along one side of the chute. This 'channel within a channel' carries most of the water during flood and is kept clear of sediment until the chute is almost competely filled in. When the chute has aggraded and the chute-side channel can no longer carry the sediment supplied to it, it fills in with one large fining upwards sequence, possibly the result of a single flood. The entire sequence is then capped with 30-50 cm of overbank silts and/or very fine sand. A model of chute infill was presented which details the above processes.

An important finding in this research is that mid channel islands are accreted to the floodplain in the Fraser River by the infilling of chutes, not by channel abandonment or channel switching as is often the case in braided rivers and in the wandering Bella Coola River (Desloges and Church, 1987).

7.1.2 Objective ii) Nature of the Floodplain

i) Floodplain Geomorphology

The floodplain in the study area has: i) a ridge and swale topography; ii) relief on the floodplain which diminishes with distance from the river; iii) a drop in elevation across the floodplain distally from the active channel zone.

The proximal zone of the floodplain (zone 2) has active sloughs and a high density of ridges and swales. Ridges in this zone average 13.2 m above sea level while swale bottoms average 11.8 masl. Average relief between ridge and swale is 1.4 m.

The midportion of the floodplain (zone 3) has no active sloughs but has a high density of ridges and swales. Ridges in this zone average 12.5 masl while swale bottoms average 11.6 masl. Relief averages 0.9 m between ridge and swale.

The distal zone (zone 4) has no active sloughs and a low density of ridges and swales. Ridges in this zone average 10.6 masl while swale bottoms average 9.9 masl. Relief between ridge and swale averages 0.7 m.

ii) Floodplain Sedimentology

Forty-five vibracore boreholes were drilled in the three zones across the floodplain. Only swales were sampled so that they could be compared with chute infill in the active channel. The principle findings of the cores and interpretation of their sediments reveal the following:

i) Sediments generally fine down channel;

ii) Although there is no consistent transition in grain size between the beds, there is a general upward fining of sediment;

iii) All beds were either massive or thinly laminated (facies Sh). No evidence of St, Sp or Sr was found although the small size of the core barrel and the disturbance of the retrieval method may be partly responsible for this lack of evidence;

iv) Silt beds thin and pinch out upstream while coarse beds thin and fine downstream.

v) One of the five cores at each cross-section shows a dip of the subsurface sand beds which is not mirrored at the paleochute surface. In 5 of 9 of these cross-sections, a single, large fining upward unit was found in the sediments. In the other four cross-sections a silt or peat plug was found. This is believed to be evidence of a subsurface, chute-side channel.

vi) Overbank fines compose approximately 50 per cent of the 'above gravel' deposits in the swale sediments.

7.1.3 Objective iii) Comparison of Active Channel Zone and Floodplain

A number of features found in the active channel zone (eg. chute-head bars, scour holes, sedimentary facies St, Sp, Sr) could not be detected on the floodplain. The true head and tail of paleochutes could not be located since considerable infilling of swales by farmers has occured on the floodplain over the past 120 years. The type and extent of the chute-head bar or lobe cannot be discriminated therefore, and the class of chute remains unknown. With the additional problem of not knowing where the true tail is, it remains unknown where on the length of the paleochute the boreholes were drilled.

Since head and tail features of a chute could not be found on the floodplain, the comparison of the active channel zone with the floodplain must lie in the sediments and features of the middle of the chute.The following similarities were found:

i) The sediments of both active channel zone chutes and floodplain swales are thickly bedded, massive or thinly laminated sands to silts above a basal gravel. Facies Sh was by far the most common. Facies St, Sp and Sr were found infrequently in the active channel zone and not at all on the floodplain.

ii) Individual beds vary in coarseness and although there is no consistent transition in grain size from bed to bed, there is a general trend of fining upwards.

iii) The sediments also fine downstream. This is due to two factors: a) a reduction in stream power in the chute during flood results in a reduction of the competence. Coarser sediment is therefore deposited as the flow moves down-chute; b) backwater brings fines into the chute tail during moderate river stages. The chute slope results in a thinning of these fines from tail to head. These processes result in coarse beds thinning downstream while fine beds thin upstream.

iv) There is a subsurface dip in the floodplain sand beds which is not mirrored at the surface. The geomorphology of this depression is similar to the chute-side channel in the active channel zone. In both locations the sediments are composed of a one unit fining upwards sequence. In some cases a silt or peat plug occurs instead of the one unit fining upwards sequence.

A secondary objective was to determine whether the floodplain constructed progressively from south to north or was pieced together through a series of avulsions or abandonments. Four separate lines of evidence were presented which shows that the floodplain was progressively constructed from south to north:

i) The relief of the floodplain and the density of sloughs and swales diminishes away from the river (see section 7.1.2).

ii) The elevation at each vibracore site reveals a progressive drop in elevation of the floodplain surface away from the river (Table 6.1). This demonstrates that not only has the floodplain been constructed progressively from south to north, but has aggraded vertically as it built.

iii) The elevation of the gravel found in the vibracore boreholes (Table 6.1) shows that there is a progressive drop in elevation in the floodplain gravel surface away from the river. This shows that most of the aggradation on the floodplain is a result of increasing gravel thickness. The supragravel sediments have thinned as the gravel has aggraded.

iv) A wood sample (VF3:240) found in the swale in the proximal zone (zone 2) at VF-3 was radiocarbon dated at 715 ± 65 BP. A wood sample (BFA3:415) in the midfloodplain zone (zone 3) at BFA-3 was dated at 2380 ± 75 BP. This shows that approximately half of the floodplain has been constructed over the last 2400 years. A lateral accretion rate of 2.10 m/yr from the midfloodplain zone and 2.80 m/yr from the proximal floodplain zone to the present river is estimated. These rates however, shoud be treated with a great deal of caution (section 6.4.1).

7.1.4 Objective iv) Relative Importance of Overbank Deposits

Paleochutes act as conduits for carrying floodwaters onto the floodplain. In doing so, silts and very fine sands are deposited in the paleochutes over time reducing relief away from the active channel. Since the floodplain has had in excess of 2400 years to accumulate sediment, the overbank deposits have had the opportunity to develop to approximately 50 per cent of the above gravel sediments.

In braided environments these overbank fines are considered to play a minor role. It is clear in the floodplain profiles presented here for a wandering river however, that overbank deposits form a significant portion of the 'above gravel' sediments.

7.2 Conclusions

The pattern of ridge and swale topography on the floodplain suggests that it was constructed by a multichannel river rather than a single thread river. The prominence of facies Sh and relative absence of facies St, Sp and Sr is a reflection of the fact that the study area floodplain sediments were deposited in a wandering type of fluvial environment rather that in a braided river. The progressive construction from south to north as well as the variation in sediment within a single core suggests that the fluvial style could not have been anastomosing.

The Fraser floodplain at Chilliwack was constructed by the wandering style of fluvial process. This assessment is supported by the fact that the sediments in chutes within the active channel zone are very similar to those in the floodplain swales and that sediments across the floodplain and spanning a time period of greater than 2400 years have a similar geomorphic and sedimentary structure.

The Fraser river near Chilliwack, B.C. is classified as a wandering gravel-bed river based on its geomorphology and sedimentology. The processes responsible for floodplain construction are similar to the accretionary processes presently occuring in the active channel zone. It is concluded that the geomorphology and sedimentology of the floodplain is a result of the accretion of mid-channel islands through the infill of chutes. It is further concluded that the overbank deposits in the floodplain swales form a significant (approximately 50%) portion of the 'above gravel' sediments on the floodplain.

REFERENCES

Armstrong, J.E., 1981. Post-Vashon Wisconsin Glaciation, Fraser Lowland British Columbia. Geological Survey of Canada Bulletin 322. 34pp.

Alexander, C.S. and Prior, J.C., 1971. Holocene Sedimentation Rates in Overbank Deposits in the Black Bottom of the Lower Ohio River, Southern Illinois. American Journal of Science 270 : 361-372.

Allen, J.R.L., 1965. A Review of the Origin and Characteristics of Recent Alluvial Sediments. Sedimentology 5(2) : 89-191.

Baumgart-Kotarba, M., 1985. Different Timescales of Examining the River Bed and Valley Floor Evolution (Braided River Bialka Tatrzanska as Example). Studia Geomorphologica Carpatho-Balcanica 19 : 61-74.

Bluck, B.J., 1979. Structure of Coarse Grained Braided Stream Alluvium. Transactions of the Royal Society of Edinburgh 70 : 181-221.

________, 1980. Structure, Generation and Preservation of Upward Fining Braided Stream Cycles in the Old Red Sandstone of Scotland. Transactions of the Royal Society of Edinburgh Earth Sciences 71 : 29-46.

Boniface, C., 1985. Vegetation Succession on Mid-Channel Bars of the Fraser River, British Columbia. M.Sc. Thesis, Dept. of Geography, Simon Fraser University, Burnaby, B.C.

Bridge, J.S. and Leeder, M.R., 1979. A Simulation Model for Alluvial Stratigraphy. Sedimentology 26 : 617-644.

Brierley, G.B., in preparation. River Planform Facies Models: The Sedimentology of Three Different Planform Reaches of Squamish River, British Columbia.

Bristow, C.S., 1987. Brahmaputra River : Channel Migration and Deposition. in F.G. Ethridge, R.M. Flores and M.D. Harvey (eds.) Recent Developments in Fluvial Sedimentology. Contributions to the Third International Fluvial Sedimentology Conference. S.E.P.M. Special Publication No. 39. Tulsa, Oklahoma. pp. 63-74.

Brotherton, D.I., 1979. On the Origin and Characteristics of River Channel Patterns. Journal of Hydrology 44 : 211-230.

Burkham, D.E., 1972. Channel Changes of the Gila River in Safford Valley, Arizona. 1846-1970. U.S. Geological Survey Professional Paper 655-G 24 pp.

Cant, D.J., 1978. Development of a Facies Model for Sandy Braided River Sedimentation : Comparison of the South Saskatchewan River and the Battery Point Formation. in A.D. Miall (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir No. 5. Calgary, Alberta. pp. 627-640.

_______ and Walker, 1978. Fluvial Processes and Facies Sequences in the Sandy Braided South Saskatchewan River, Canada. Sedimentology 25 : 625-648.

Carson, M.A., 1984a. Observations on the Meandering-Braided River Transition : Canterbury Plains, New Zealand:Part One. New Zealand Geographer 40 (1) :12-17.

_________, 1984b. Observations on the Meandering-Braided River Transition : Canterbury Plains, New Zealand : Part Two. New Zealand Geographer 40 (1) : 89-99.

_________, 1984c. The Meandering-Braided River Threshold : A Reappraisal. Journal of Hydrology 73 : 313-334.

Chang, H.H., 1979. Minimum Stream Power and River Channel Patterns. Journal of Hydrology 41 : 303-327.

_________, 1980. Geometry of Gravel Streams. Journal of the Hydraulics Division, American Society of Civil Engineers. 106 (HY9) : 1443-1456.

Cheetham, G.H., 1979. Flow Competence in Relation to Stream Channel Form and Braiding. Geological Society of America Bulletin 90 : 877-886.

Church,M., 1983. Pattern of Instability in a Wandering Gravel Bed Channel. in J.D. Collinson and J. Lewin (eds.) Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publication No. 6. Blackwell Scientific Publications, Boston. pp. 169-180.

_________ and Jones, D., 1982. Channel Bars in Gravel-Bed Rivers. in R.D. Hey, J.C. Bathurst and C.R. Thorne (eds.) Gravel-Bed Rivers. John Wiley and Sons pp. 291-338.

_________, McLean, D., Mannerstrom, M. and Evans, D., 1984. Reference Materials on Sedimentation and Morphology of the Lower Fraser River. University of British Columbia, Dept. of Geography. Fraser River Project Progress Report No.1 243 pp.

Clague, J.J., Luternauer, J.L. and Hebda, R.J., 1983. Sedimentary Environments and Post Glacial History of the Fraser Delta and Lower Fraser Valley, B.C. Canadian Journal of Earth Sciences 20 : 1314-1326.

Coleman, J.M., 1969. Brahmaputra River : Channel Processes and Sedimentation. Sedimentary Geology 3 : 129-239.

Collinson, J.D., 1970. Bedforms of the Tana River, Norway. Geografiska Annaler 52A (1) : 31-56.

Costello, W.R. and Walker, R.G., 1972. Pleistocene Sedimentology, Credit River, Southern Ontario : A New Component of the Braided River Model. Journal of Sedimentary Petrology 42 (2) : 389-400.

Desloges, J.R. and Church, M., 1987. Channel and Floodplain Facies in a Wandering

Gravel-Bed River. in F.G. Ethridge, R.M. Flores and M.D. Harvey (eds.) Recent Developments in Fluvial Sedimentology. Contributions to the Third International Fluvial Sedimentology Conference. S.E.P.M. Special Publication No. 39. Tulsa, Oklahoma. pp. 99-109.

Doeglas, D.J., 1962. The Structure of Sedimentary Deposits of Braided Rivers. Sedimentology 1 : 167-190.

Fahnestock, R.K., 1963. Morphology and Hydrology of a Glacial Stream - White River, Mount Rainier Washington. U.S. Geological Survey Professional Paper 422 A 69pp.

Fraser River Board, 1964. Final Report on Flood Control and Hydro-Electric Power in the Fraser River Basin. Victoria, B.C. 106 pp.

Friend, P.F., 1983. Towards the Field Classification of Alluvial Architecture or Sequence. in J.D. Collinson and J. Lewin (eds.) Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publication No. 6. Blackwell Scientific Publications, Boston. pp. 345-354.

Gibbard, J.E., 1977. Agricultural Settlement of the Fraser Valley. in The Frasers History. The Burnaby Historical Society. pp. 39-50.

Graf, W.L., 1978. Fluvial Adjustments to the Spread of Tamarisk in the Colorado Plateau Region. Geological Society of America Bulletin 89 : 1491-1501.

Hein, F.J. and Walker, R.G., 1977. Bar Evolution and Development of Stratification in the Gravelly, Braided, Kicking Horse River, British Columbia. Canadian Journal of Earth Sciences 14 : 562-570.

Hickin, E.J., 1984. Vegetation and River Channel Dynamics. Canadian Geographer 28(2) : 111-126.

Hong, L.B. and Davies, T.R.H., 1979. A Study of Stream Braiding. Geological Society of America Bulletin 90(2) : 1839-1859.

Jackson, R.G., 1978. Preliminary Evaluation of Lithofacies Models for Meandering Alluvial Streams. in A.D. Miall (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir No. 5. Calgary, Alberta. pp. 543-576.

Kellerhals, R. and Church, M. (in press). The Morphology of Large Rivers : Characterization and Management. International Symposium on Large Rivers. Sponsored by FAO and the Ontario Ministry of Natural Resources. Sept. 1986. Special Issue of the Canadian Journal of Fisheries and Agriculture Sciences, Proceedings.

___________, ___________, and Bray, D.I., 1976. Classification and Analysis of River Processes. Journal of the Hydraulics Division, American Society of Civil Engineers, Proceedings 120 (HY7) : 813-829.

Kesel, R.H., Dunne, K.C., McDonald, R.C., Allison, K.R. and B.E. Spicer, 1974. Lateral Erosion and Overbank Deposition on the Mississippi River in Louisiana Caused by 1973 Flooding. Geology 2 : 77-84.

Knighton, A.D., 1972. Changes in a Braided Reach. Geological Society of America Bulletin 83: 3813-3822.

___________, 1984. Fluvial Forms and Processes. Edward Arnold Publishing Co. London, Eng. 218 pp.

Krigstrom, A. 1962. Geomorphological Studies of Sandur Plains and their Braided Rivers in Iceland. Geografiska Annaler 44 : 328-346.

Lattman, L.H., 1960. Cross-section of a Floodplain in a Moist Region of Moderate Relief. Journal of Sedimentary Petrology 30(2) : 275-282.

Leeder, M.R., 1982. Sedimentology : Process and Product. George Allen and Unwin, London. 344 pp.

Leopold, L.B. and Bull, W.B., 1979. Base Level, Aggradation and Grade. Proceedings of the American Philosophical Society 123 : 168-202.

_________ and Maddock, T. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. U.S. Geological Society Professional Paper 252 56 pp.

_________ and Wolman, W.G., 1957. River Channel Patterns : Braided, Meandering and Straight. U.S. Geological Survey Professional Paper 282-D pp. 39-85.

_________, _________, and Miller, J.P., 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Co. San Francisco. 522 pp.

Lewin, J., 1978. Floodplain Geomorphology. Progress in Physical Geography 2 : 408-437.

Lisle, T.E., 1986. Stabilization of a Gravel Channel By Large Streamside Obstructions and Bedrock Bends, Jacoby Creek, Northwest California. Geological Society of America Bulletin 97 : 999-1011.

Mathews, W.H., 1977. From Glaciers to the Present. in The Frasers History from Glaciers to Early Settlements. The Burnaby Historical Society, Burnaby, B.C.

McKee, E.D., Crosby, E.J. and Berryhill, H.L., 1967. Flood Deposits, Bijou Creek, Colorado, June, 1965. Journal of Sedimentary Petrology 37(3) : 829-851.

McLean, D.G., 1985. Lower Fraser River Survey, 1984 : Agassiz-Rosedale Bridge to Mission. Fraser River Project. University of British Columbia Department of Geography Progress Report No. 2. A Report to Water Resources Branch, Environment Canada. 26 pp.

McLean, D.G., and Church, M., 1986. A Re-examination of Sediment Transport Observations in the Lower Fraser River. Fraser River Project. University of British Columbia Department of Geography Progress Report No. 2. A Report to Water

Resources Branch, Environment Canada. 56 pp.

McLean, D.G. and Mannerstrom, M.C., 1985. History of Channel Instability Lower Fraser River : Hope to Mission. Fraser River Project. University of British Columbia Department of Geography Progress Report No. 2. A Report to Water Resources Branch, Environment Canada. 18pp.

Miall, A.D., 1977. A Review of the Braided-River Depositional Environment. Earth Science Reviews 13 : 1-62.

_________, 1978. Lithofacies Types and Vertical Profile Models in Braided River Deposits : A Summary. in A.D. Miall (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir No. 5. Calgary, Alberta. pp. 597-604.

Morisawa, M., 1968. Streams : Their Dynamics and Morphology. McGraw-Hill Book Company, New York. 175 pp.

Nanson, G.C., 1980. Point Bar and Floodplain Formation of the Meandering Beatton River, Northeastern British Columbia, Canada. Sedimentology 27 : 3-29.

Neill, C.R., 1973. Hydraulic and Morphologic Characteristics of Athabasca River Near Fort Assiniboine. Alberta Research Council, Edmonton. Highway River Engineering Division Report REH/73/3 23pp.

Page, K. and Nanson, G. C., 1982. Concave Bank Benches and Associated Floodplain Formation. Earth Surface Processes and Landforms. 7 : 529-543.

Parker, G., 1976. On the Cause and Characteristic Scales of Meandering and Braiding in Rivers. Journal of Fluid Mechanics 76 : 457-480.

Ramos, A., Sopena, A. and Perez-Arlucea, M., 1987. Evolution of Buntsandstein Fluvial Sedimentation in the Northwest Iberian Ranges (Central Spain). in F.G. Ethridge, R.M. Flores and M.D. Harvey (eds.) Recent Developments in Fluvial Sedimentology. Contributions to the Third International Fluvial Sedimentology Conference. S.E.P.M. Special Publication No. 39. Tulsa, Oklahoma. pp. 862-875.

Richards, K. 1982. Rivers. Methuen Co. London, England. 358 pp.

Ritter, D.F., Kinsey, W.F. and M.E. Kauffman, 1973. Overbank Sedimentation in the Delaware River Valley During the Last 6000 Years. Science 179 : 374-375.

Rust, B.R., 1972. Structure and Process in a Braided River. Sedimentology 18 : 221-245.

_______, 1978a. A Classification of Alluvial Channel Systems. in A.D. Miall (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir No. 5. Calgary, Alberta. pp. 187-198.

_______, 1978b. Depositional Models for Braided Alluvium. in A.D. Miall (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir No. 5. Calgary, Alberta. pp. 605-625.

_______ and Legun, A.S., 1983. Modern Anastomosing Fluvial Deposits in Arid Central Australia and a Carboniferous Analogue in New Brunswick, Canada. in J.D. Collinson and J. Lewin (eds.) Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publication No. 6. Blackwell Scientific Publications, Boston. pp. 385-392.

_______ and Nanson, G.C., 1986. Contemporary and Paleochannel Patterns and the Late Quaternary Stratigraphy of Cooper Creek, Southwest Queensland, Australia. Earth Surface Processes and Landforms 11 : 581-590.

Schmudde, T.H., 1963. Some Aspects of Landforms of the Lower Missouri River Floodplain. Annals of the Association of American Geographers 53 : 60-73.

Schumm, S.A., 1968. River Adjustment to Altered Hydrologic Regimen - Murrumbidgee River and Paleochannels, Australia. U.S. Geological Survey Professional Paper 598 65 pp.

__________, 1985. Patterns of Alluvial Rivers. Annual Reviews of Earth Planet Sciences 13 : 5-27.

__________ and Lichty, 1963. Channel Widening and Floodplain Construction Along the Cimarron River in Southwestern Kansas. U.S. Geological Survey Professional Paper 352-D pp. 71-88.

Sinclair, F.N., 1961. A History of the Sumas Drainage, Dyking and Development District. Chilliwack Historical Society, Chilliwack, B.C. 20 pp.

Smith, D.G., 1973. Aggradation and Channel Braiding in the North Saskatchewan River, Alberta Canada. Unpublished Ph.D. Dissertation, Department of Geography, John Hopkins University. 85 pp.

_________, 1976. Effect of Vegetation on Lateral Migration of Anastomosed Channels of a Glacier Meltwater River. Geological Society of America Bulletin 87 : 857-860.

_________, 1983. Anastomosed Fluvial Deposits : Modern Examples From Western Canada. in J.D. Collinson and J. Lewin (eds.) Modern and Ancient Fluvial Systems. International Association of Sedimentologists Special Publication No. 6. Blackwell Scientific Publications, Boston. pp. 155-168.

_________, 1984. Vibracoring Fluvial and Deltaic Sediments : Tips on Improving Penetration and Recovery. Journal of Sedimentary Petrology 54(2) : 660-663.

_________, 1986. Anastomosing River Deposits, Sedimentation Rates and Basin Subsidence, Magdalena River, Northwestern Columbia, South America. Sedimentary Geology 46 : 177-196.

_________ and Putnam, P.E., 1980. Anastomosed River Deposits : Modern and Ancient Examples in Alberta, Canada. Canadian Journal of Earth Sciences 17 : 1396-1406.

________ and Smith, N.D., 1980. Sedimentation in Anastomosed River Systems : Examples from Alluvial Valleys Near Banff, Alberta. Journal of Sedimentary Petrology 50(1) : 157-164.

Smith, N.D., 1971. Transverse Bars and Braiding in the Lower Platte River, Nebraska. Geological Society of America Bulletin 82 : 3407-3420.

Taylor, G. and Woodyer, R., 1978. Bank Deposition in Suspended Load Streams. in A.D. Miall (ed.) Fluvial Sedimentology. Canadian Society of Petroleum Geologists Memoir No. 5. Calgary, Alberta. pp. 257-275.

Turner, R.M., 1972. Quantitative and Historical Evidence of Vegetation Changes along the Upper Gila River, Arizona. U.S. Geological Survey Professional Paper 655-H 20 pp.

Wells, N.A. and Dorr, J.A., 1987. A Reconnaissance of Sedimentation of the Kosi Alluvial Fan of India. in F.G. Ethridge, R.M. Flores and M.D. Harvey (eds.) Recent Developments in Fluvial Sedimentology. Contributions to the Third International Fluvial Sedimentology Conference. S.E.P.M. Special Publication No. 39. Tulsa, Oklahoma. pp. 51-61.

Williams, G.P., 1978. Bank-Full Discharge of Rivers. Water Resources Research 14(6) : 1141-1154.

Williams, P.F. and Rust, B.R. 1969. The Sedimentology of a Braided River. Journal of Sedimentary Petrology 39(2) : 649-679.

Wolman, W.G. and Leopold, L.B., 1957. River Floodplains : Some Observations on their Formation. U.S. Geological Survey Professional Paper 282-C pp. 87-107.