YUKON RIVER EVOLUTION SINCE WHITE RIVER ASH

by

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Yukon River Evolution Since White River Ash

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ABSTRACT

White River Ash, a widespread tephra sheet in southern Yukon, was used to measure river changes of Yukon River. The 1230 yr BP tephra is a time datum by which medium term (ca. 10^3 to 10^4 yr) channel changes and floodplain accretion rates for Yukon River can be gauged. Average rates of lateral migration, island growth and vertical accretion were determined by mapping the tephra on floodplains and islands in three reaches of the river.

The reaches include two with meandering planforms and one anastomosed. The meander reaches are within the limit of the last glaciation (McConnell advance) with confining terraces of outwash and glaciolacustrine deposits varying in height from 6 to 130 m above river level. Floodplain scrolls on alluvial plains below the outwash terraces show that the river has meandered for about the last 7000 years. Between the end of the last glacial advance and about 7000 years before present recessional outwash and paraglacial gravels and glaciolacustrine sediments were deposited.

The upstream meander reach (Hootalinqua-Big Salmon reach) has migrated least; typical bend migrations are 100 m (0.08 m/yr) with a maximum rate of 0.8 m/yr. Vertical accretion above the ash layer is restricted to floodplains 4 m or less above river level; average accumulation is 0.41 m (0.34 mm/yr)

with a maximum rate of 0.81 mm/yr. Islands are uncommon in this reach and lack ash.

The middle reach (Eagle's Nest Bluff-Carmacks reach) comprises a more active meander belt with multiple point bar deposition downstream of meander apices. Typical floodplain widths without ash are 150 m (0.12 m/yr) and maximum lateral migration is 0.4 m/yr. Accretion is restricted to floodplains within 4 m of river level and averages 0.29 mm/yr with a maximum rate of 0.73 mm/yr. Two midchannel islands have buried ash along their axes.

The downstream anastomosed reach (Rink Rapids-Minto reach) lies mainly beyond the limit of the McConnell advance but was glaciated by at least three previous glacial advances (Reid and pre-Reid advances). Islands are numerous and generally two main channels are present. Volcanic ash was observed on 13 islands and along most cutbanks. The channel has widened and islands have grown and been eroded during the last millennium. Bedrock benches, which are common along this reach, help anchor the channel. The maximum lateral migration rate is 0.8 m/yr. Accretion on islands and floodplain up to 4 m above river level averages 0.67 mm/yr with a high rate of 1.8 mm/yr. The minimum height of volcanic ash was 0.1 m above river level indicating that the Yukon River has not incised its bed significantly in the last 1230 years.

This research concerns a time span which is rarely documented in fluvial geomorphology research. Most literature on channel changes and floodplain accretion deals with shorter term. The White River Ash, a distinctive, widespread time marker, permits precise analysis and documentation of river changes over the last 1230 years.

DEDICATION

This work is dedicated to Hugh S. Bostock, formerly of the Geological Survey of Canada. His early contribution and interest in the surficial geology of central Yukon Territory and the White River Ash stimulated me to pursue this study.

ACKNOWLEDGMENTS

The idea of the thesis and continuing interest and enthusiastic support came from Dirk Tempelman-Kluit of the Geological Survey of Canada. His assistance and confidence in the author helped make this thesis possible. Owen Hughes, also of the Geological Survey of Canada, provided timely training in surficial geology and geomorphology field and office methods as part of three summers of employment with the Terrain Sciences Division. The freighter canoe used on the river was provided by Grant Abbott, a Department of Northern Affairs geologist in Whitehorse, who also suggested the possibility of using the White River Ash as a time marker during a canoe trip down the Yukon.

Brian Lueck, a geology graduate from University of British Columbia, acted as a capable and keen assistant during the 1984 field season. His ideas and hard work made the field work enjoyable and enlightening.

My senior supervisor, Mike Roberts made helpful comments on the organization of the thesis and edited earlier versions of this report.

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CHAPTER ONE

INTRODUCTION

Geomorphological processes have been studied at various timescales with emphasis on the long term (5 ka to 1 Ma) and the short term (ca. 10 to a few hundred years) time spans. Research on the medium term span of a few hundred to thousands of years (Thornes and Brunsden, 1977, p. 185) remains to be done.

Research on river channel changes, a subfield of geomorphology, can also be divided between short term, medium term and long term timescales. Most fluvial research tends to focus on short timespans with few studies of long term changes. A gap remains in understanding river behaviour in the medium timespan especially at the lower end and outside the limit of reliable radiocarbon dating (Hickin, 1983).

The emphasis on short term changes in river systems is attributed to the availability of methods limited to this timescale. For example, the chronology of short term fluvial activity in western Canada has been determined by; (1) comparing serial airphotos (1 - 35 years) (Northwest Hydraulics, 1975; Humphrey, 1978; Hickin and Nanson, 1984; Sichingabula, 1985), (2) comparing historical maps (1 - 100 years) (Hansen, 1934), (3) repeated observations (sounding and surveying) (1 - 30 (?) years) (Crickmay, 1960; Hein and Walker, 1977; Bostock, 1979), and (4) dendrochronology (1 - 400 (?)

years) (Eardley, 1938; Strang, 1973; Hickin and Nanson, 1975; Church, 1977; Nanson, 1977). These methods allow reconstructions of sequential development in the continuum of channel changes.

Long term river changes are based on morphology, terrace height, stratigraphy, (eg. Thorson and Dixon, 1983) archeological evidence, soils, eolian sequences, lava extrusions (Hickson and Souther, 1984) and radiocarbon dating (Brackenridge, 1984; 1985).

Medium term chronology, the timespan of this work, involves radiocarbon dating, palynology, artefacts, thermoluminescence, optical dating, and recent tephra.

Tephra deposits from Cenozoic volcanic eruptions can be used to establish a geomorphic chronology (Cullingford et al., 1980). This method, called tephrochronology, was first established by Thorarinsson (1944) in Iceland. A historical perspective of tephra layers as tools for research is provided by Thorarinsson (1981).

Tephrochronology can be used in the Cordillera because dated tephra deposits from Cenozoic volcanoes are widespread. The method can be used to study local erosion and aggradation rates (Thornes and Brunsden, 1977, p. 39) for medium term time scales.

Examples of some recent volcanic ash layers that can be used by geomorphologists in the Cordillera, are White River Ash in Yukon Territory, (ca. 1230 and 1890 yr BP) (Lerbekmo et al., 1975; Denton and Karlen, 1977), Bridge River Ash (ca. 2350 yr BP) (Mathewes and Westgate, 1980) in southern British Columbia and Edziza Ash (ca. 1000 yr BP) in northern British Columbia (Souther, 1976). Tephrochronology permits better time control and correlation between sites without numerous age determinations.

1.1 Previous Use of White River Ash and Other Cordilleran Tephras in Geomorphological Research

The occurrence of White River Ash in all but the most recent floodplains of the Yukon led to the idea of using this tephra as a time datum for recent fluvial geomorphic processes (D. Tempelman-Kluit, 1983 pers. comm.). Fernald (1965) noted that the presence of White River Ash on all low terraces provides a reference point for the interpretation of the surficial geology of the upper Tanana River valley. He documented a section of floodplain deposit with 42 inches (1.1 m) of bedded silt and sand with organic debris above the ash. He did not use the ash or outline methods to use it in unravelling upper Tanana River valley migration or incision rates. Dawson (1889) used the near-surface ash to infer minor downcutting of Yukon River. Bostock (1969) cited an abandoned fan with volcanic ash and a grassland without ash adjacent to an active Duke River fan west of Kluane Lake.

Other workers have used White River Ash to determine lake level fluctuations and landslides in southwestern Yukon

Territory (Clague, 1981a; Rampton, 1981; Clague and Rampton, 1982; Gustavson, 1986), to date palynological samples (Rampton, 1969, 1971; Denton and Karlen, 1977; Mathewes and Westgate, 1980; Bourgeois, 1982; MacDonald, 1983; Bourgeois and Geurts, 1983; Slater, 1985), and to determine rates of peat accumulation (Kershaw and Gill, 1979).

Geomorphological uses of other tephras in western Canada include evidence of aggradation in South Saskatchewan River (Smith, 1972; Kostaschuck and Smith, 1983); accretion on alluvial fans in Thompson, Bonaparte, and Similkameen Valleys and Kamloops area (Ryder, 1969); terraces, fans and debris slides in Thompson Valley (Anderton, 1970); valley side slope activity in Bridge River valley (Howes, 1975); paraglacial fan activity in Bow River valley (Jackson et al., 1982) and terrace sequences in Klondike area, Fort Selkirk area, Porcupine River area, and Fairbanks area (Naesar et. al., 1982). Loess deposition chronologies were established using Bridge River and Mazama tephras in Alberta (Dumansky et al., 1980; Waters and Rutter, 1984).

In Washington State, volcanic ashes were used to correlate floodplain deposits (Moody, 1977) and date the most recent scabland flood (Mullineaux et al., 1978).

Mapping tephra to determine successive channel changes and the highest flood in 1200 years is thought to be original. I know of no other record where tephrochronology is applied to lateral migration of river channels.

1.2 Thesis Objective

The objective of this thesis is to use a widespread tephra deposit as a time stratigraphic marker to evaluate river behaviour for three reaches of Yukon River. The ca. 1230 yr old east lobe of the White River Ash was selected for its broad distribution and known occurrence in floodplains and islands in central Yukon Territory. The mapping of the tephra allows for the reconstruction of the sequential evolution of river planform and establishment of sediment accumulation rates in vertical and lateral sequences over a timespan of about 1200 years. These average rates provide a more conservative estimate of short term rates than those extrapolated from the measurement of "contemporary" activity.

The three Yukon River reaches were selected to represent examples of active planform development mappable at a reconnaissance scale of 1:50 000.

Channel activity along the reaches is estimated from the distribution of ash on floodplains.

1.3 Layout of the Thesis

The study is divided into five chapters. The first is an overview of the study area with brief descriptions of physiography, glaciation, bedrock geology, vegetation, climate and hydrology. Geomorphic features, such as slope of river, sinuosity, bend radius, and average width, of each of the three reaches follow and lead in to the second chapter which deals with the White River Ash and its geomorphological uses.

Field and office compilation methods used in the research are discussed in chapter three.

The results for each reach are given in chapter four. River behaviour, lateral migration, and vertical accretion are discussed and documented with maps and down river profiles. The sequence of geomorphic events leading up to the formation of floodplains is presented with examples.

The summary and conclusions in the final chapter contain a summary of the relative activity of the reaches.

1.4 Study Area

The study area comprises three widely-spaced reaches of the Yukon River between the Teslin River confluence and Minto in Laberge (105E), Glenlyon (105L), and Carmacks (115I) map areas (Fig. 1.1). The centre of the study area is 150 km north of Whitehorse with road access to the intermediate reach and downstream reach by Robert Campbell Highway and Klondike Highway. The upstream reach is accessible by boat from Lake Laberge or Little Salmon River.

1.4.1 Physiography

The study area lies within Lewes Plateau. Lewes Plateau, a subdivision of the Yukon Plateau (Bostock, 1948), forms a surface of low relief in the study area. Rounded hills rise between 1000 and 1200 m with intervening broad valleys between 400 and 600 m elevation. It is bordered by the higher Pelly Mountains on the east and the rugged glacierised St. Elias Mountains on the southwest.

Drainage anomalies in Yukon Plateau were noted by Bostock (1948) who recognized that the Yukon crosses some spurs of resistant ranges and passes flatter low ground and long straight trenches. Bostock (1970, pp. 21-23) in his work on the Yukon Plateau found remnants of old erosion surfaces which were presumably uplifted in early Tertiary time.

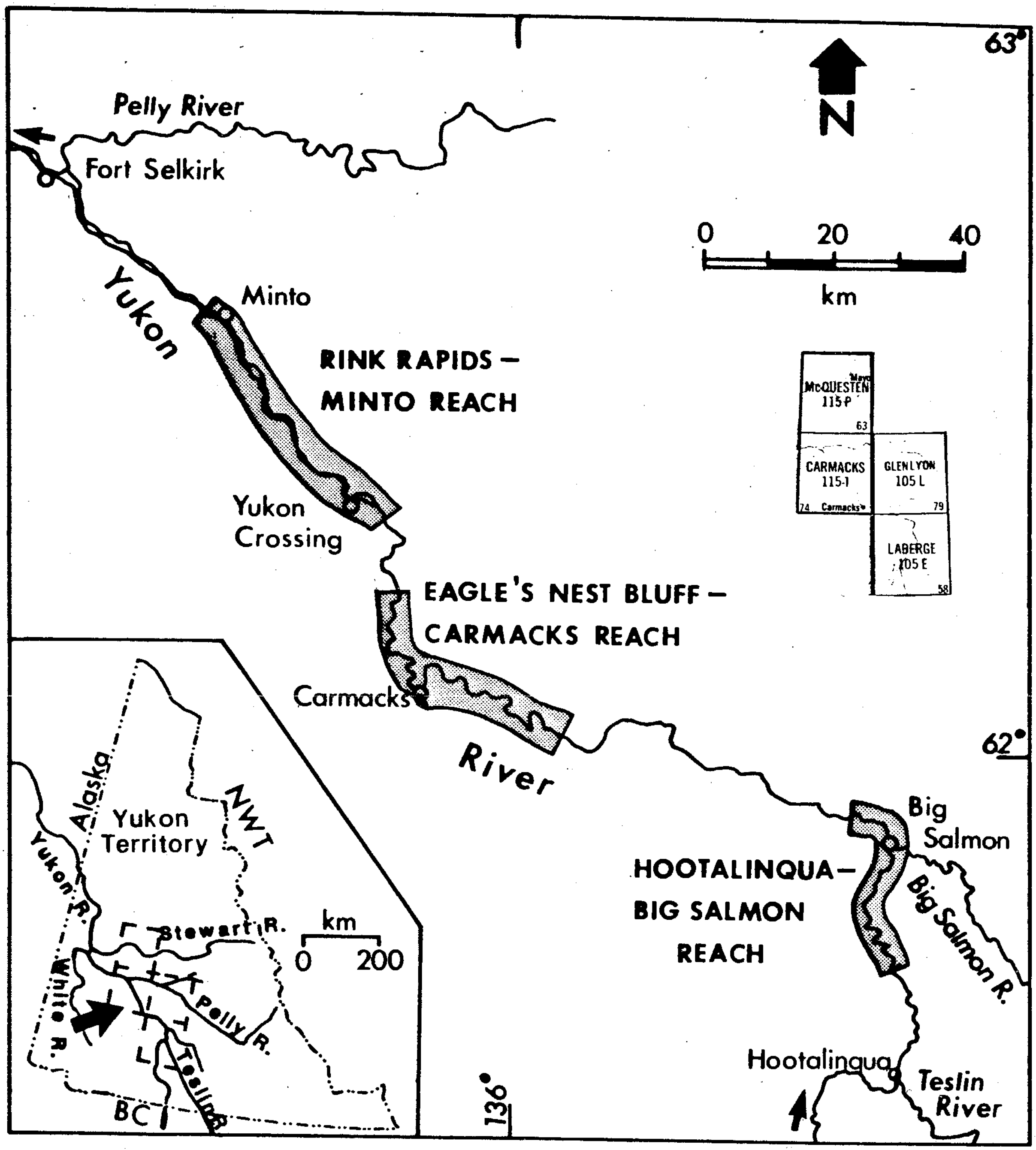


Figure 1.1 Study area showing location of reaches mapped along Yukon River, central Yukon Territory.

This uplift lead to the entrenchment of rivers into these plateaus. The larger valleys have bedrock terraces with lower gradients than the present rivers (Bostock, 1970).

Tempelman-Kluit (1980) postulated a sequence of drainage development spanning Tertiary and Quaternary Periods, from evidence of topography, stream intercepts, terrace heights, glaciation and tectonic history of southern Yukon Territory. He envisioned a former south flowing trunk stream draining to the Pacific Ocean in a more direct route than at present. General but uneven uplift in Late Miocene or Pliocene time led to entrenchment of streams established in a former low surface. Glaciation also blocked former routes which were never reestablished. This southwesterly route was abandoned during deglaciation in favour of a northwest route through progressive stream capture. Tempelman-Kluit (1980, p. 1202) concluded that the present northwest drainage was in danger of being captured by the more aggressive Pacific draining rivers (see long profile, Tempelman-Kluit (1980, p. 1202), and National Atlas of Canada, (1974)).

1.4.2 Bedrock Geology

The geology of central Yukon Territory comprises tectonostratigraphic terranes which are characterized by distinctive stratigraphic and tectonic histories. These terranes have been named and mapped by Tempelman-Kluit (1978) as Yukon Crystalline Terrane, Yukon Cataclastic Terrane, Cassiar Platform, and Whitehorse Trough.

The study area lies within a Mesozoic assemblage of sedimentary and volcanic rocks in a basin named Whitehorse Trough (Wheeler, 1961) (Fig. 1.2). Reconnaissance scale mapping has most recently been compiled by Tempelman-Kluit (1984). Reports on geology began with the traverses of Dawson in 1887, and followed by more detailed mapping by Bostock (1934, 1936), Bostock and Lees (1938), and Tempelman-Kluit (1978).

The evolution history of Whitehorse Trough is taken from Tempelman-Kluit (1978). During Late Triassic time a basin existed with deposition of clastic sediments in fans, river deltas and foredeeps. Volcanic dominated clastic material became more and more granitic with time. Carbonate reefs formed along the margin. In Early Jurassic time coarse sediment was deposited as fanglomerates close to the sediment supply while other areas apparently received very little sediment input. Coarse sediment gave way to arkose during early Middle Jurassic. The size of the basin decreased in Late Jurassic or Early Cretaceous time leaving interbedded conglomerate, shale and coal.

Mesozoic intrusions and volcanic rocks also occur in the study area within a deformed assemblage called Yukon Cataclastic Complex (Tempelman-Kluit, 1978).

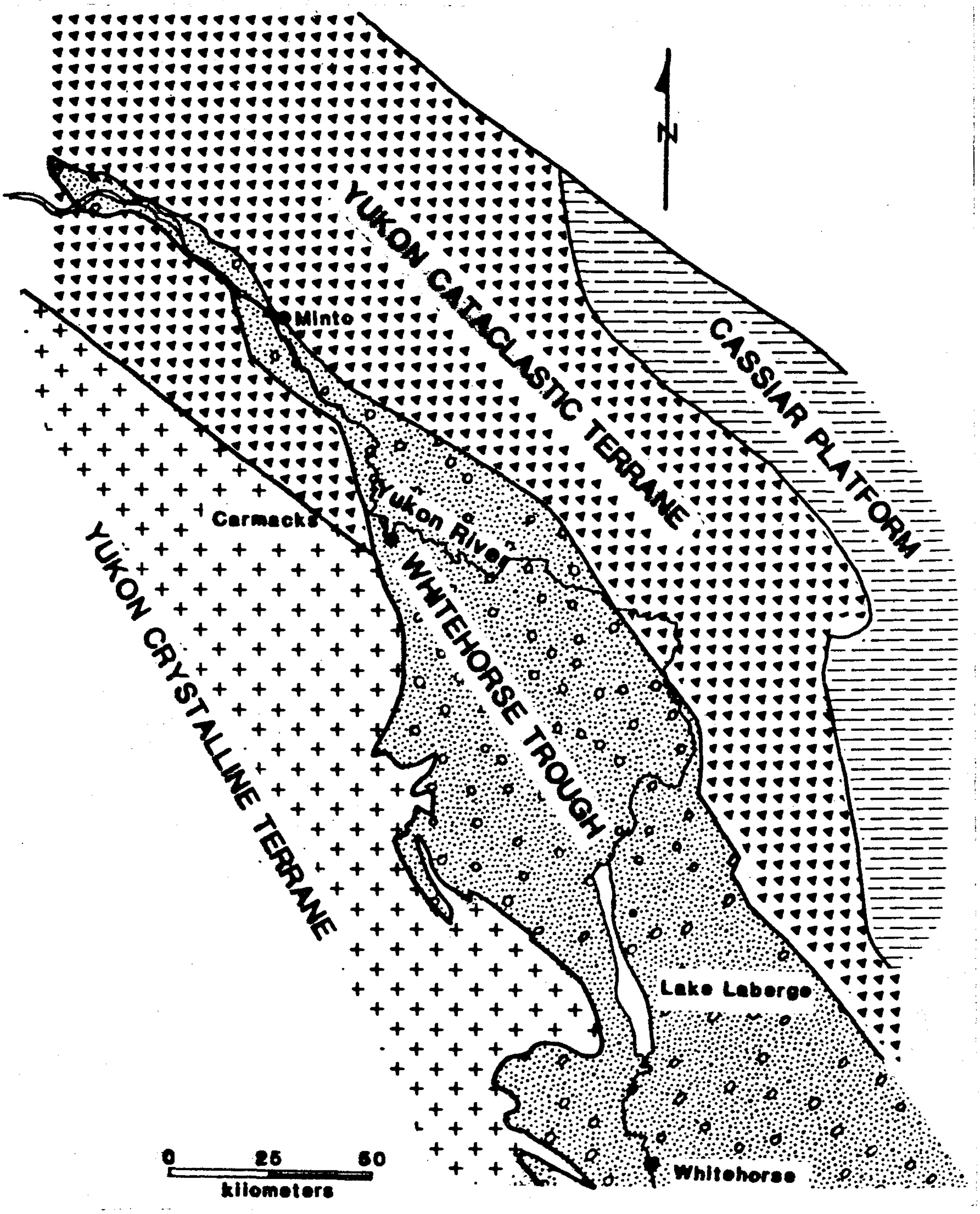


Figure 1.2 Terrane map of study area

1.4.3 Glaciation

Glacial features and associated chronologies for various parts of the study area have been reported by Lees (1934), Bostock (1936, 1966), Campbell (1967), Hughes et al., (1969), Hughes, et al., (1972), Morison (1979), Hardy Associates (1980) and Morison and Klassen (1980). Ice flow directions and glacial limits have been mapped on a regional scale (1:1 000 000) by Hughes et al. (1969) (Fig. 1.3). In addition, surficial geology maps are published at 1:250 000 scale for Glenlyon (105L) (Campbell, 1967) and at 1:100 000 scale for Packers Mountain and Anticline Mountain (105E) (Morison and Klassen, 1980).

Four glacial advances are postulated for central Yukon Territory (Bostock, 1966) and are named informally from oldest to youngest as Nansen, Klaza, Reid and McConnell. Although details of chronology are sketchy the following tentative dates have been published (Tarnacai et al., 1985) as follows; Pre-Reid (Klaza and Nansen) (0.12-1.2 Ma), Reid (80-120 ka), and McConnell (14-30 ka).

Ice flowed northwestward during each advance down the Yukon valley north of Carmacks and was less extensive with each glaciation (Fig. 1.3).

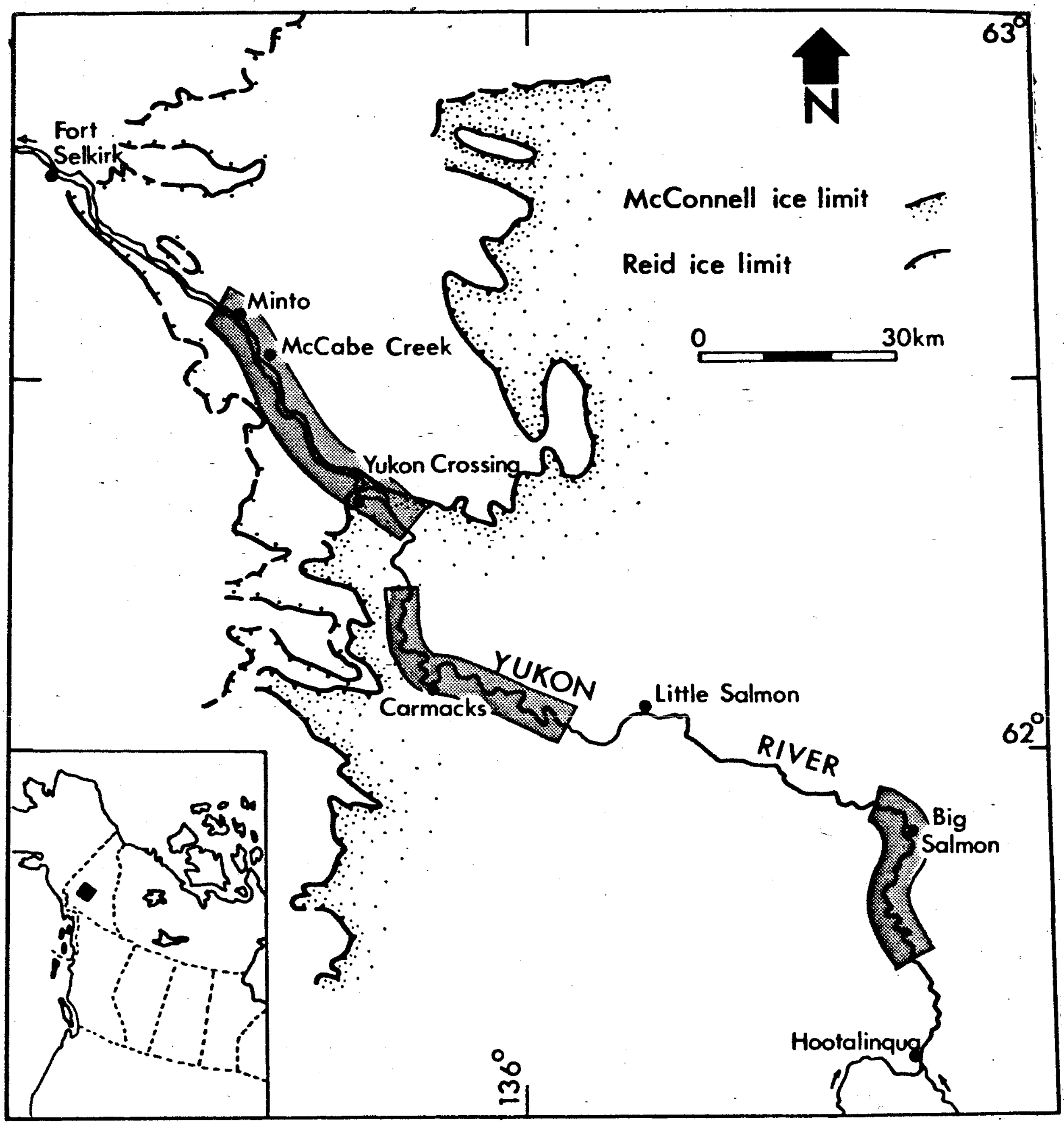


Figure 1.3 Glacial limits in the study area.

Source: Hughes et al., 1969.

1.4.3.1 Pre-Reid Glaciations (0.12-1.2 Ma)

The limit of glacial advance during Bostock's (1966) Klaza and Nansen glaciations (called here the pre-Reid glaciations) were derived from exposures of boulder clay in Nansen Creek and Klaza River in Carmacks map area (Bostock, 1966). Till below the Selkirk volcanics and striae on basalt flows were inferred to result from two glaciations older than the Reid. Subsequent workers have not subdivided the two glaciations in Mayo and McQuesten map areas but have treated them as pre-Reid advances (Foscolos et al., 1977; Hughes et al., 1969; Tarnacai et al., 1985).

1.4.3.2 Reid Glaciation (80-120 ka)

During the Reid advance glacial ice extended down the Yukon River Valley to about Fort Selkirk (Hughes et al., 1969). The type area of the Reid Moraine is at Reid Lakes in McQuesten map area (Bostock, 1966, p. 2). Drift was deposited in the Yukon River valley from ice contact environments and outwash valley trains. The highest outwash adjacent to hummocky drift surface is referred to informally as the "Reid terrace". Its most upstream limit is near McGregor Creek where the terrace is adjacent to very hummocky knob-and-kettle topography.

Tributary terraces corresponding to the presumed valley fill of drift were built up along creeks on both sides of the river from meltwater streams. Remnants of these terraces are preserved on McGregor Creek, McCabe Creek, Von Wilczek Creek, Williams Creek and Hoochekoo Creek.

A loess covered, low-level valley train downstream of Minto contains ventifacts and is interpreted to be a recessional outwash of Reid Glacial retreat.

1.4.3.3 McConnell Glaciation (14-30 ka)

The McConnell advance was the last major glaciation of central Yukon Territory. The type area of McConnell Moraine is in Stewart River valley west of Mayo (Bostock, 1966, p. 1; McConnell, 1903, p. 42A). Its deposits are the freshest and best preserved of all the Pleistocene glaciations. Glacial limits can be traced on air photographs over Carmacks map area as a distinctive digitate margin invading valleys and wrapping around hill sides.

The Cordilleran ice sheet of the McConnell advance has been divided into two lobes by Wheeler (1961) and Campbell (1967). The Cassiar lobe, with source areas in Cassiar Mountains, flowed in a northwest direction down Yukon River valley (Campbell, 1967, p. 22) while Selwyn lobe flowed more westerly from a source area in Selwyn Mountains. The Cassiar lobe and Selwyn lobe were separated by the Pelly Mountains (Hughes et al., 1969, p. 2). The Cassiar lobe probably had the greater effect on the surficial geology in the study area.

A stagnant ice feature of the last advance in Yukon River valley near Carmacks is well preserved and largely unreworked by Yukon River or tributaries. It consists of hummocky glacial and glaciofluvial deposits with crevasse fillings and kettles extending from the Nordenskiold River valley 28 km downstream to Yukon Crossing. This dead ice feature, recognized by Campbell (1967), is correlated with the northwestward sloping moraine ridge on the east wall of the valley. The Yukon River may have flowed in this north trending valley prior to the last glaciation (Owen, 1959c).

McConnell ice appears to have dammed the confluence of Tatchun River resulting in deposition of glaciolacustrine silts up to 58 m above river level. Two fresh looking tills, believed to be of McConnell age, are exposed near the mouth of Tatchun River indicating the presence of glacial ice in the valley. One of these tills, exposed between gravels downstream of the river mouth (Dawson, 1889, p. 144) is pink. A grey till, also fresh looking, was noted by Bostock (1966, p. 4) in a nearby gravel pit. The relationship of these tills is unresolved.

A broad valley train extends from the McConnell limit at least as far as Minto. It is referred to as the "McConnell terrace" traceable from the end moraine near Yukon Crossing to McCabe Creek (Fig. 1.3). Other outwash terraces below the "McConnell terrace" extend on both sides of the valley at higher gradients than the present river surface in a shingle like fashion.

During deglaciation Cassiar lobe ice retreated southward in Whitehorse map area (Wheeler, 1961) and is believed to have retreated similarly in the study area. Selwyn lobe ice, although thinning during deglaciation, invaded areas previously occupied by the retreating Cassiar lobe (Hughes et al., 1969) complicating the geomorphological record. For example, in Glenlyon map area (Campbell, 1967, p. 25) Selwyn lobe ice invaded Little Salmon River valley after the Cassiar lobe retreated to the south. Proglacial lakes fed by melting ice were established along portions of the study area with outlets draining to the north or northwest and dammed by ice to the south. During Holocene time many of these lakes were drained and the beds incised by streams creating high silt terraces.

1.4.4 Climate

1.4.4.1 Present Climate (last 34 years)

The present climate is continental with long cold winters and short warm summers. It is classified by Thomas (1975) as boreal from the presence of spruce, fir, larch, poplar, and mountain ash. Foscolos et al. (1977) refer to the present climate more specifically as subarctic semiarid.

Records of temperature and precipitation in the study area have been compiled for Carmacks since 1951 (Environment Canada, 1981). Mean annual temperature at Carmacks is -5^{o} C with mean annual precipitation of 247 mm (Oswald and Senyk, 1977).

1.4.4.2 Quaternary Climate (last million years)

The climate during the Quaternary has been inferred (Foscolos et al., 1977) from pedological and geomorphic evidence derived from the outwash and drift of pre-Reid, Reid and McConnell age in the Mayo and McQuesten map areas. A humid period followed pre-Reid glaciation leading to the development of Luvisols. Intensely cold dry periods gave rise to sand wedge formation by thermal cracking or dessication during the Reid and McConnell glaciations. Brunisols developed after the Reid and McConnell advances, indicating a more humid climate.

Climatic reconstruction of the last 30,000 years based on palynology at "Antifreeze Pond", 230 km west of Yukon Crossing, (Rampton, 1971) suggests that precipitation has increased during the last 6000 years and that tree line fluctuations have occurred. Logs in alluvial fan gravels were found at least 100 feet above modern tree line. A sample was dated at 5250 ± 130 yr BP (GSC-718; Lowdon and Blake, 1968). Stumps protruding through White River Ash were found up to 200 feet above modern tree line.

1.4.4.3 Late Holocene Climate (last 2000 years)

Climatic changes for the Late Holocene were inferred from palynology and sediment type for the last 2000 years (Bourgeois and Geurts, 1984) for a tributary of Duke River, 180 km southwest of Carmacks. Three pollen zones, from cores taken from Volcano Creek and Grizzly Creek, were established: the first and third zones (zone I and III) suggest climatic conditions similar to the present. The second zone (zone II) suggests a slightly drier and warmer climate due to the amount of loess, increase in Artemesia, and decrease in Pinus.

Zone I and III have high spruce values and Zone II has decreasing spruce values in pollen samples.

The effect of volcanic eruptions on temperature changes due to increased albedo is discussed by Bray (1979). He concluded that temperatures decrease following ash deposition from 0.07^{o} to $0.41^{o}C$ which persist for several decades.

A 400-year tree-ring chronology from a site along Dempster Highway in Ogilvie Mountains (370 km north of Carmacks) has been used to extend past temperature variations beyond the Dawson City records (beginning at 1902) (Jacoby and Cook, 1981). They infer a warmer period in the late 1700's (p. 414) and a drop in temperature in the mid-1800's followed by Northern Hemisphere warming.

Tree ring evidence on spruce (Rampton, 1971) indicates $2^{o}F$ cooler temperatures during the 200 years prior to 1940.

Climatic changes during the last 300 years inferred from data on ^{14}C production rates and tree ring widths has been reported by Stuiver (1980).

1.4.5 Vegetation

The study area lies in the boreal forest of Oswald and

Senyk (1977). Vegetation on floodplains and islands is mainly white spruce (Picea glauca), balsam poplar (Populus balsaminifera), aspen (Populus tremuloides), willow (Salix sp.), birch (Betula papyrifera) and alder (Alnus crispa) with an understory of prickly rose (Rosa acicularis), horsetail and mosses. Lodgepole pine (Pinus) is found on dry terraces. Grasses and sagewort (Artemesia frigida) occur on southerly facing terrace slopes.

1.4.6 Soils

Floodplain soils are classified as Cumulic Regosols and are found adjacent to the Yukon River where they are associated with Brunisols (Clayton et al., 1977). These soils are found in the subarctic climate of Yukon Valley and arctic climate of Mackenzie Delta.

Older soils have been studied most recently north of the study area but in a similar setting by Tarnacai et al. (1985). Previous pedological studies include that of Foscolos et al. (1977) and Rutter (1970). The McConnell soils which formed during the last 14 000 years are weakly developed. The Reid soils have moderate chemical weathering, exhibit frost shattered fragments and common occurrence of ventifacts. Pre-Reid soils have strong chemical weathering, well developed clay skins, common ventifact occurrences on surface and oriented stones.

1.4.7 Hydrology

The drainage area of the Yukon River above Carmacks is 81,800 km^2. The trunk stream is the northwest flowing Yukon River and the main tributaries are Big Salmon and Teslin Rivers. The Yukon River itself is the fifth largest system in North America with mean annual discharge of 2360 m^3/s at the International Boundary (Hydrological Atlas of Canada, 1978). The length of the Yukon River from Marsh Lake to the Bering Sea is 3600 km. Total drainage area is 845,000 km^2.

The Yukon River at Carmacks peaks during the summer (June, July, August) fed by melting snow accumulated during the winter. Hydrographs indicate a rapid rise in river level followed by a gentle decline after the peak (Appendix I). Discharges at Carmacks are summarized in Table 1.1.

TABLE 1.1 Yukon River Discharge at Carmacks (1952 to 1982)

	m^3/s
Mean annual discharge	746
Mean annual flood	1960
5-year flood	2410
100-year flood	3650
200-year flood	3970
Maximum daily discharge	3600
Maximum instantaneous discharge	5070

Source: Environment Canada. Stage-Discharge Table. Surface Water Data, Yukon and Northwest Territories, 1983.

Reconnaissance scale flood risk and ice jam studies of the Yukon River basin were carried out on behalf of Environment Canada (Fennco Consultants, 1974; Underwood McLellan Ltd., 1983; and Gerard, 1984). These reports outline areas of flood hazards.

1.4.7.1 River Channel Changes (short term)

The earliest research on river channel changes of the Yukon River is that by Eardley (1938). He reported on lateral migration of a wide meander belt in the lower Yukon River in Alaska. His chronology was based on tree diameter from a wooded scrolled floodplain. He concluded from calculated migration rates that the Yukon could migrate across the full 10 mile width of the valley in 1000 years.

More recently short term (about 20 years) changes were established for Water Survey of Canada stations along Yukon River, Yukon Territory as part of a project on geomorphology and hydrology of Yukon River drainage basin (Northwest Hydraulics, 1975). These changes included scour around a bridge pier which was constructed in 1957 at Carmacks.

Studies of river channel changes for other rivers of the same order of discharge include Squamish River (Sichingabula, 1985) and the Missouri River (Hallbury et al., 1979). The Squamish River has migrated at one meander bend 450 m over the time interval of airphotos (1948-1984). The Missouri River has migrated up to 2.5 km during the interval from 1890 to 1923 at a bend near the confluence of the Platte River. Few studies have been carried out on short term migration rates of northern rivers. The annual migration rate of the Noatak River flowing in permafrost conditions in Alaska is 1.5 to 3 metres per year (Kreig and Reger, 1982).

1.4.7.2 River Channel Changes (long term)

Long term river channel changes related to glaciation and lava flows in the Yukon Territory have been documented by Hughes et al. (1972), Thomas and Rampton (1982), Bostock (1936, p. 8-11, 47), Bostock and Lees (1938, p. 4-5), Baird (1964) and Owens (1959). A postulated restoration of the preglacial Yukon River is given by Roddick (1967). High-level valleys in Laberge map area occur at 2700 to 3000 feet elevation of which one valley, extending from Lake Laberge to Mandanna Creek, may have been the original course of Yukon River (Bostock and Lees, 1938, p. 4). In Carmacks map area an earlier valley of the Yukon lies north of Minto along the route of the Klondike Highway to Stewart River (Bostock, 1948, p. 62). Farther downstream but still in Carmacks map area the presence of flows of Selkirk volcanics in the bottom of valleys suggest that the present topography was established at the time of lava flow. Volcanic flows opposite Fort Selkirk dammed rivers and forced the Yukon to cut across a spur of its former valley (Bostock, 1936, p. 47).

Owen (1959c) suggested that the Yukon River previously occupied the centre of the valley west of Five Finger Rapids now occupied by decaying ice deposits. As a result the Yukon was forced to cut a new channel on the eastern side of the valley, partly through bedrock. Other diversions related to glaciation are the diverting of Big Creek into a bedrock canyon southwest of Minto (pers. comm., D. Tempelman-Kluit). The previous course was through the more direct route to the east. Merrice Creek and Crossing Creek have been similarly diverted (Bostock, 1936, p. 11). Another example of stream capture was noted by Bostock in Tatshenshini River valley (Coutts, 1980, p. 211). The tributary, Pirate Creek, had captured the headwaters of Robbed Creek. Another example of stream capture was given by Bostock (Hughes, 1983, pers. comm.) where Pirate Creek and Tonsure Creeks in McQuesten map area have been altered by glaciation.

The Klondike River, a tributary of the Yukon, flowed southeast prior to glaciation (Hughes et al., 1972). Its course was blocked by glacial ice of the earliest glaciation diverting the drainage to the opposite direction (Thomas and Rampton, 1982). Other examples of river channel changes related to glaciation in the Yukon River drainage basin can be inferred from the meltwater channels shown on the glacial map of central Yukon Territory (Hughes et al., 1969).

1.5 The Reaches

Three reaches were selected from the area covered by the east lobe of the White River Ash where the tephra is more than 10 cm thick (using the isopach maps of Bostock (1952) and Lerbekmo et al. (1975)). These reaches provide a range of planforms from multichannel, single channel, straight to winding channel.

The limit of the last advance (McConnell) separates the reaches with and without meanders. The winding reaches are in the most recently glaciated area.

The geomorphology, surficial geology and channel characteristics of each reach is described.

1.5.1 Hootalinqua - Big Salmon Reach

This reach extends, along the centreline of the river, from 14 km downstream of Hootalinqua to 12 km below Big Salmon (Fig. 4.1 in pocket). The total reach length is 44 km and the river surface drops about 20 m in this distance giving an average water surface slope of 0.00047.

A single winding channel predominates though it is interrupted by a few islands particularly at Cassiar Bar and downstream from Big Salmon River. Four subreaches based on channel geometry and terraces are: (1) a 21 km long meander belt with terraces 30 to 100 m above river level, (2) a 10 km single channel stretch with terraces below 100 m, (3) a 10 km moderately sinuous multichannel stretch with 40 and 66 m high glaciolacustrine terraces, and (4) a 7 km meander belt with scrolled alluvial plains below 10 m and outwash above 15 m.

Channel width averages 200 m and varies between 75 m and 300 m widening near the Big Salmon River confluence. The valley is 1.5 to 3.5 km wide and has an average slope of 0.0008. Bend radius varies from 200 m to 800 m in the upstream meander belt where the sinuosity index is 2.24.

1.5.2 Eagle's Nest Bluff - Carmacks Reach

This reach lies in a west-northwesterly trending valley downstream from Eagle's Nest Bluff to Carmacks (Fig. 4.2 in pocket) and continues in a northwest trending valley. The reach is 68 km long, along the centreline, and between 100 and 275 m wide.

A meander belt 2.5 to 3 km wide is entrenched in recessional (retreatal) outwash terraces 6 to 20 m above river level in the first 40 km and entrenched in ice contact valley fill with knob-and-kettle topography up to about 100 m above the river for the last 28 km. Multiple point bars occur downstream from bend apices and near the convex bank. Floodplains have meander scrolls and arcuate patterns along short straight channels.

The river is incised in glacial and glaciofluvial deposits and postglacial alluvium. The highest terrace remnants coincide with the 610 m (2000 ft) contour. These highest terraces are associated with knob-and-kettle topography and coincide approximately with hanging glacial deltas. Above this level abandoned meltwater channels form a northwest drainage pattern up to 760 m (2500 ft).

Braided channel patterns are evident on airphotos downstream of Mandanna Creek valley in a northerly prograding fan. Gravel dominated fluvial deposits and till form valley fill the depth of which (from borehole and seismic surveys; Hardy Associates, 1980) is up to 110 m and as wide as 1000 m.

The sinuosity index is high for the study area (1.85) but not as high as local sinuosity in the upstream sub-reach of Klondike Bend (2.24). The river surface slope averages 0.00041 and the valley slope is 0.001.

1.5.3 Rink Rapids - Minto Reach

This downstream reach extends from Rink Rapids to Minto in a northwest trending valley (Fig. 4.3 in pocket). The main channel is 50 km long and divided by numerous midchannel islands in a low sinuosity (1.13) anastomosed reach. Bars which are vegetated, include examples of crescentic, medial, and lateral bar types.

Yukon River is entrenched in McConnell age outwash plains for most of the reach with Reid age drift at the downstream end (Hughes et al., 1969; 1972). Channels pinch and swell with nodes (pinches) at bedrock anchored walls and swells where the channel bifurcates around midchannel islands. The glacial history of the valley differs from the other two reaches which were last glaciated by McConnell ice. The McConnell limit extended to Yukon Crossing (Hughes et al., 1969) with a thick valley outwash sloping from 93 m above river level (about 580 m elev.) at Yukon Crossing to about 30 m (about 500 m elev.) at McCabe Creek. A lower outwash terrace was traced to Minto where it is 6 m above river level. Before the last glaciation this part of the valley was buried by Reid ice to an elevation of about 600 m based on the map of Hughes et al. (1969).

Terraces 6 m and more above river level are gravel to within 1 m of the top. They are crudely stratified and pebbles and cobbles are imbricated. The gravel is covered by sand with a veneer of loess. Sand dunes occur on terraces below 16 m in the Yukon Crossing area. Terraces above 30 m exhibit braided channel patterns discernible on airphotos. Fans extend from the tributaries and entrenched in older terrace deposits.

Terraces 3 m and lower are sand, silty sand, silt and organic layers. Volcanic ash is buried or absent. Gravel was observed locally below river level to 1.5 m above river level. On island cutbanks the sharp contact between gravel and sand dips downstream.

CHAPTER TWO

WHITE RIVER ASH

2.1 Introduction

Postglacial volcanic ash covers parts of British Columbia, Alberta, and Yukon in western Canada and adjacent northwestern United States (Figure 2.1) (Bostock, 1952; Powers and Wilcox, 1964; Hanson, 1965; Nasmith et al., 1967; Westgate and Dreimanis, 1967; Lerbekmo et al., 1975; Souther, 1976; Clague, 1981b). The eruptions from which they derive are associated with Cordilleran volcanics in the Garibaldi, Anahim, Wrangell and Stikine Belts (Rogers and Souther, 1983). The ash provides stratigraphic markers between 6400 years BP and 1000 years BP.

The deposition time of recent volcanic eruptions such as Krakatoa in 1883 and Mount Hekla in 1947 lasted only a couple of days. The Mount Mazama eruption may have lasted three years (Kittleman, 1979). Volcanic eruptions of Mount St. Helens, Washington during 1980 spanned about three months (Waitt et al., 1981). The time range of deposition shows that ashes are precise geologic time markers.

The White River Ash, derives from a source in the Wrangell belt (Lerbekmo and Campbell, 1969; MacKevett, 1978), is interpreted to be a Plinian eruptive (Hanson, 1965; Downes, 1985). Plinian eruptions result from extreme explosive power and produce widely dispersed ash (Walker and Croasdale, 1970;

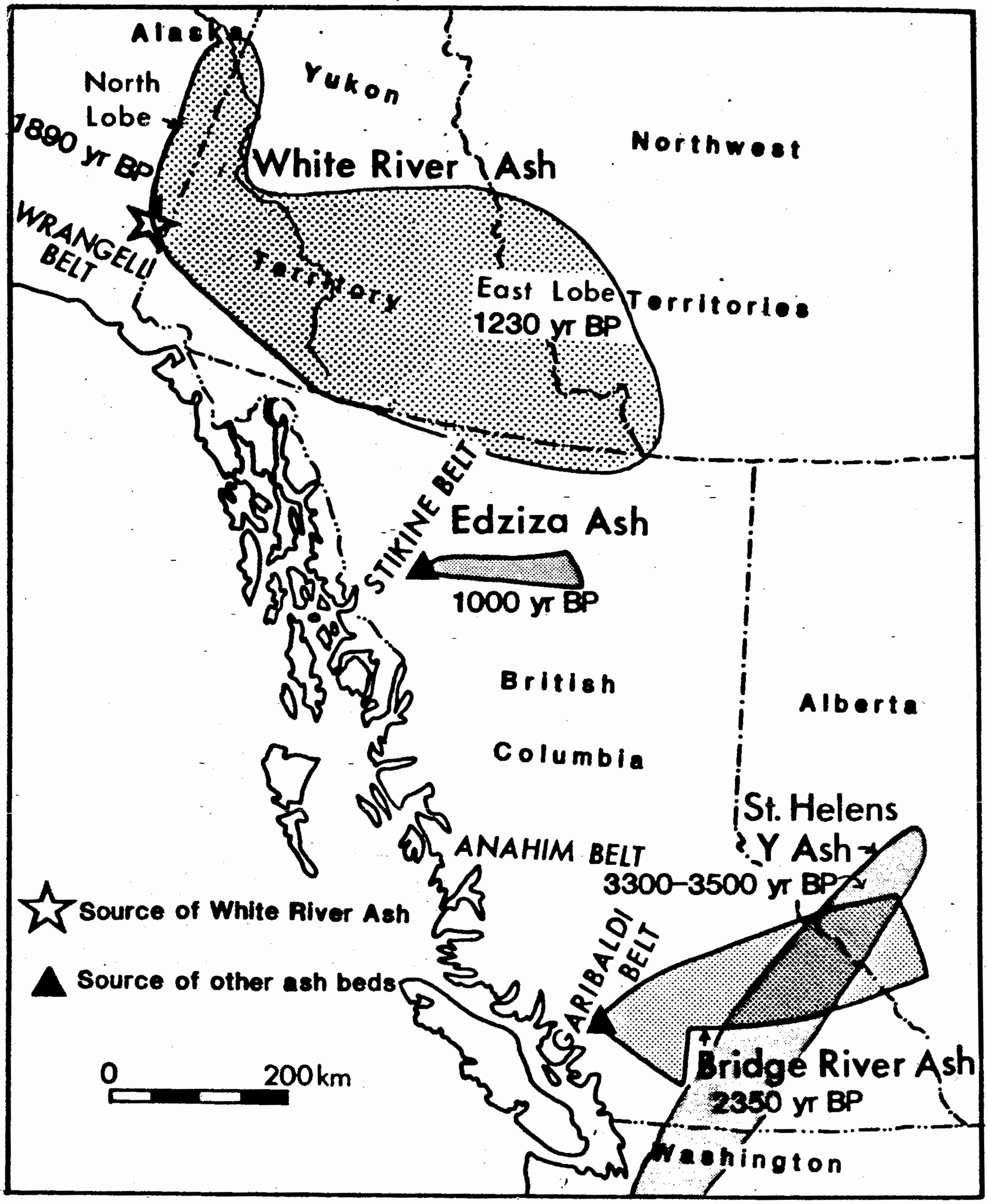


Figure 2.1 Distribution and sources of volcanic ash beds younger than 3500 yrs BP in Canadian Cordillera and ajacent Alaska.

Source: Lerbekmo et al., 1975; Souther, 1976; Mathewes and Westgate, 1980, Clague, 1981b.

Walker, 1981). Paleocene volcanic ash near Norman Wells, NWT is believed to represent Plinian eruptions in central Yukon Territory (Ricketts, 1985) from a similar source.

The White River Ash is an extensive and thick Cordilleran tephra; it covers 324,000 km^2 (Lerbekmo and Campbell, 1969). It was noted by geologists and surveyors exploring the Yukon in the late 1800's and early 1900's particularly along river courses (Schwatka, 1885; Dawson, 1889; McConnell, 1890; Hayes, 1892; Brooks, 1900; Moffit and Knopf, 1910; Cairnes, 1910; Cairnes, 1915; Capps, 1915; Lees, 1936, p. 22; Johnston, 1936, p. 17).

2.2 Petrology

The ash is rhyodacite in composition; its constituents are glass, hornblende, hypersthene, and magnetite (Lerbekmo and Campbell, 1969; Lerbekmo et al., 1975).

2.3 Distribution and Age

The ash forms a discrete white layer on or near the top of surficial deposits extending from near the Klutlan Glacier (Lerbekmo et al., 1975) to the headwaters of the Keele River some 720 km to the east (Capps, 1915). Traces of White River Ash were noted near the Fisherman Lake, NWT some 970 km from the source (Charles Schweger, pers. comm. in Workman, 1978, p. 45) and at Eildun Lake, NWT 940 km from the source (Slater, 1985).

White River Ash was noted by Gabrielse (1985, pers. comm.) near Blue River in northern British Columbia. G. M. MacDonald noted White River Ash 10 cm below the top of a peat along the Natla River, Northwest Territories (Blake, 1982).

The distribution was studied by Capps (1915) who outlined one lobe and by Bostock (1952) who recognized two distinct lobes. Bostock attributed these to a sudden change in wind direction during one eruption or to two surges of the same eruption during a gradual wind shift. The larger lobe lay on the east and a second narrow lobe lay to the north. A map (Fig. 2.2) shows the study area in relation to the 15 cm isopach. Others have modified Bostock's isopach map (Hanson, 1965; Lerbekmo and Campbell, 1969; Rampton, 1969; Hughes et al., 1972).

The two lobes differ in age as determined from radiocarbon dates on organic matter above and below the ash. The north lobe is about 1890 yr BP (Fernald, 1962; Lowden and Blake, 1968; Stuiver, 1969; Hughes et al., 1972; Lerbekmo et al., 1975; Denton and Karlen, 1977; Blake, 1982, p. 14-15) and east lobe, of interest here, is dated as about 1230 BP (Denton and Karlen, 1977). During this work a sample of wood from within ash 1 km downstream of Williams Creek was dated at 1210 $\pm$ 60 yr BP (GSC-7441).

Present wind directions suggest that the east lobe fell during winter and the north lobe during summer (Hanson, 1965, p. 27-28). Hanson suggested that the east lobe's preservation may reflect eruption during a snow fall which might aid compaction

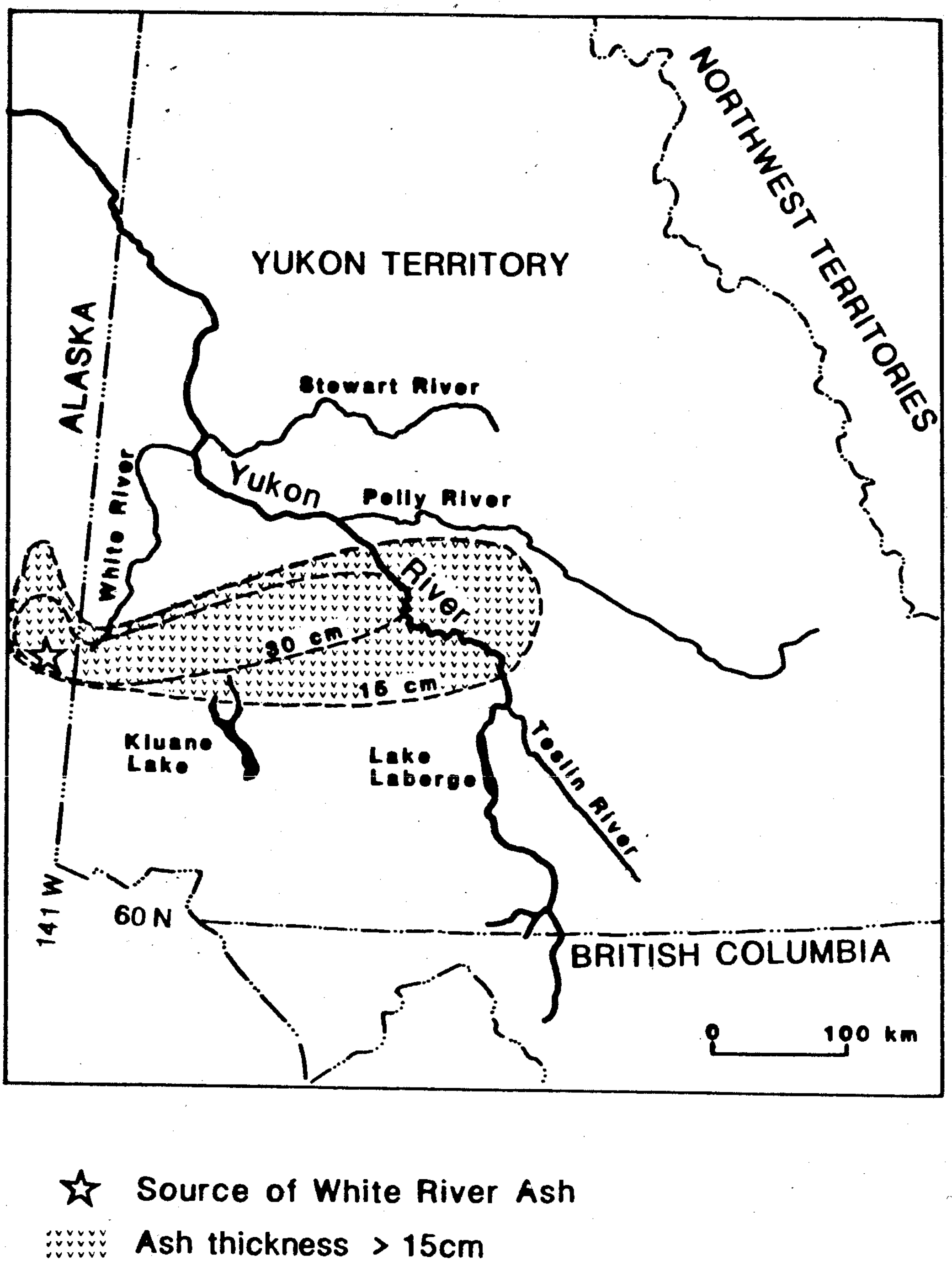


Figure 2.2 Isopach map of White River Ash.

Source: Bostock, 1952.

and account for preservation on slopes.

Grain size uniformity of the east lobe ash implies a violent short-lived event (Hanson, 1965; Lerbekmo et al., 1975) characteristic of Plinian eruptions.

2.4 Stratigraphic Position

The ash occurs from mountain tops to valley bottoms but its position within other recent valley deposits, particularly floodplains, is discussed to show how it fits in with fluvial, eolian and organic deposits.

White River Ash is locally overlain by fluvial deposits of silt and sand particularly on floodplains. On high terraces it is overlain by eolian deposits and recent soils. In Dezadeash map area, 170 km south of Carmacks, wind blown soil up to 0.6 m thick covers the ash (Kindle, 1952).

Buried organic accumulations including peat occur locally above the ash (Moffit and Knopf, 1910). Ash is well preserved on level ground and on slopes up to 40^{o} (Lerbekmo and Campbell, 1969).

Lees (1936) noted the ash about 1 m above river level along part of Teslin River. Dawson (1889) noted the ash along Pelly River and Yukon River where in one place it is underlain by undecayed logs and a few feet of sand. Bostock (1952, p. 37) noted ash on two islands beyond the study area; one island is near the mouth of Selwyn River and the other is a few kilometers above the mouth of White River.

CHAPTER THREE

METHODS

3.1 Introduction

The study area was delimited through a literature review and through study of topographic maps for river patterns of different geomorphic settings. Air photographs were interpreted and compiled on 1:50 000 and 1:250 000 topographic maps. Four reaches were selected for field examination as examples of typical river planforms for Yukon River. The furthest downstream reach, from Minto to Fort Selkirk, includes Ingersoll Islands; it was rejected because observable ash is rare.

The field work was carried out by the author and Brian Lueck from a freighter canoe between June 7 and August 3, 1984.

3.2 Field Methods

A reconnaissance canoe traverse from Lake Laberge to Minto familiarized us with the river, its ash and the cutbank exposures.

3.2.1 Traverses

Floodplain traverses allowed us to map the ash distribution and the thickness of post-ash accretion. The floodplain includes the river channel, point bars, meander scrolls, sloughs, levees and overbank deposits (Leopold et al., 1964, p. 317). The floodplain is where volcanic ash is eroded or where material is deposited above the ash; it is not a specific flood recurrence interval stage. Leopold et al. (1964) suggest a flood level reached on average two out of three years (a recurrence interval of 1.5) is found on well-defined floodplains. They also note that floodplains are covered by 0.8 of the mean bank height with a recurrence interval of about 50 years. Their findings are based on rivers in southern United States and are not considered applicable to northern rivers. Smith (1980) has determined an average bankfull discharge of large northern rivers at a recurrence interval of nine years. Ths is attributed to river ice enlarging the channel; a geomorphic process not active in Leopold's river examples. Ice damming can also cause flooding. Floodplains are divided into two types along the Yukon River. The first is floodplain without ash; formed following erosion of the ash layer during post-ash time or formed in an area previously occupied by the river channel(s) and the second is floodplain with ash; formed both before and after ash deposition (Fig. 3.1). The floodplain is simply the zone of fluvial deposition since ash deposition.

Accreted floodplain is the surface attached to the bank, possibly a former island. For area computations, total floodplain includes accreted floodplain, islands, bars and sloughs.

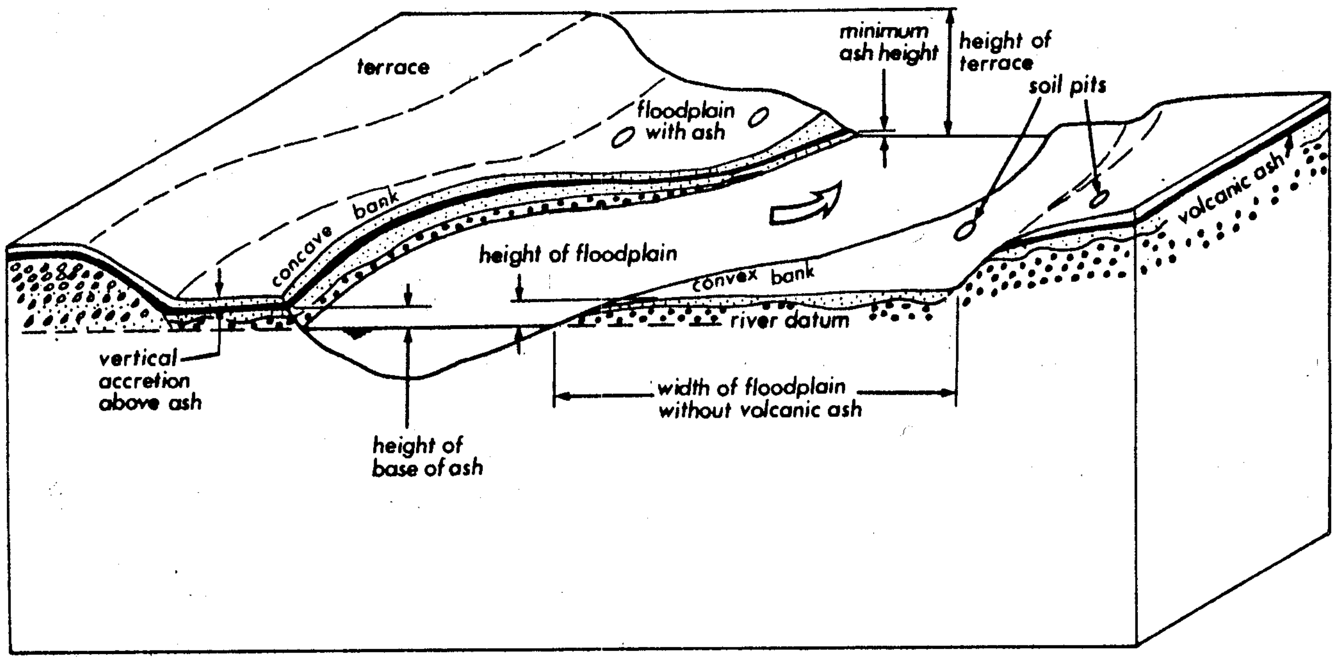


Figure 3.1. Block diagram illustrating features measured for a hypothetical section of Yukon River.

Soil pits were dug along chained and paced compass lines perpendicular to the channel to establish the ash limits. A soil auger was used with a depth limit of 1.8 m. Dug pits were limited in their maximum depths by the permafrost table; permafrost occurs at a 30 cm depth in the study area. Natural exposures along riverbanks augment the shallow pits.

The limits of ash were plotted on airphotos (Appendix IV) and transferred to 1:50 000 scale topographic maps which were used to infer the area traversed by the river following eruption.

Floodplain with ash was identified at sites if some or all of the sediment overlying the ash layer resembled fluvial deposits. Bedding and buried organic layers were interpreted as fluvial process indicators. Eolian deposits are massive, well sorted, and cohesive by contrast with the fluvial material. Gill (1972) differentiated eolian from fluvial deposits in the point bars of Mackenzie Delta by homogeneity and stratification.

The relative heights of terraces adjacent to the channel and farther away were measured with altimeters and a level and 1.5 m range pole. Terrace stratigraphy was studied in cutbanks, bare slopes, road cuts, and soil pits. Distribution of tephra on scarps, benches and gullied surfaces was noted to permit qualitative evaluation of ash preservation and of terrace stability.

As used here terraces are surfaces without evidence of post-ash flooding although dunes, organic material and soil are present locally. This matches Leopold et al.'s (1964, p. 459) definition of terraces as abandoned floodplain.

Terraces are subdivided by morphology, composition, height, surface deposits and continuity. Scrolled terraces show ridge and swale morphology. Anastomosed terraces have irregular secondary channels with or without water (abandoned or active). Paired terraces occur at the same level on both sides of the valley. Channelled terraces have channel scars resembling the braided pattern of meltwater channels.

3.1.2 Vertical Control (elevations)

Vertical control of the river level was afforded by hand levelling Geodetic Survey of Canada bench marks located near the river (Appendix III). Bench marks not amenable to hand levelling were levelled by altimeter. Surveyor's field notes (provided by Surveys and Mapping) indicate the bench mark position above river level. The drop in river level upstream and downstream of Five Finger Rapids is 0.82 m as determined from the surveyed river surface in July, 1956 (Owens, 1959c). Surfaces less than 15 m abover river level were measured by hand. Hand levels are considered accurate to 3 cm for banks below 3 m and 15 cm for higher banks and inland readings. Surfaces higher than 15 m above the river were measured by altimeters with an accuracy of 1 m.

3.3 Office Compilation Methods

Morphological measurements were made from 1:50 000 scale topographic maps (NTS 105E, 105L, 115I). Sinuosity, the ratio of river centreline length to down valley distance, was calculated. Meander loops were classified according to Brice's (1974) scheme. Bend radius was measured subjectively as the arc closest to the channel centreline. The procedure is outlined by Williams (1984). Floodplain area was measured with a planimeter calibrated to graph paper and checked by the grid method (Brinker, 1969).

Bar type terminology follows Church and Jones (1982) (eg. lateral bars, longitudinal bars), and Nanson and Page (1983) (eg. concave benches).

3.3.1 Vertical Floodplain Accumulation Diagrams

The relationship between height of ash in floodplains and the vertical accretion above ash was graphed to show the influence of floodplain elevation on accretion rates (Fig. 4.15, 4.27, and 4.41). Envelopes of maximum accretion were sketched in to show the limit of flood deposition. These envelopes define maximum accretion in relation to floodplain elevation above river datum. Best fit lines by least squares linear regression permit predictions of floodplain accretion beyond data points. The equation of the best fit lines allows for the calculation of average accretion.

3.3.2 Long Profile Construction

The longitudinal profile or long profile is a graph of the height of the river against downstream distance. The river surface was drawn from located and surveyed bench marks and interpolated. The downstream profiles in this work (Fig. 4.16, 4.28, 4.42 and 4.43) also include terrace level and height of ash (m) matched with channel distance (river km) using the most upstream point of Hootalinqua reach as the origin (0 km). Elevations were adjusted to the minimum rate of change of river level date of June 23, 1984 (the river datum date) (Appendix I). Measurements were adjusted to the river datum date using the daily stream gauge records at Carmacks station (Water Survey of Canada) (Appendix II).

Some bench marks that approximate the height of terraces but which were not levelled were projected onto the profile. This was useful particularly for outwash terrace correlation in Rink Rapids reach.

The lowest level of ash on floodplains was drawn on the profile. It measures the amount of incision of Yukon River. The highest flooded level of floodplain with ash approximates the 500-year flood. Shadings identify the generalized floodplain without ash, floodplain with ash, and alluvial terraces. Ash bearing and ash free floodplains overlap by about 1.5 m.

3.3.3 Reach Maps

Three reach maps (Fig. 4.1, 4.2, and 4.3 in pocket) compiled from airphoto interpretations, measured sections and profiles are the main data set. The map units are based on morphology, composition, elevation, soil development and relationship to glaciation.

CHAPTER FOUR

RESULTS

The fundamental principle used in analysis is that those parts of the floodplain with ash are not eroded since ash deposition. The stability of the present planform is addressed in terms of extent of floodplain without ash. River activity is divided subjectively into low activity (0.02 m/yr of lateral migration), moderate activity (between 0.02 and 0.1 m/yr of lateral migration), and high activity (greater than 0.1 m/yr of lateral migration).

4.1 Hootalinqua - Big Salmon Reach

This reach (Fig. 4.1 in pocket) has a meandering planform with varied sinuosity and channel morphology and confining terraces at different levels (Fig. 4.4 and 4.5). The channel is typically a single thread entrenched in outwash and glaciolacustrine deposits with isolated exposures of till overlying bedrock. Downstream it includes a multiple channel meandering planform.

Downstream from this reach the Yukon River changes from a meandering planform to a dominantly single channel low sinuosity reach. The valley narrows and the river is confined by ice-contact glaciofluvial deposits mapped by Morison and Klassen (1980).

Surficial geology in this reach was carried out by Owen (1959a,b) and Boyer (1960) who mapped the geology of two dam sites; Hootalinqua dam site at the junction of Teslin and Yukon Rivers and Big Salmon dam site 19 km below the mouth of Big Salmon River. Bostock and Lees (1938) noted terraces and elevated valleys of Laberge map area (Coghlan and Ogilvie valleys, terrace levels at 790 m and 850 m). Northwest Hydraulic Consultants (1975) reported on hydrology and geomorphic characteristics of the Yukon River at Water Survey of Canada stations. Morison (1979), in an unpublished manuscript of field notes and location map, described surficial geology sections along the Yukon River between Lake Laberge and Carmacks.

4.1.1 Glacial History of Hootalinqua Reach

This reach was ice covered during the pre-Reid, Reid and McConnell advances. Pre-Reid and Reid age landforms and related periglacial features and paleosols were not recognized in the valley. One till was observed in riverbank exposures overlain by gravel, sand, and laminated silt in several places in high-level terraces. The fresh glacial landforms suggests deposition during the last advance (McConnell) although glacial deposits are not dated in the reach. Ice flow directions mapped by Hughes et al. (1969) and Campbell (1967) trend northwesterly. The final advance of glacial ice probably

Figure 4.4. Meander bend in upstream stretch of Hootalinqua - Big Salmon reach with unvegetated gravel accreted to wooded floodplain in foreground. Ridge and swale topography occurs on floodplain. Island in centre is referred to in text as Stage 2 in floodplain accretion scenario (see section 4.2.5).

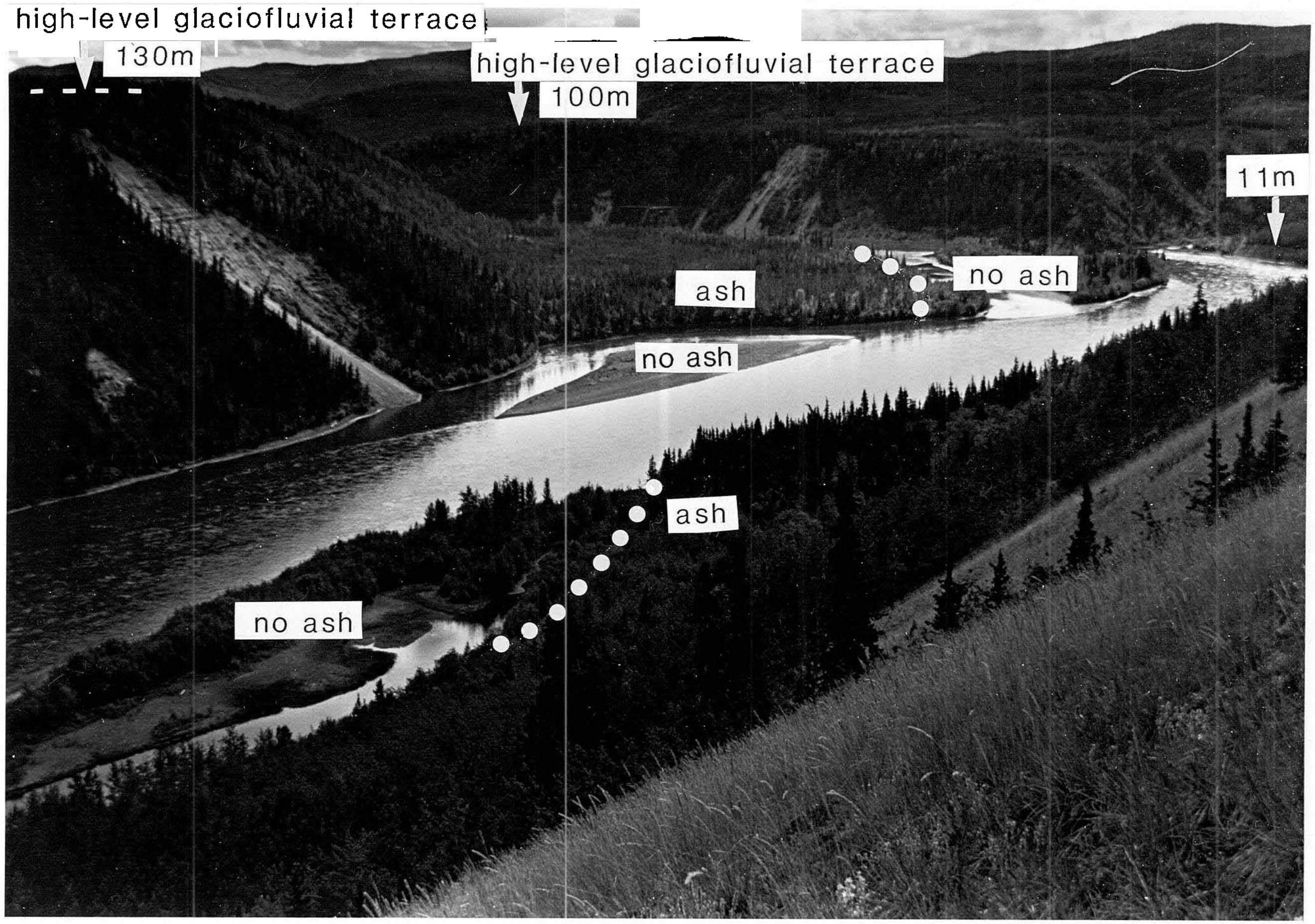


Figure 4.5 Yukon River is entrenched in high-level glaciofluvial terraces at Cassiar Bar downstream of the first meander belt. Vegetated point bar and lateral bar are devoid of ash. A logjam blocks the mouth of the minor channel in foreground.

followed the valleys of Yukon and Big Salmon Rivers. Ice-contact deposits occur up to about 610 m elevation along both valley walls. Above these hummocky surfaces abandoned lateral meltwater channels are cut presumably along the successively lower glacial margin during retreat. Similar lateral meltwater channels have been described in Whitehorse map area (Wheeler, 1961) and in Glenlyon map area (Campbell, 1967).

Ice stagnation followed leaving disintegration topography. Meltwater deposited gravel in esker and kame complexes and deposited fine sand and silt in proglacial lakes. Meltout of buried ice led to pitted outwash fans which were dissected and deflated supplying eolian sediment. A blanket of widespread loess covering the glaciofluvial terraces was deposited. This loess is tentatively correlated with the "McConnell loess" on the terraces of Stewart River valley in McQuesten map area north of Fort Selkirk. The loess may derive from unvegetated outwash in the valley. The loess helps distinguish glaciofluvial terraces and postglacial alluvial terraces. After glaciation a weak brunisol, characterized by a weakly developed B horizon and a well developed Cca horizon, formed on the loess.

4.1.2 Major Geomorphic Map Units of Hootalinqua Reach

The last glaciation of this reach and postglacial incision produced terraces and fans of various compositions, age and height. The terraces are the key in establishing the geomorphologic evolution of the valley. The terraces can be grouped into four sets on height, morphology and composition. The present channel planform may be influenced strongly by the nature of the confining terraces. High cobbly terraces would constrain migration more than low sand terraces.

The geomorphic units are:

Fans

Paired terraces:

High-level glaciofluvial terraces (90-130m)

Glaciolacustrine terraces (30-75m)

Low-level glaciofluvial terraces (15-40m)

Scrolled terraces and floodplains:

Low-level terraces with volcanic ash (3-11m)

Floodplain without volcanic ash (0-4m)

4.1.2.1 Fans

Tributary fans are commonly incised to the level of low glaciofluvial terraces and younger alluvium. The fan morphology emanates from tributaries cut through high-level terraces. Irregular shallow channels are present on the surface of the fans. Most of the larger fans, for example in Klondike Bend subreach, have been incised since deposition both by tributary streams and Yukon River.

The incised fans contain stratified washed gravel and sand with diamictons. Gritty sand, which is absent in valley floor alluvium, occurs in the fans.

The fans are interpreted as paraglacial. Church and Ryder (1972) and Jackson et al. (1982) consider that following glaciation abundant sediment is available for transport and redeposition at higher rates than those that prevail during nonglacial intervals. Toward the end of the paraglacial period the sediment yield drops to the nonglacial levels (Fig. 9 of Church and Ryder, 1972).

A fan that was active before and after White River Ash deposition is incised by the river opposite the island at Big Salmon (river km 33.2). The cutbank shows a gravelly fan-shaped body sloping upstream and downstream from a tributary above river level. Ash exposed about 1.5 m above river level follows the landform surface. The ash is also overlain by 0.4 m of gravelly sediment. The present tributary channel is at one end of the fan.

4.1.2.2 Paired Terraces: High-level Glaciofluvial Terraces (90-130 m)

The highest terraces are 90 to 130 m above the river (see Fig. 4.4 and 4.5). Hummocky knob-and-kettle topography and meltwater stream channels along valley margins suggest proximity to glacial ice. Landforms include pitted outwash, kames, eskers and crevasse fillings. Remnants of this terrace set can be traced from Klondike Bend to 3 km downstream from Cassiar Bar adjacent to the east wall of the valley (Fig. 4.1 in pocket, Fig. 4.4 and 4.5). An esker complex merges with this surface at the upstream end in a valley occupied by irregularly shaped lakes. The long eskers, kettle holes and lack of recessional moraines (Shaw, 1985, p. 68) indicate that this terrace is the product of a former stagnant ice mass rather than a retreating ice margin.

In river bank exposures these terraces are composed of crudely- to well-stratified gravel and sand, glaciolacustrine silt, and diamicton. Bedrock occurs at the base of some cutbanks. Exposures are capped by loess overlain by volcanic ash and soil. Cliff top dune sands overlie and underlie volcanic ash near the crown of banks. The high-level terraces are deeply entrenched and severly restricts meander bend migration.

Volcanic ash on the slopes up to some high terraces away from the river banks (for example, river km 19, 20.8, and 23) suggests that parts of these scarps are stable in the 1230 year term.

4.1.2.3 Paired Terraces: Glaciolacustrine Terraces (30-75 m)

The second set of terraces are 30 to 75 m above river level and typically have flat surfaces modified by eolian deposits; they may abut large kettle-like features (for example, south of

Cassiar Bar, west side of valley, river km 11). A myriad of ponds interpreted as thermokarst ponds cover the terrace surface between Walsh Creek and Big Salmon River east of the limit of mapping. Klassen (1979) described how melting frozen silts produced similar irregularly shaped ponds in valley flats near Whitehorse.

Bostock and Lees (1938, p. 5) noted 30 m of silt beds exposed in the bank downstream of Big Salmon River. Near the mouth of Walsh Creek the silt was measured to 40 m above river level (Fig. 4.6). This silt abuts a 66 m high bench in the lowland between Big Salmon River and Walsh Creek and along the west side of Yukon River. Upstream and downstream of these terraces pitted outwash occurs at least 90 m above the river along both sides of the river.

Sections of the 66 m bench upstream of Big Salmon (river km 26-37) are composed of laminated light-coloured silt and fine sand sometimes with gravel capping top surfaces. Scarps not actively eroded are gullied. A white salt (?) precipitate is present near the base of the sections presumably from groundwater seepage.

The deposits are interpreted as glaciolacustrine fills deposited in proglacial lakes. They are mapped as two units, a lower bench at about 40 m and a higher bench at about 66 m. The two levels may reflect lowering of the lake outlet during its evolution. Alternatively post-depositional faulting may have occurred in what was originally a single high terrace or the river was ponded by a readvance of Selwyn lobe.

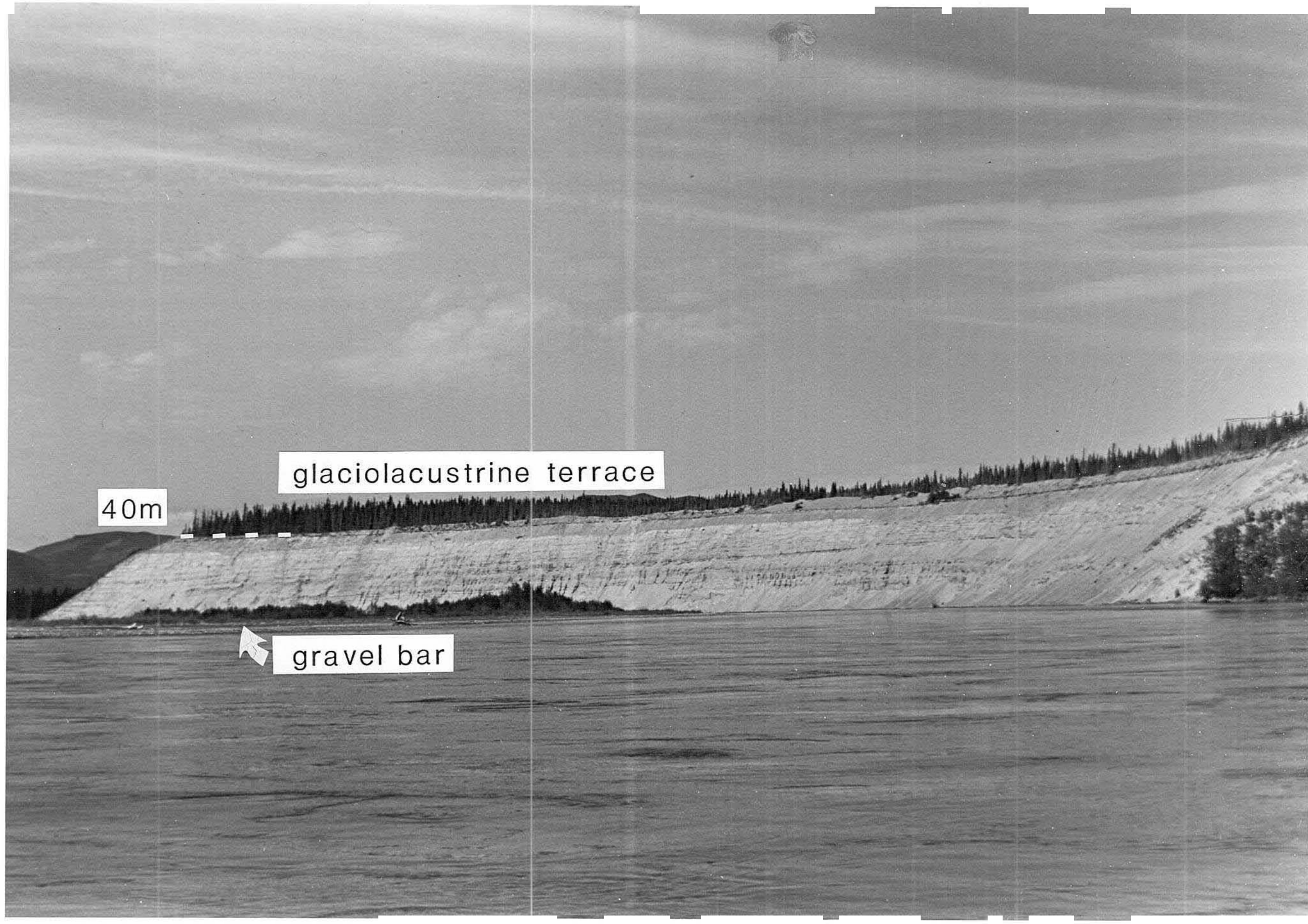


Figure 4.6 Exposure of glaciolacustrine bench in Big Salmon subreach. The height of this terrace level is 40 m above river level. A gravel bar with alder vegetation in the mid-distance is an example of the lowest bars found in this multiple channel bend.

4.1.2.4 Paired Terraces: Low-level Glaciofluvial Terraces (15-40 m)

The third set of terraces are gently downstream sloping benches between 15 to 40 m above the river. Remnants are found along the straight channel upstream from Cassiar Bar as narrow benches on both sides of the river. No channel scars were noted on airphotos to suggest deposition from braided rivers. The postglacial Yukon River may have filled this narrow stretch which is only about 300 m wide between the 90 m high-level glaciofluvial terraces.

Cutbanks are of poorly-stratified gravel and sand with silt interbeds. Tabular cross-bedding was noted near the tops of some exposures. Reddish loess forms a veneer in turn overlain by volcanic ash.

These terraces are interpreted as recessional outwash. They are the immediate precursors of the meander belt deposits deposited when the sediment supply was reduced and vegetation abundant.

4.1.2.5 Scrolled Terraces and Floodplain: Low-level Terraces and Floodplain with Volcanic Ash (3-11 m)

The fourth and lowest set of terraces in Hootalinqua reach are 3 to 11 m high and have ridges and swales (scrolled alluvial plain) accentuated by vegetation (see Fig. 4.4). Oxbow lakes are absent unlike some Yukon River tributaries.

This valley fill commonly merges with the ash free floodplain.

The low terraces are mostly a fining-upward alluvial fill. The lower part is washed cobbly gravel. It is overlain by rhythmically bedded sand with low angle cross-stratification (epsilon cross-bedding (?) Allen, 1963) and the top metre or so is finer sand and silt with organic horizons capped by volcanic ash and soil. Bedded sand or gravel are absent above the ash but organic horizons and forest litter are present locally.

The terraces may represent meandering river deposits formed as successive point bars. The basal gravel is interpreted as channel and bar; the upper sand as overbank sediment.

4.1.2.6 Scrolled Terraces and Floodplain:
Floodplain without Volcanic Ash (0-4 m)

The floodplain, or surface with post-ash fluvial deposits, is most commonly 1.5 m above the river; other surfaces occur at 0.5 and 1.0 m. The 1.5 m surface probably marks the 5-year flood level; at Carmacks it is 1.29 m above river datum. The bankfull height of Yukon River probably corresponds to the 1.5 m level.

The floodplain includes islands and unvegetated bars near the banks exposed during mapping or visible on airphotos. Islands show a fining-upward sequence in sections and soil pits. The bars are gravel with or without a thin sand covering.

Floodplain with and without ash are identical in the field and they overlap in height (above river level).

Alder, willow, and poplar are common on the floodplain without ash. Vegetation changes with distance from the channel and floodplain level. Alder is present to river level and willows dominate farther back. Still farther from the river poplars dominate. Behind the poplars stand the spruce. Buried ash locally floors floodplains with spruce forest and willow covered abandoned sloughs, but not under the alders along the bank. Poplar forest areas also lack ash.

4.2 Post-ash Channel Behaviour of Hootalinqua Reach

Bank sections and traverses show that the channel has been stable since the ash was deposited. Only minor changes have occurred for much of this reach except for a 5 km stretch downstream of Big Salmon River. The area traversed by the river is inferred to be that area of total floodplain without ash which is 3.1×10^6 m^2.

The Hootalinqua reach is subdivided into four subreaches: Klondike Bend, Cassiar Bar, Big Salmon and Walsh Creek (Fig. 4.7).

Klondike Bend subreach comprises a dominantly single channel meandering planform extending from the beginning of this reach to near Cassiar Bar. Lateral migration of the river eroded fans, high-level glaciolacustrine sediments, high-level glaciofluvial terraces and more recent alluvial plain fills as the Yukon has migrated across the valley.

Gravel (cobble) bars occur downstream of bend apices as crescentic lags overlain by sand (see Fig. 4.4) with buried organic horizons in the top metre. Floodplain banks opposite midchannel islands are being cut and ash is exposed in these banks.

Terraces of glaciofluvial and glaciolacustrine fill on the concave (outer) bank are eroded. Ash is preserved on some uncut, steep scarps of these terraces indicating slopes have been stable for at least the last millennium.

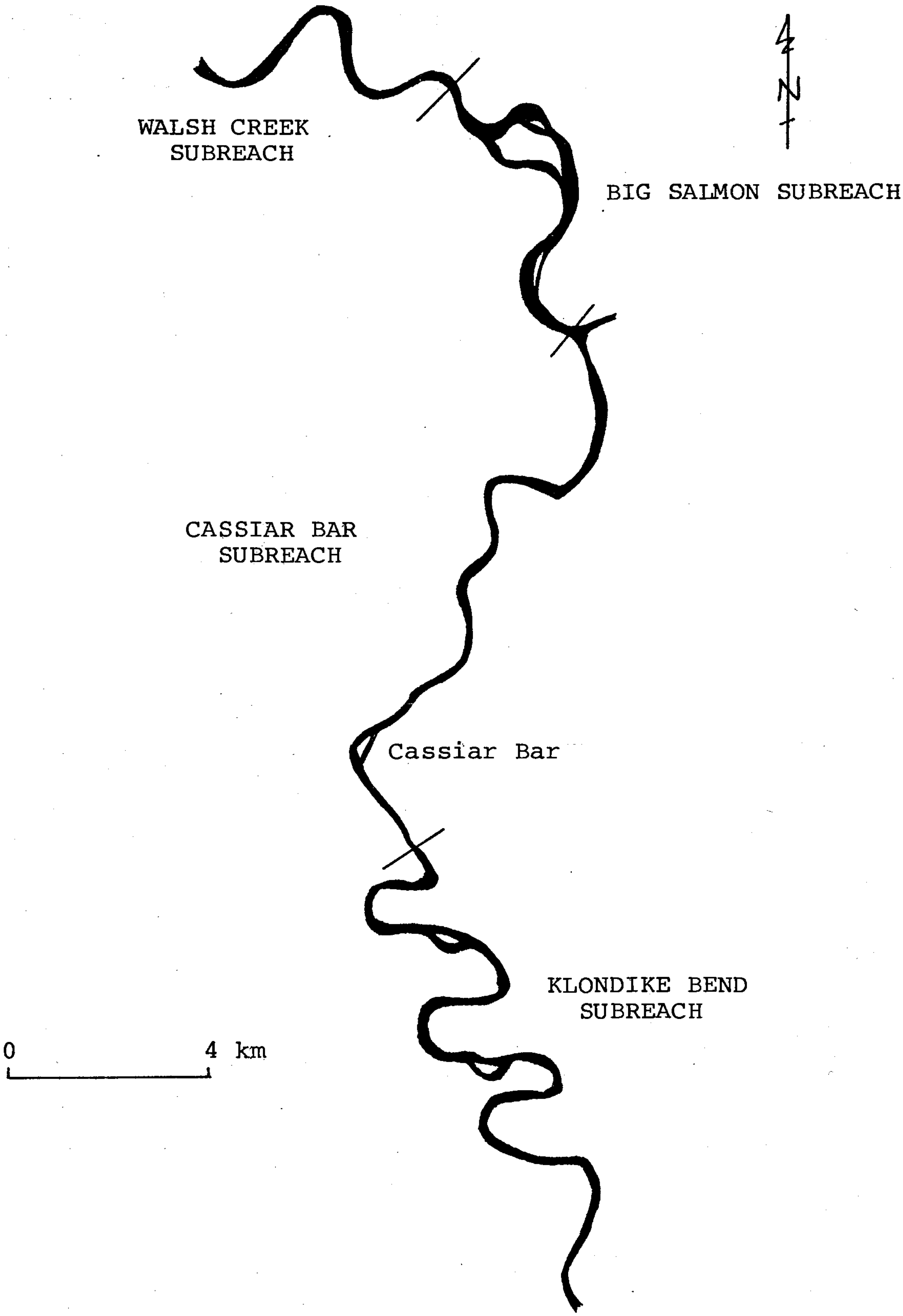


Figure 4.7. Subreaches of Hootalinqua reach.

At Cassiar Bar subreach the river has cut into terraces on Fyfe Creek. Gravel and sand are deposited in near-bank point bars and lateral bars (Fig. 4.5).

Straighter channel segments have migrated the least. Where the sinuosity increases downstream lateral channel migration is evident with alternate ash-free slivers of floodplain on opposite sides of the river.

At Big Salmon subreach the Yukon River has constructed many low islands and cut the face of a moderate-level glaciolacustrine bench.

Along Walsh Creek subreach the channel has migrated downvalley leaving scrolled floodplain while incising older alluvial fill and recessional outwash.

4.2.1 Post-ash Lateral Migration of Hootalinqua Reach

The river has produced 3.1 x 10^6 m^2 of floodplain by lateral migration during post-ash time. The calculated average deposition of floodplain per kilometer of reach is 76.4 m^2/km/yr. Much of this area is attributed to point bar formation and accretion. Migration rates and number of ridges and swales produced are inferred from the ash-free scrolled floodplain. An example of post-ash migration resulting from point bar formation suggests that one ridge and swale was produced in the last millennium (Fig. 4.8). Along much of the reach ash is missing along 10 m wide strips across from actively eroding banks. The average migration rate of this less active zone is about 1 cm/yr. However, alluvium without ash forms strips up to 110 m wide downstream of bend apices. The maximum migration rate is 9 cm/yr.

At Cassiar Bar subreach lateral migration was evident as accreted floodplain on alternate sides of the river. The amount of migration varies as a few examples of floodplain traverses will illustrate. In the first example, at river kilometer 20.8, post-ash migration is inferred to be 115 m (9.3 cm/yr) on the convex bank (Fig. 4.9). The concave bank is of outwash gravel terraces occupying part of Fyfe Creek valley. The terraces vary between 11 m to 42 m in height. In the second example (Fig. 4.10), at river kilometer 25, the width of floodplain without ash is about 85 m (6.9 cm/yr). In both cases the limit of ash was marked by a terrace scarp.

This subreach appears to have experienced migration rates of less than 10 cm/yr. Ash was observed on both sides of the channel along much of this stretch of the river. The low migration rate is attributed to the lower discharge (upstream position), presence of high-level terraces some of which have bedrock at river level, low input of sediment, and low water surface gradient (0.00047).

The Big Salmon subreach provides an example of a multiple channel meander bend between Big Salmon confluence and Walsh Creek. The many islands and bars in this bend are less than 1.5 m above river level, lack ash and vary in vegetative cover. The largest island is covered in spruce, balsam, and willow, the smallest in alder. Bare gravel bars have driftwood near

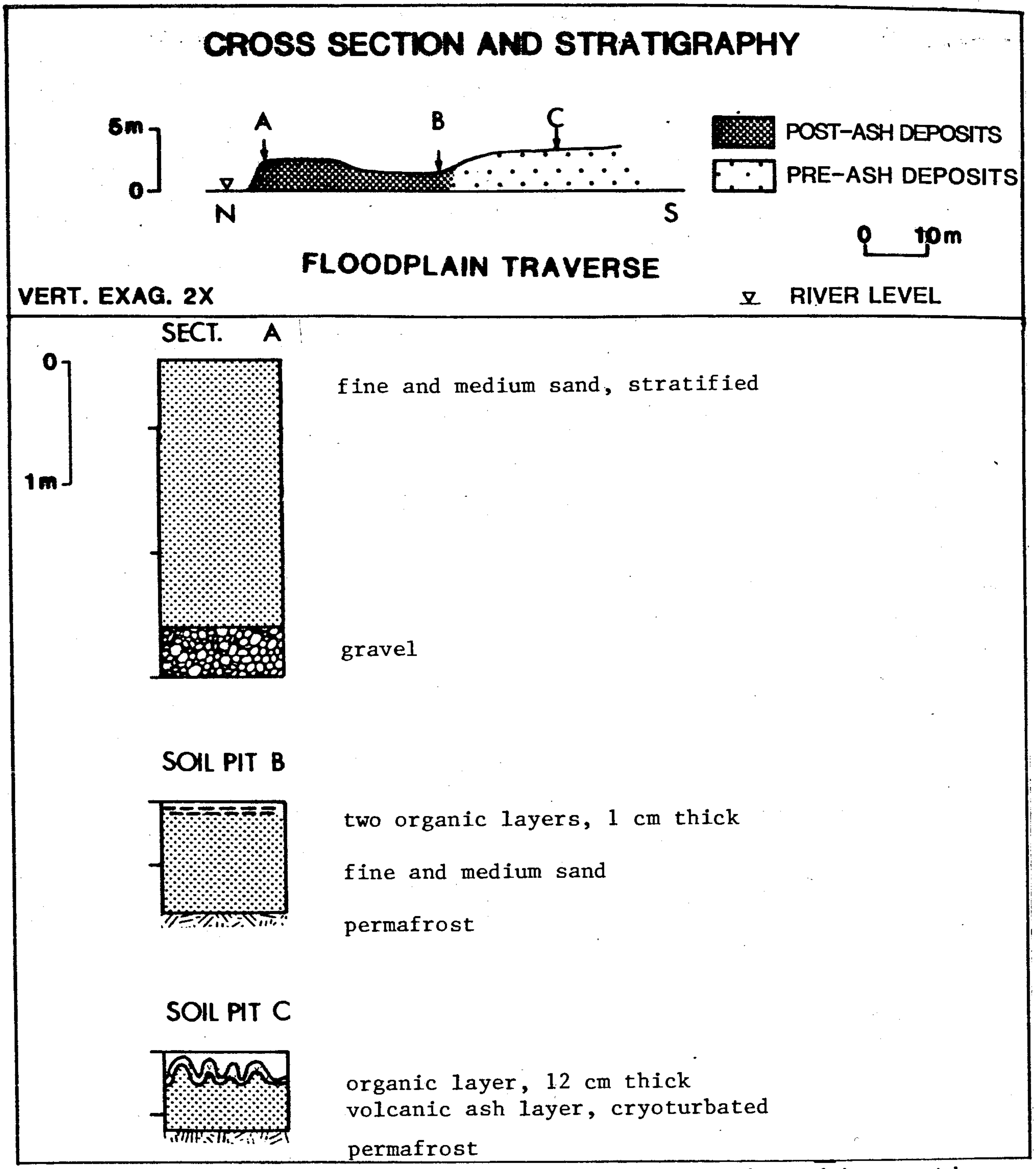


Figure 4.8 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 8.8, right bank. See map legend (in pocket) for identification of patterns in cross-section. One ridge and swale is preserved on this floodplain without ash. The floodplain with ash is slightly higher than ash free floodplain.

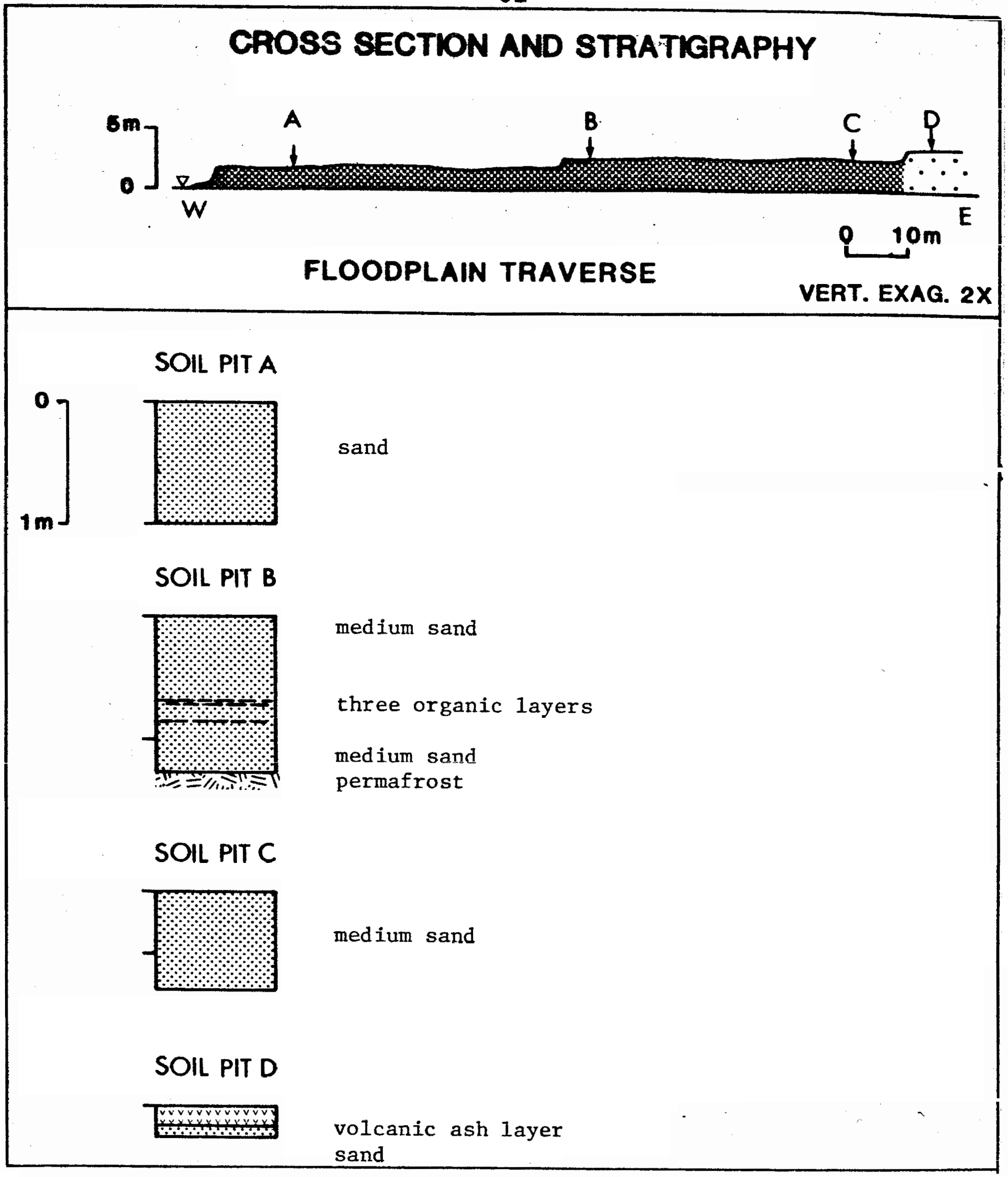


Figure 4.9 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 20.8, right bank. There are two levels of floodplain without ash and a higher terrace with ash at the surface. The average migration rate based on 115 m width of floodplain is 9.3 cm/yr.

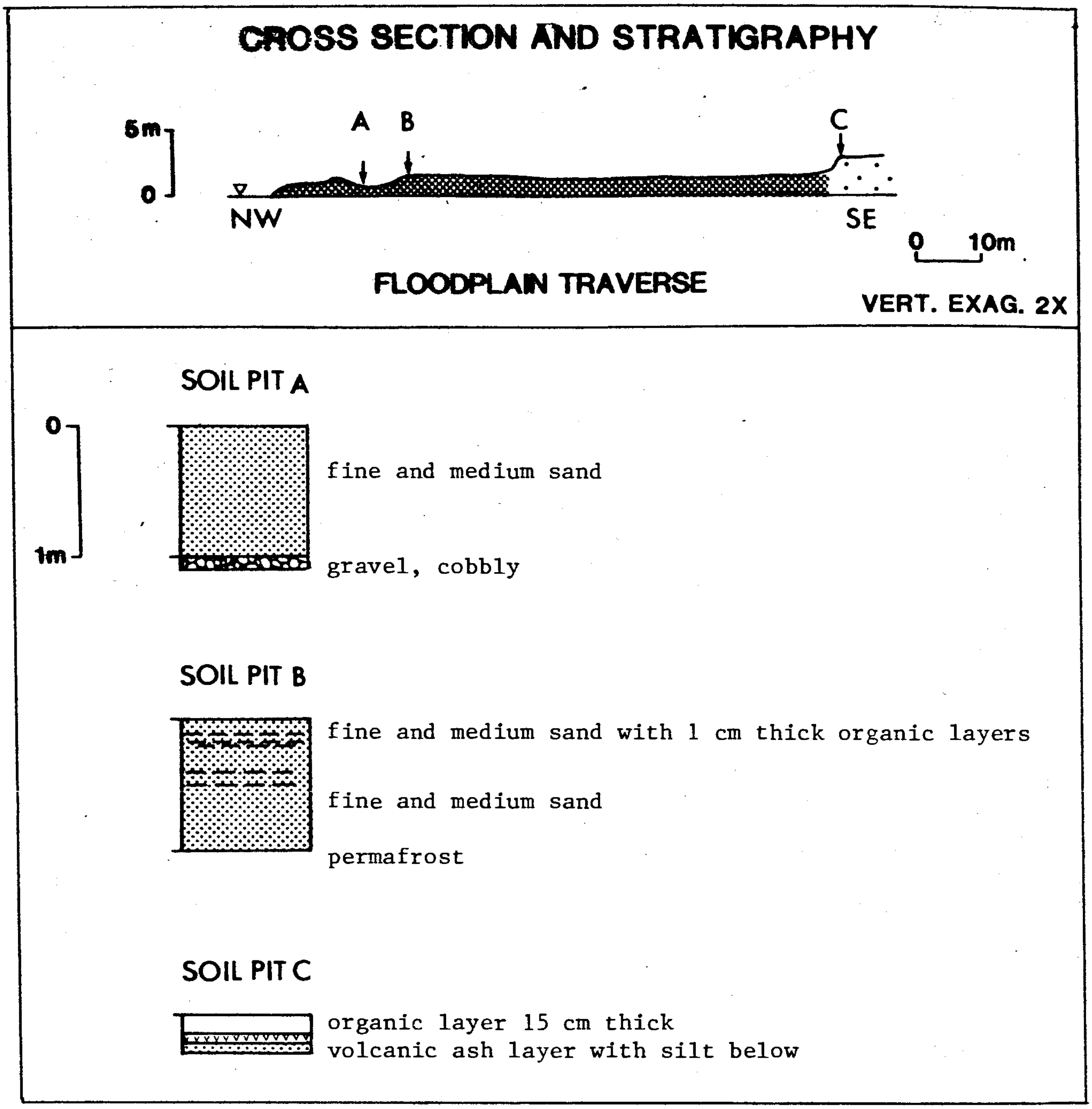


Figure 4.10 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 25, right bank. An abandoned slough is present near the bank. The boundary between floodplain without ash and the adjoining terrace is marked by a scarp.

river level. Opposite the largest island the ash layer is conformable to low-angle epsilon cross-stratification down to where it merges with the basal gravel along the inner left channel bank at river km 37. Here the ash is preserved on the slip-off slope of a former point bar to the basal gravel where ash was likely washed away.

Lateral migration has captured a meander loop of the Walsh Creek meander belt. The former mouth of this tributary is 500 m downstream (Fig. 4.1 in pocket).

Two examples from this subreach illustrate the amount of lateral migration. The first example (Fig. 4.11), is from river kilometer 32.2. About 270 m of floodplain without ash is present on a scrolled floodplain yielding a migration rate of 22 cm/yr. This accretion is the narrowest width of ash free floodplain in this subreach. The second example (Fig. 4.12), is also from a scrolled floodplain on the opposite side of the river. The floodplain lacking ash is about 300 m wide yielding a migration rate of 24 cm/yr. The two examples have similar settings and the width of floodplain without ash is the same; they share a common migration rate and accretion process.

The maximum post-ash migration is about 1 km (81 cm/yr) at river km 37. This is calculated from the width of islands at their widest. More rapid channel shifting is accomplished by sloughing of silt banks and toppling of spruce trees. Perhaps thawing of permafrost along cutbanks has led to more rapid erosion of these low banks.

The activity of this subreach may reflect rapid cutting of

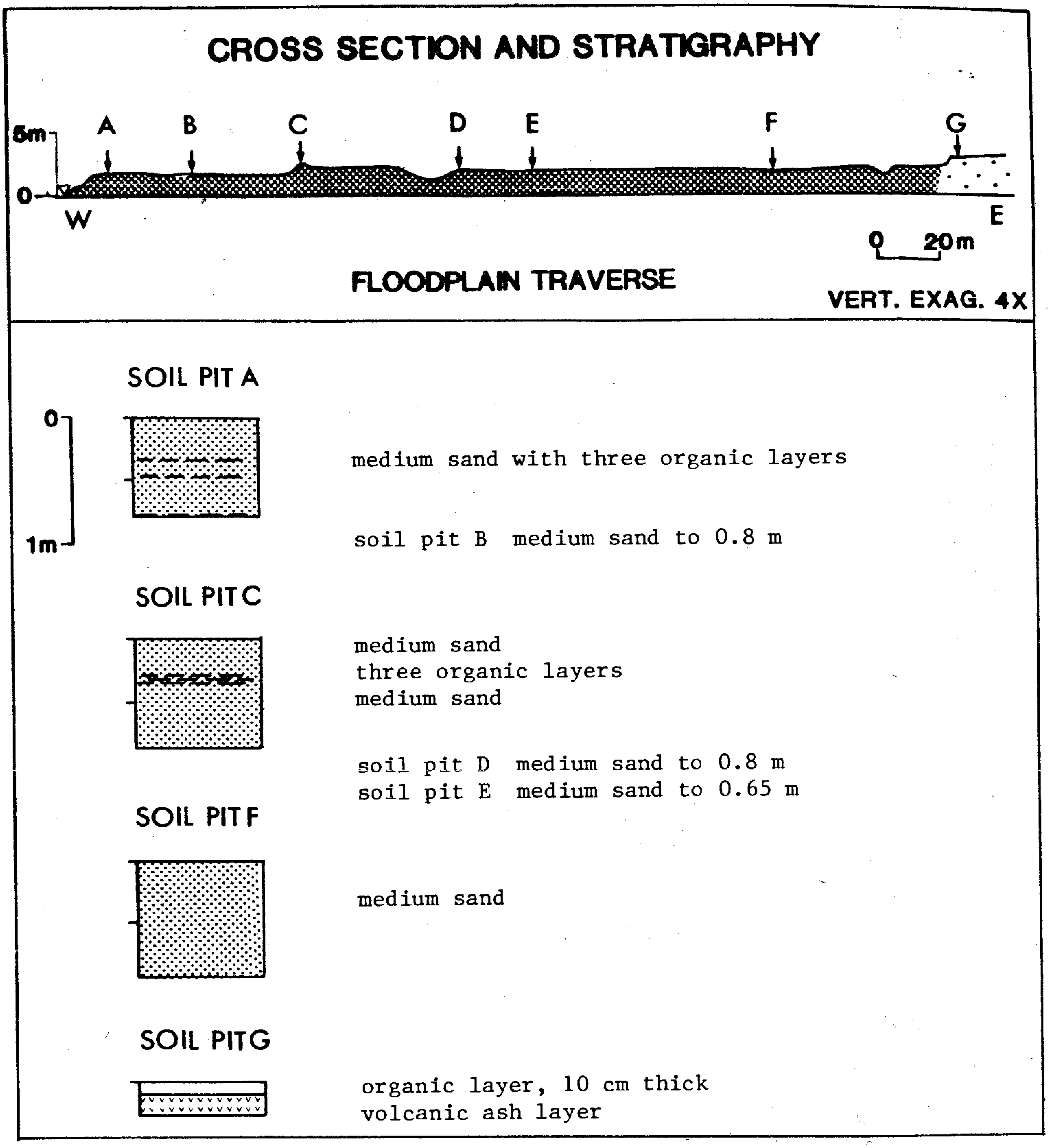


Figure 4.11 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 32.2, right bank. Abandoned channels remain on the floodplain as narrow depressions and a levee occurs at site "C". An unflooded terrace at site "G" is close to the level of the floodplain.

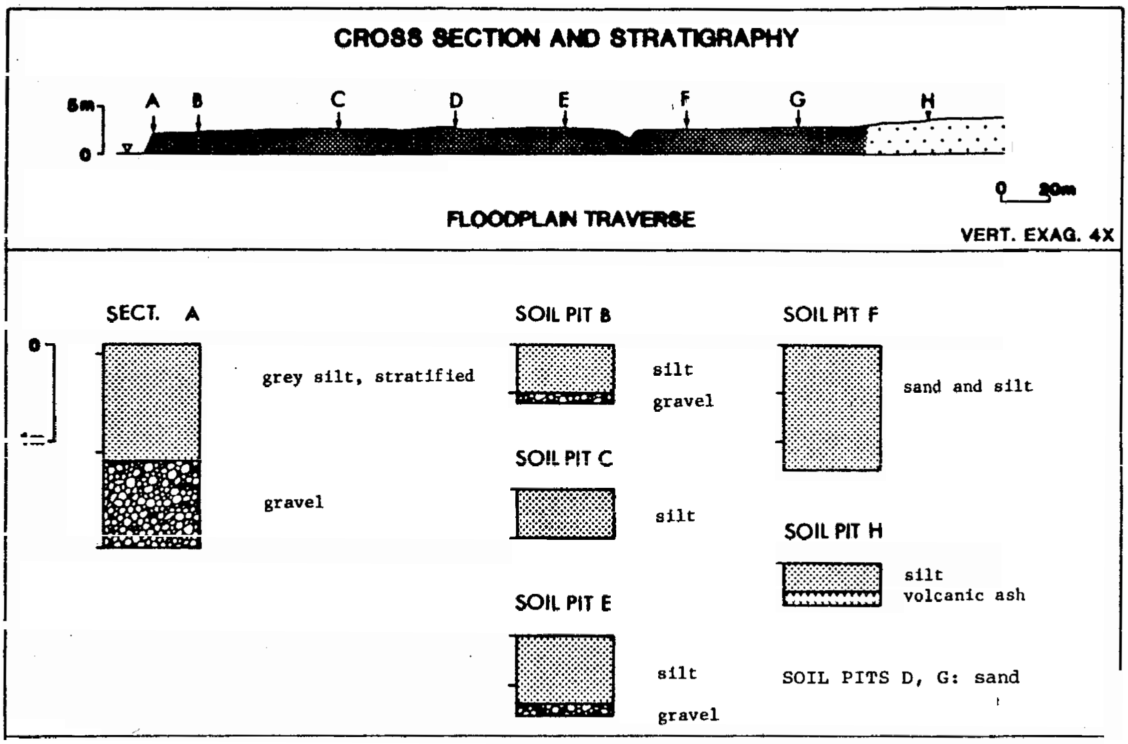


Figure 4.12 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 35.3, left bank. The boundary between the floodplain with ash and floodplain without ash is not distinct. The floodplain level rises gently away from the channel.

silts, increased local sediment supply, thermal bank slumping, and lack of bedrock and till at river level.

The Walsh Creek subreach has a single channel in a meander belt entrenched in outwash gravels. Sections, 1000 m long, in the scrolled floodplain (Fig. 4.13 and 4.14) illustrate the geology and topography. Alluvial surfaces drop in elevation downstream direction. The gravel-sand contact also falls in the same direction. The maximum measured height of the fining-upwards alluvium is 10.5 m. Its scrolled surface abuts a higher loess-capped gravel outwash terrace 16 to 20 m above river level which was eroded before the fining-upward sequence was deposited.

Logs and branches are exposed above gravel in a section of one 6.4 m high fining-upwards alluvial terrace (Fig. 4.13). A sample of spruce from 10 cm above the gravel and within bedded sands was dated by radiocarbon at the Geological Survey of Canada (GSC 3791). The reported date of 4770 $\pm$ 40 years BP approximates the time when Yukon River was at this location; maximum incision has been about 6 m (1.25 mm/yr). Extrapolating the radiocarbon date to the highest fining-upward terrace here suggests that the river meandered for 6000 years.

The floodplain without ash along the same bank is 110 m wide. The average rate of lateral migration is determined from the dated wood and the volcanic ash respectively; 23 cm/yr and 9 cm/yr.

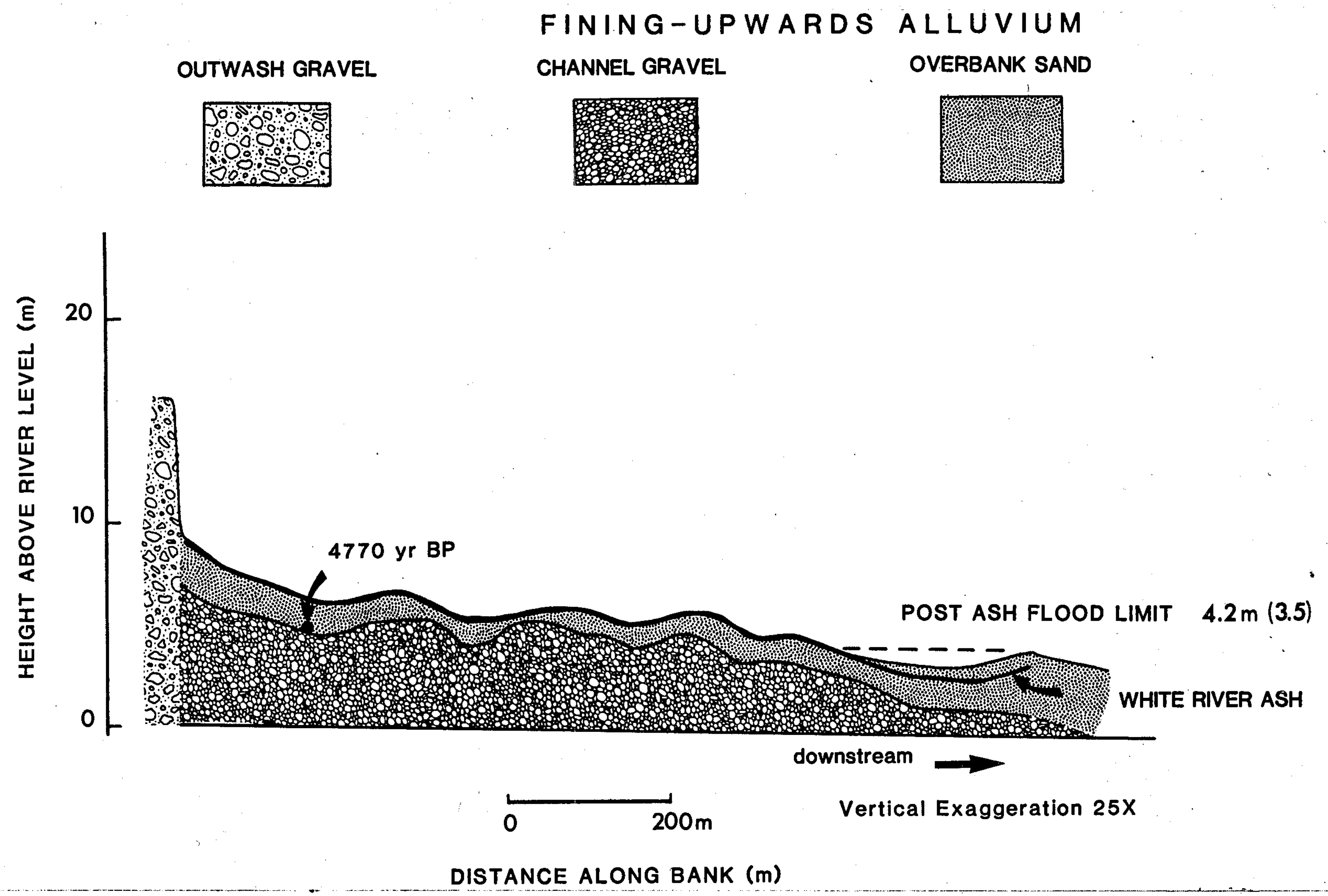


Figure 4.13 Cutbank section of scrolled alluvium in meander belt downstream of Walsh Creek (river km 41.4, left bank). The ash is buried by bedded sand in the active floodplain. The meander belt is confined by recessional outwash terraces.

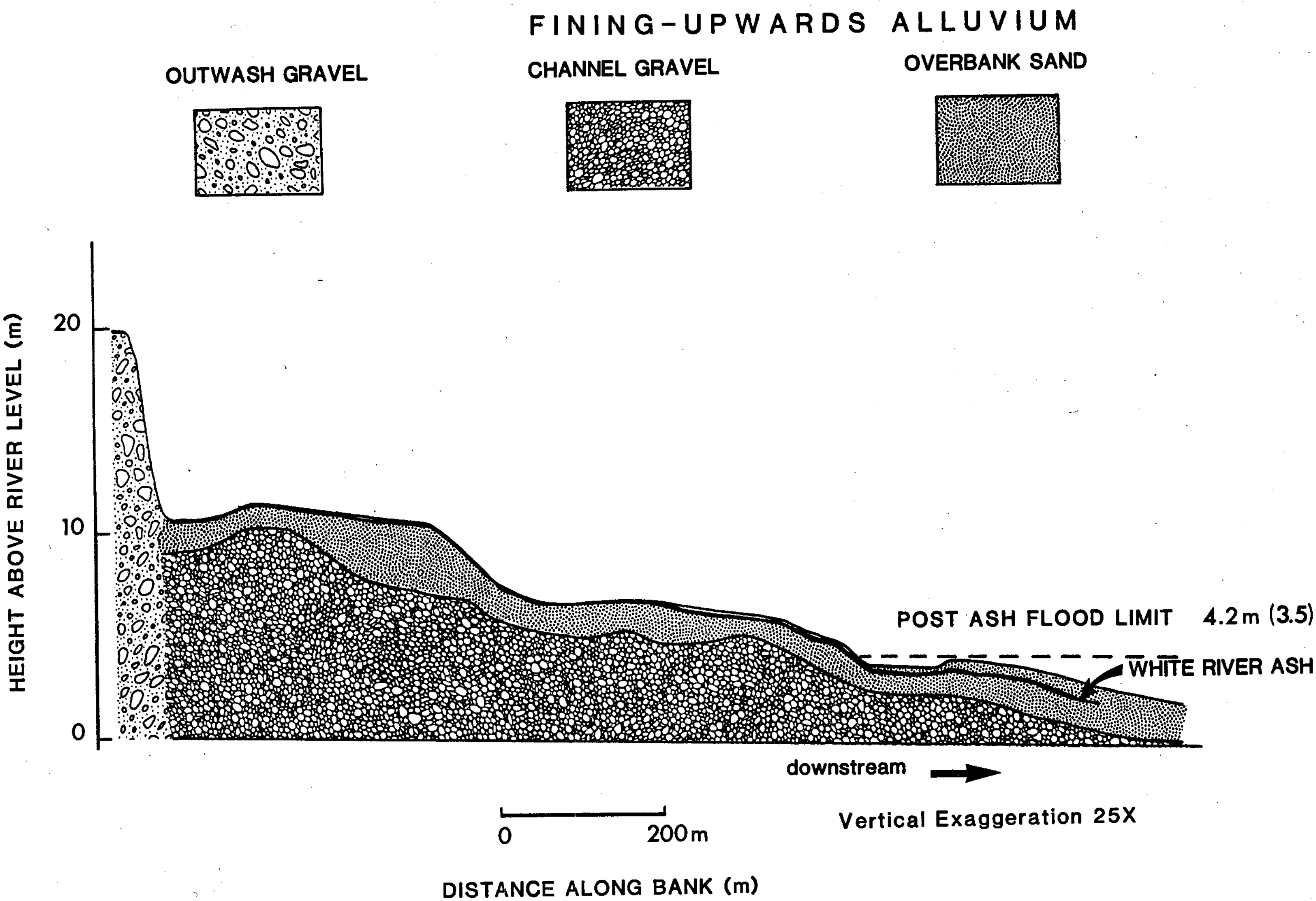


Figure 4.14 Cutbank section of scrolled alluvium in meander belt downstream from Walsh Creek (river km 39.7, right bank). The ash is buried by bedded sand at the downstream end in floodplain up to 4.2 m above river level. Recessional outwash terraces confine the meander belt.

In short, lateral migration of bends with radii between 200 and 800 m have migrated laterally down the valley. The highest average rates calculated from the width of floodplain without ash are 81 cm/yr (for example, opposite the mouth of Walsh Creek). The lowest rate is less than 1 cm/yr (for example, for much of the Klondike Bend subreach).

4.2.2 Post-ash Vertical Accretion of Hootalinqua Reach

Post-ash accretion on floodplains was measured at sites along the river and inland. Average rates of vertical accretion were calculated for the post-ash period. The preservation of White River Ash permits precise estimates of the rate of sediment accumulated outside the channel.

The sedimentary sequence in the floodplain deposits of this reach form one fining-upward succession of gravel covered by sand. Channel lag gravel at the base is overlain by rhythmically bedded sand fining upward to silty sand and silt. Low-angle epsilon crossbedding is common in the sand. Scrolled alluvial plain deposits have the same cycle. Organic horizons between 1 cm and 10 cm thick are seen in soil pits within the upper 1.5 m.

Examples of floodplain traverses and downriver sections include information on the thickness of sediment above the ash (Fig. 4.12, 4.13, 4.14). The surficial geology map (Fig. 4.1 in pocket) provides site information of the sections with post-ash accretion.

Accumulation on floodplain with ash for various heights above the river datum (Table 4.1) averages 0.42 m which requires an average rate for the post-ash period of 0.34 mm/yr. The maximum rate is 0.81 mm/yr. Aggradation rates, however, are variable with abandoned sloughs building up most rapidly. For example, a slough underlain by ash at river km 3.8 has 0.8 to 0.9 m of silt above the ash. The local infilling rate here is 0.65 to 0.73 mm/yr almost double the average rate for the reach.

TABLE 4.1

Vertical post-ash accumulation on floodplains at different levels for Hootalinqua - Big Salmon Reach

Downstream distance (km)	Base of ash (m)	Vertical accumulation (m)	Accretion rate (mm/yr)
0.82	2.3	0.3	0.24
0.82	2.9	0.07	0.057
2.35	2.5	0.20	0.16
2.35	2.2	0.36	0.29
3.25	2.0	0.5	0.41
3.75	2.2	0.3	0.24
6.6	2.1	0.9	0.73
6.6	3.3	0.1	0.08
10.5	2.8	0.25	0.20
10.5	1.7	0.40	0.33
15.4	1.8	0.70	0.57
16.6	2.3	0.60	0.49
17.0	2.43	0.30	0.24
17.0	2.75	0.10	0.08
17.7	2.5	0.15	0.12
18.2	2.5	0.20	0.16
20.75	4.15	0.00	0.00
21.6	3.5	0.00	0.00
23.8	3.0	0.00	0.00

Downstream distance (km)	Base of ash (m)	Vertical accumulation (m)	Accretion rate (mm/yr)
24.4	2.2	0.30	0.24
24.8	2.3	0.00	0.00
25.4	3.8	0.00	0.00
26.0	1.15	0.65	0.53
26.5	3.9	0.36	0.29
26.55	1.65	0.63	0.51
26.6	1.25	0.90	0.73
29.6	1.62	0.30	0.24
34.0	1.1	0.64	0.52
34.4	1.74	0.28	0.23
37.25	1.77	0.60	0.49
37.25	0.40	1.00	0.81
41.0	2.85	0.15	0.12
41.0	2.88	0.33	0.27
41.1	2.6	0.60	0.49
41.6	1.82	0.32	0.26

4.2.3 Floodplain Accretion Diagram of Hootalinqua Reach

The floodplain accretion diagram (Fig. 4.15) illustrates the nature of vertical accumulation with respect to the pre-ash floodplain (the floodplain that existed at the time of volcanic ash deposition). Although plotted data are widely scattered the overall tendency is decreasing accretion thickness with increasing floodplain height. This was the expected result if lower floodplains are more frequently flooded than higher floodplains. Points located on the horizontal axis indicate sites where the ash layer lacked overlying fluvial sediment. This suggests a limit of deposition during post-ash time at about 3.9 m above river datum. The linear regression line provides an equation for vertical accretion for floodplains of different height.

$$y = -0.256\,x + 0.986$$

where: y = vertical accumulation (m)

x = floodplain height (at base of ash)

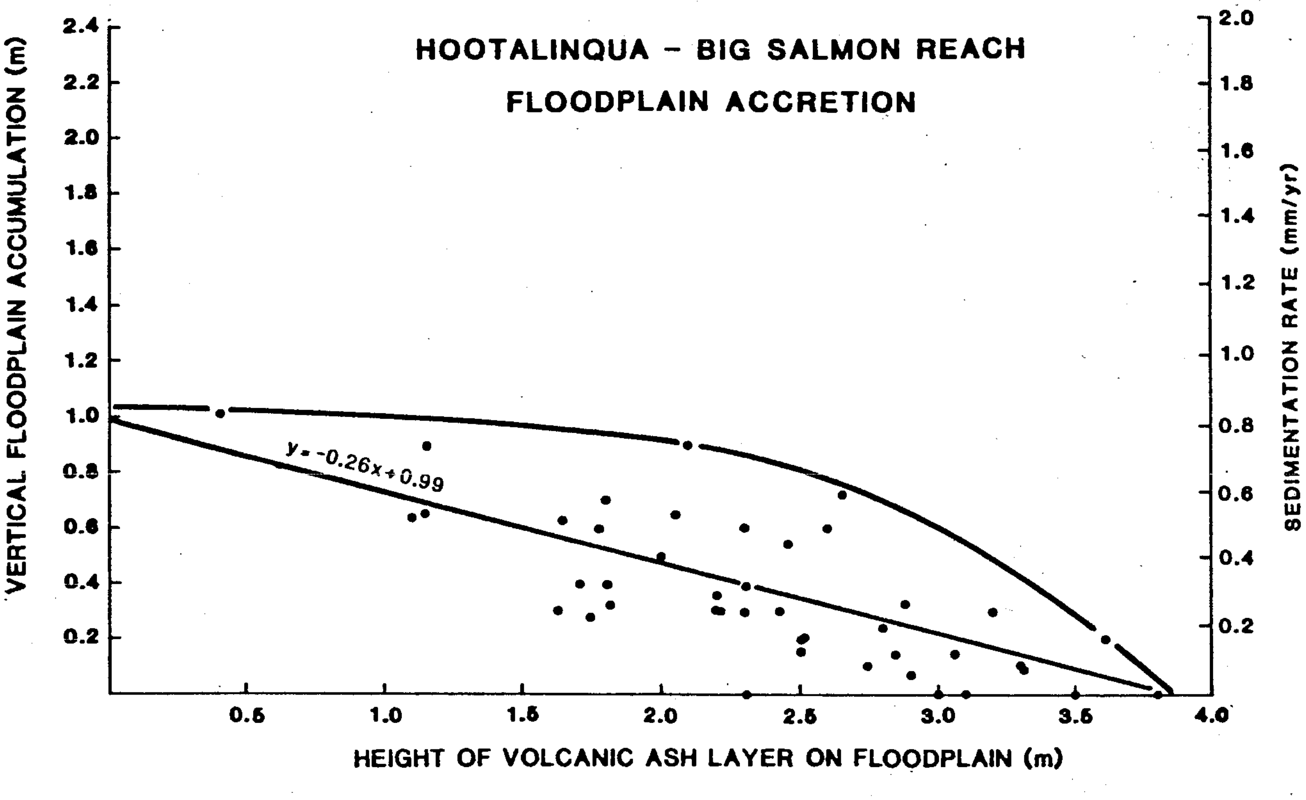


Figure 4.15 Hootalinqua - Big Salmon reach floodplain accretion diagram. The upper curved line is a sketched in envelope suggesting an upper limit to floodplain accretion. The scatter in points may reflect different position of site with respect to channel.

4.2.4 Long Profile of Hootalinqua Reach

The long profile (Fig. 4.16 in pocket) summarizes ash distribution in terraces and floodplains along the river length. The limit of post-ash aggradation line suggests that floodplains higher than 4 m above river level were not flooded since ash was laid down. Floodplain levels below 4 m have varying thicknesses of post-ash deposits. Field observations at Walsh Creek show that the thickest post-ash deposits occur where the ash is lowest in cutbanks and decrease as the ash rises with respect to the river. Floodplain without ash occurs up to 3 m above river level. This suggests that the maximum aggradation (sand and gravel) with respect to river datum is 3 m (2.5 mm/yr).

The lowest level of ash, a segmented line denoting sites where ash is close to river level, provides information on the net amount of incision which has occurred during the last millennium. The amount of downcutting is inferred from the position of the lowest ash and river level. The lowest occurrence of ash was observed at 0.3 m above river level at river km 37 near Walsh Creek. The average incision rate is, therefore, from 0.25 to 0.8 mm/yr.

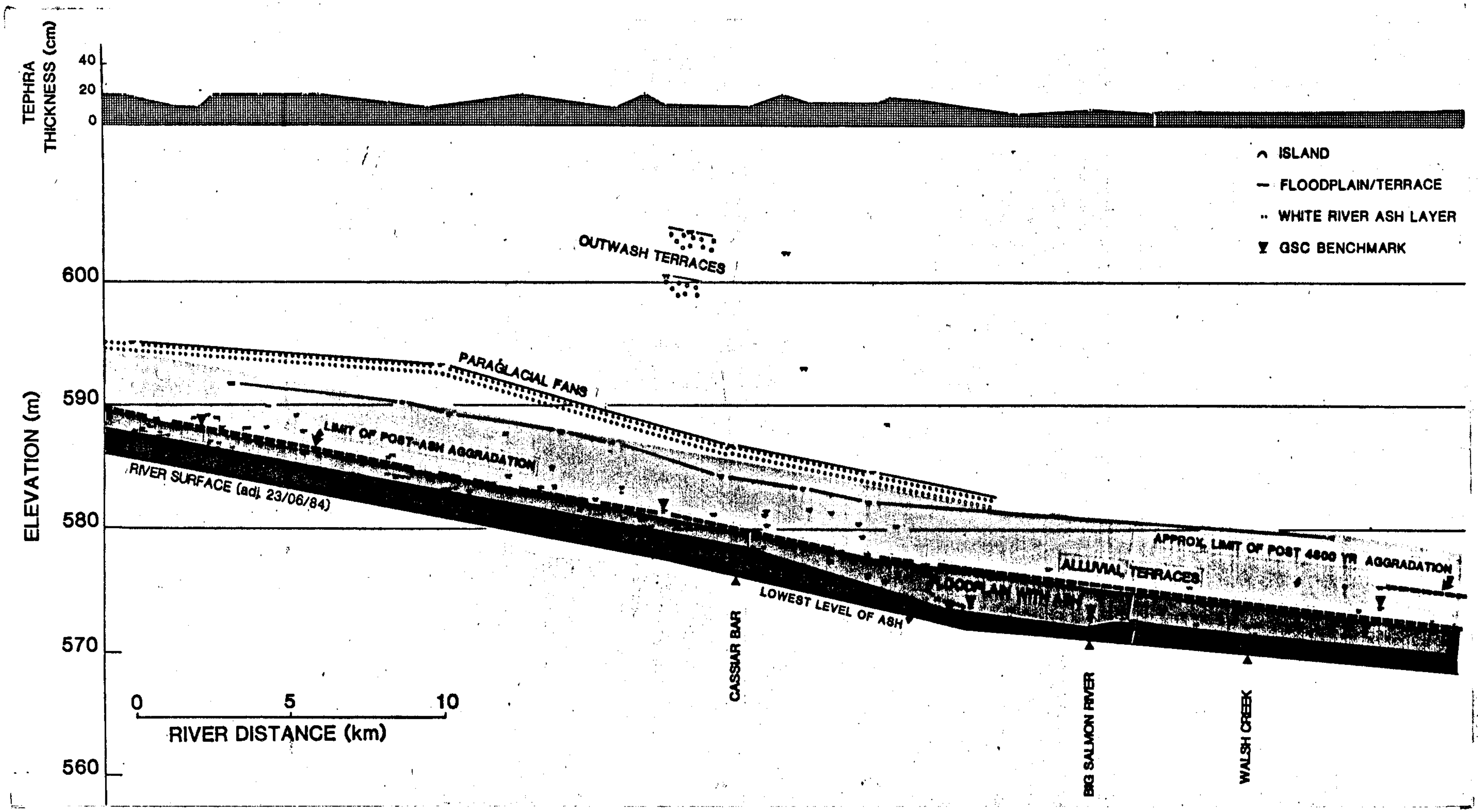


Figure 4.16 Long profile of Hootalinqua-Big Salmon reach showing White River Ash thickness, limit of post 4800 yr aggradation, limit of post-ash aggradation, lowest level of ash, and levels of map units with position of ash layer. This is a reduced version of figure in pocket.

4.2.5 Midchannel Bar Accretion to the Floodplain

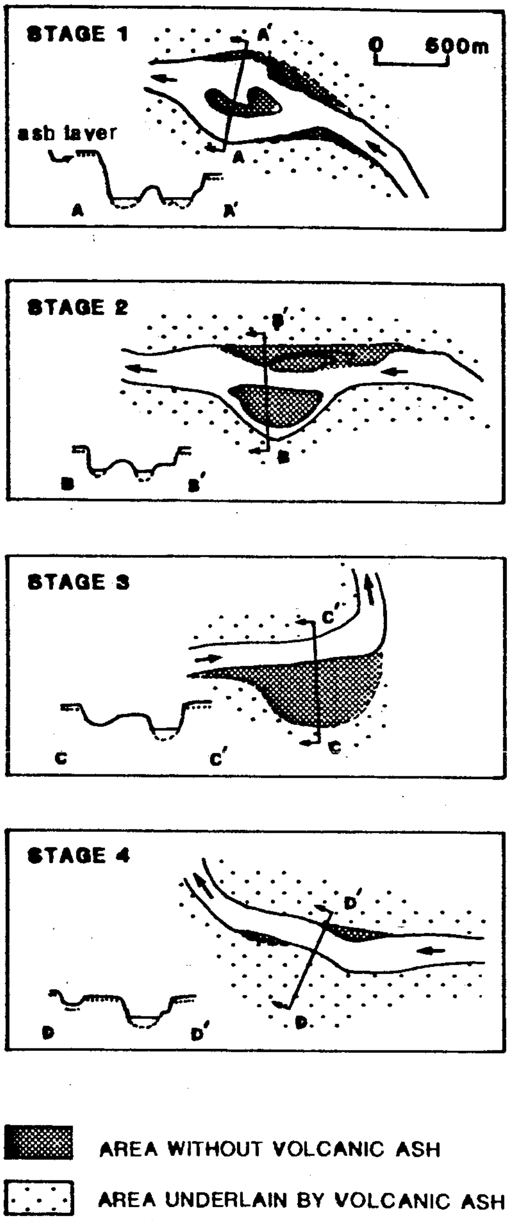
Midchannel islands are uncommon; those upstream of Cassiar Bar range from unvegetated bars to wooded accreted floodplain with abandoned slough.

An example of the stages of evolution is shown (Fig. 4.17) from Klondike Bend subreach. The meander pattern, although not shown in the figure, is composed of bends with similar radii of curvature and orientations. The first stage of bar formation results in a longitudinal island with bank cutting on both sides of the main channel. Accretion has occurred in the upstream direction with unvegetated sand at the tip. A "horn" or "wing" has developed around the upstream side of this island forming an arcuate ridge which appears to be growing downstream. The process was described by Walker (1976) for the South Saskatchewan River.

Holes dug in the high point of this island (1.5 m) to a depth of 1.2 m uncovered clean layered sand with two 1 cm thick organic layers at 33 cm and 40 cm depth and no ash. The time span required for deposition of the top 1.2 m of this island was short compared to the adjacent 1.4 m floodplain with 13 buried organic horizons in the top 30 cm.

The second stage shows the island considerably enlarged by lateral accretion. Ash occurs on the floodplain but not on the island.

In the third stage the slough between the former island and floodplain is filled with silt. The "island" is still actively



BIFURCATION OF CHANNEL AROUND MIDCHANNEL ISLAND ACCRETING UPSTREAM, LONGITUDINAL ISLAND IS ACCRETING ON RIGHT BANK

ISLAND ACCRETING OUTWARDS FROM CENTRE, DIMINISHING CHANNEL ON LEFT BANK, CONTINUING LATERAL ACCRETION ON RIGHT BANK

ABANDONED CHANNEL ON RIGHT OF "ISLAND", FINAL ACCRETION TO FLOODPLAIN

DRY SLOUGH WITH BURIED ASH RIVER CUTTING FORMER ISLAND, BAR ACCRETING ON RIGHT BANK

Figure 4.17 Stages of midchannel bar accretion to the floodplain. Sections are not drawn to scale. The stages were traced from Klondike Bend subreach.

aggrading. Ash underlies the floodplain on the slough's landward side.

The fourth stage has ash buried beneath a 0.8 to 0.9 m blanket of grey mud (silt) in the abandoned slough. Ash is present on top of the former island. The floodplain has built up to a level which is rarely flooded. This former island is in turn being eroded by the present river thus showing a cross-section through its stratigraphy. The ash layer follows a land surface which tapered in the upstream and downstream direction about 1230 years ago.

4.3 Eagle's Nest Bluff - Carmacks Reach

This reach (Fig. 4.2 in pocket) has a meandering river planform downstream of Hootalinqua reach. It contains a winding channel and scrolled meander lobes similar to the upstream reach with some differences. First, the meander belt is enclosed by low glaciofluvial terraces rather than high-level terraces. Where the outwash is removed the river is cutting higher kame terraces and ice-contact deposits. Second, the channel contains numerous vegetated point bars, lateral bars and medial bars. Multiple point bars occur downstream of bend apices and near the convex bank (inner bank) upstream of Carmacks. Concave benches are also evident on the recent floodplain. They are found as low floodplains on the concave side of bends (outer bank). In the lower part of the reach islands are less common. The channel is confined by thick, extensive ice stagnation deposits perhaps restricting the width of the channel.

4.3.1 Glacial History of Eagle's Nest Bluff Reach

Previous work on surficial geology and geomorphology for the Yukon River between Big Salmon and Carmacks has been carried out as part of dam site investigations. Owen (1959b) as part of his dam site investigations mapped the site upstream of the reach, Hardy Associates (1980) reported on dam site geology and drilling results as well as an airphoto interpretation map of the eastern portion of the reach. Campbell (1967) published a 1:250 000 scale map of the surficial geology in Glenlyon map area which includes the upstream portion.

During the McConnell advance (and earlier advances) this reach was invaded by ice which flowed northwestward and was probably controlled by topography (Hughes et al., 1969). Ice-marginal channels were cut on both sides of the valley at successively lower elevations as ice retreated. The last valley glacier occupied the valley to about 2000 feet elevation. It disintegrated rapidly leaving ice buried by glacial and glaciofluvial drift. Stagnation features remain as hummocky topography associated with eskers and crevasse fillings. Adjacent to the stagnant ice ice-marginal lakes were fed by tributary streams depositing stratified sand and gravel. These sediments presently form kame terraces along the valley walls.

Outwash valley trains were built up at the ice margin establishing various high level gravel and sand plains. Incision of these outwash fills by the latest meltwater channels left high terraces while the meltwater channels built lower recessional outwash fills. Paraglacial fans merged with these lower terraces from the abundant sediment supply in their upstream courses.

The lower fills were probably incised in postglacial time leaving low-level terraces and depositing alluvium in a meander belt. Paraglacial fans were entrenched by streams carrying lower sediment loads and merging with a lower Yukon River in Holocene time.

4.3.2 Major Geomorphic Map Units of Eagle's Nest Bluff Reach

The terraces along this reach are grouped into three sets based on morphology, height and composition. These terrace sets are:

Channelled terraces:

High-level Glaciofluvial Terraces (90-100 m)

Low-level Glaciofluvial Terraces (5-15 m)

Scrolled terraces and floodplain:

Low-level Terraces and Floodplain with Volcanic Ash (9-5.0 m)

4.3.2.1 Channelled Terraces: High-level Glaciofluvial Terraces (90-100m)

High terraces have smooth surfaces and merge with ice stagnation (knob-and-kettle) topography between about 550 and 610 m elevation. They tend to be associated with tributary stream terraces and are best preserved near tributaries such as Mandanna Creek. An esker or crevasse filling was surveyed at 52 m above river level about halfway down the reach.

The terraces are probably composed of gravel and sand overlying and possibly underlying till of the last advance.

Tributary streams previously graded to the general level of this fill are deeply entrenched at present.

The terraces and related dead ice features probably were deposited when tongues of ice in Yukon River valley stagnated. Outwash was deposited on the ice forming kettled outwash and crevasse fillings and under the ice forming eskers. Tributaries carried fluvial load into ice-marginal basins and channels. These became hanging glacial deltas and kames. Ponds may have been connected by ice-marginal streams along the valley sides.

4.3.2.2 Channelled Terraces: Low-level Glaciofluvial Terraces (5-25 m)

Terraces extending outward from valley sides and inset in older higher glaciofluvial terraces are prevalent in the section from Eagle's Nest Bluff to Carmacks. They were partly destroyed by later meandering of the river leaving meander cusps. These terrace remnants are readily traced along the river channel and across the valley. Their surface has channel scars resembling those of braided rivers.

They are composed of cobbly gravel overlain by eolian sand and tephra. Coarse sand near the top shows tabular crossbedding and the gravel is imbricated. The eolian sand forms dunes with a parabolic tendency. The volcanic ash covers the bedded sand in all exposures.

The terraces may have originated as outwash deposits from meltwater issuing from ice upvalley or as braided river deposits formed after glaciation but before the floodplain was vegetated; dunes, with ash on them, were observed on airphotos and in the field over stretches of these terraces.

4.3.2.3 Scrolled Terraces and Floodplain:
Low-level Terraces and Floodplain with Volcanic Ash (0.9-5.0 m)

The scrolled alluvium containing tephra forms meander lobes in recessional outwash. The lobes are up to 1.5 km wide and their elevation falls step-wise downstream from the outwash terraces. The elevation of the volcanic ash falls with the floodplain. The scrolled alluvium is a fining-upward sequence. Bedded sand overlies basal gravel which rises to 3.2 m above river level. The ash is enclosed in sand in floodplains between 0.9 m and 3.6 m. Surfaces (at river km 123, 144.7, 147, 163, and 166) about 3 m high show no post-ash deposition.

The fining-upward sequence is interpreted as the product of meander type point bar deposits and slough fill before and after ash deposition. Vegetation cover may have been as extensive as today as no dunes occur on this alluvium.

4.3.2.4 Scrolled Terraces and Floodplain:
Floodplain without Volcanic Ash (0-2.3 m)

The floodplain without ash, the lowest alluvial surface, overlaps with ash covered floodplain. It covers 3.8×10^6

m^2 mainly on the downvalley side of meander lobes. The surface comprises en echelon point bars in varying stages of accretion. Recently abandoned sloughs are covered with grass and have willow and alder growing on them. In cutbanks the fining-upward sequence has basal gravel overlain abruptly by bedded sands.

Midchannel islands occur singly or in small groups. Where ash is present on both banks opposite the island the island appears to have expanded at the expense of erosion of the ash bearing banks.

The gravel is interpreted as channel lag and bar deposits and the sand, 0.5 to 2.0 m thick, as overbank detritus.

4.4 Post-ash Channel Behaviour of Eagle's Nest Bluff Reach

Post-ash behaviour in this reach (Fig. 4.2 in pocket) includes: lateral accretion around meander bends, development of narrow islands near the convex bank, development of midchannel islands at points of maximum curvature, expansion of two midchannel islands in straight stretches, and accretion of floodplain on both convex and concave sides of channel bends.

Narrow sloughs between islands and floodplain without ash are sinuous where the islands are heavily vegetated and straight where the islands are thinly vegetated or bare. Ash is exposed locally along the sloughs where the channel cuts high floodplain.

Thickly wooded midchannel islands occurring in straight stretches are underlain by ash along their long axes (2.9 m high) but lack ash around margins up to 100 m from the bank. Pits show that the ash was buried by alternate sand and organic layers. The ash layer varies from 0.4 m to 1.5 m above river level.

Lenticular midchannel islands which occur at bend apices lack ash suggesting that they have formed in post-ash time.

4.4.1 Post-ash Lateral Migration of Eagle's Nest Bluff Reach

Evidence of the extent of lateral migration is shown by the distribution of floodplain without ash (Fig. 4.2 in pocket). The river channel is inferred to have swept over 3.8×10^6

m^2 during post-ash time. The calculated average rate of floodplain deposition per km of reach length is 44.7 m^2/km/yr. Meander bend migration is described for a few examples taken along the reach. The two stage development of a concave bench at a tight bend is detailed with an example and part of the reach is restored to its pre-ash configuration.

An important difference between this reach and that upstream is the height of the terraces; confining the river. The confining terraces are lower in height than Hootalinqua Reach. It is believed that lower terraces are more rapidly eroded than higher terraces of the same lithology. This would be supported by greater widths of floodplain without ash for low-level terrace areas.

The channel has migrated in the downvalley direction as inferred by the mapped floodplain without ash. The relatively low outwash terraces are being eroded as a consequence of migration. Where the river is cutting higher terrace remnants the width of floodplain without volcanic ash decreases.

Examples of bend migration follow beginning with the upstream bends and moving downstream. The most upstream bend (river km 106-113) has a compound form and is locally called "Big Bend" (surveyor's notes) (Fig. 4.2). It is a tight bend with a point bar and concave bench along the left bank in an actively migrating channel. A bedrock bluff occurs at the apex of the bend restricting northward migration. Down the valley the river is cutting low-level gravel outwash terraces and a higher silt terrace. The maximum width of floodplain without ash on the vegetated point bar is 550 m and the maximum width of the concave bench without ash is also 550 m. Both floodplain areas appear to have migrated at the same average rate of 0.45 m/yr in the last 1230 years.

Two floodplain traverses on the concave bench (Figures 4.18 and 4.19) indicate that the top 0.5 m of the floodplain is sand with organic layers. Gravel occurs about 0.5 m down in the soil pits. The floodplain has ridge and swale morphology.

An ash covered debris flow abuts the floodplain of the concave bench (Fig. 4.29). The flow drapes a 14 m high outwash terrace cutbank almost to an abandoned channel at the edge of the concave bench. The ash layer is in the slide debris at the terminus indicating movement of the toe after ash deposition. Part of the flow terminus appears to have been cut by a former channel occupying the swale.

Farther downstream (river km 113-117) (Fig. 4.2 in pocket) the channel has changed very little; a few lateral bars are added since ash deposition. The meander lobes downstream from here are simple and symmetrical (river km 116-122). They cut low outwash terraces leaving strips of floodplain without ash as point bars and concave benches. For example, a strip of floodplain without ash at river kilometer 117.1 is 110 m wide opposite two point bars and 130 m wide at kilometer 118.8 downstream of the point bars. The average migration rate is 9.7 cm/yr at these point bars. Around the next bend a low island is developing near the concave cutbank (river km 119.5).

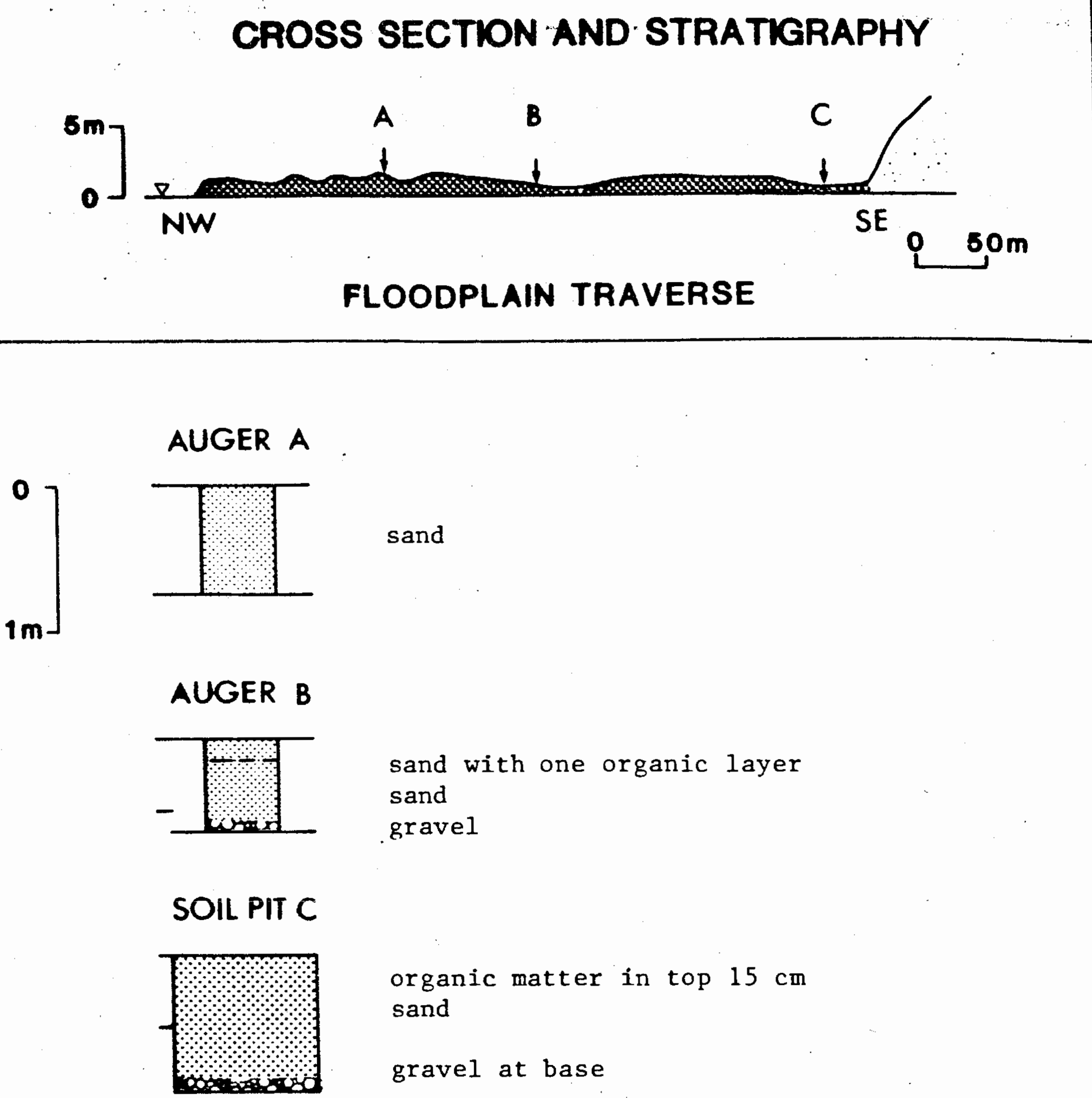


Figure 4.18 Geomorphic profile and stratigraphic section and auger logs from a floodplain traverse at river km 111.6, left bank. The floodplain without ash is underlain by a sand veneer over gravel. This is part of a concave bench abutting the toe of a debris slide.

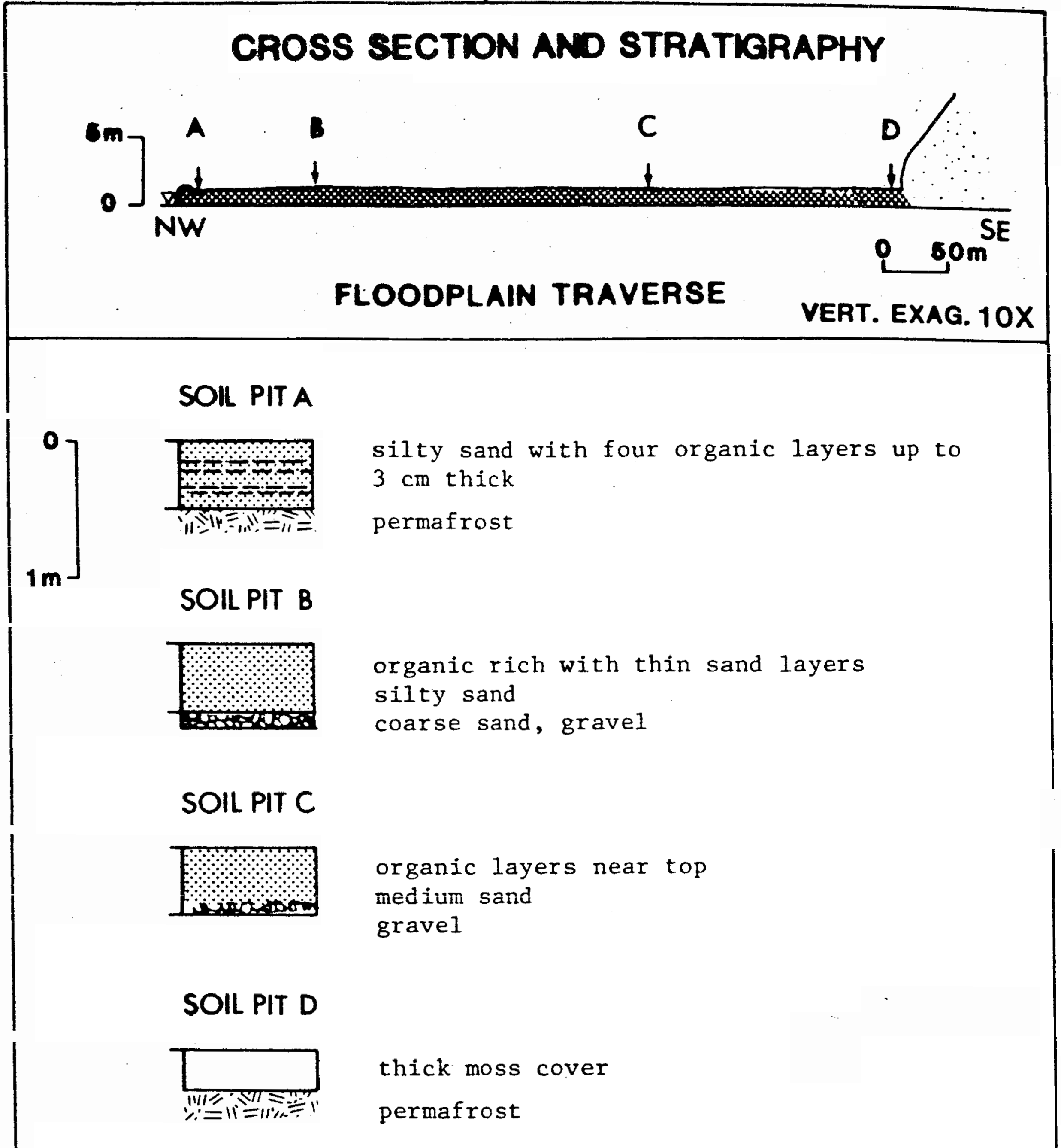


Figure 4.19 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 112, left bank. The floodplain has a veneer of sand overlying gravel next to the toe of a debris slide with contorted ash. This is part of the concave bench of figure 4.18.

A pair of meander lobes are simple asymmetrical forms at river km 123 to 129 (Fig. 4.2 in pocket). Floodplain without ash was measured at 140 m in width at river kilometer 125.2 opposite the downstream end of the first point bar, giving a migration rate of 11 cm/yr. Farther along on the same floodplain at kilometer 126 the ash limit is a swamp. A surface 1 m higher than the swamp is vegetated with spruce and contains ash below 20 cm of black organic matter and minor silt. The ash-free floodplain is 197 m wide here; the migration rate is therefore 16 cm/yr. The sinusoidal outline of the ash-free floodplain follows ridges discernible on airphotos and parallels the present bank line.

Around the second simple asymmetric loop ash is buried by 30 cm of sand only 70 m from the river at the apex of the bend which has migrated at an average rate of 5.7 cm/yr. Farther downstream (river km 128.4) ash was encountered first in a soil pit 157 m east of the river bank on a terrace with a north trending scarp.

A symmetrical meander loop (river km 129-132) occurs farther downstream opposite a high terrace with local kettle hole topography (Fig. 4.2 in pocket). This bend has migrated very little after ash deposition. The ash occurs at, or near, the bank around its convex and concave sides.

A medial island (river km 137.8) low in Eagle's Nest Bluff reach and underlain by volcanic ash in the central area (Fig. 4.20) is a good example of limited lateral migration and island growth following ash eruption. Opposite the island on the right bank, ash is exposed in a 3 m cutbank while on the left bank ash lies on an 8 m glaciofluvial terrace. On the north side of the island the floodplain without ash is 50 m wide and on the south side it is 20 m wide. An auger hole in the upstream end of the island (river km 137.5) cut volcanic ash at 75 cm 40 m from the river. The ash appears to drape over the island sloping toward the channel. Although it has eroded low terraces and widened its channel the river has only widened the island by 70 m. Island growth averages 5.7 cm/yr.

In a tortuous section of Eagle's Nest Bluff reach just downstream of Carmacks, a lateral bar has developed along the edge of another low outwash terrace. Nine close-spaced floodplain traverses were made to the ash boundary. The width of floodplain without ash increases downstream from 34 m to 150 m. Between one and four minor sloughs are present on this floodplain. An example of one traverse (Fig. 4.21) shows the relationship between the outwash terrace, narrow low-level terrace and floodplain with and without ash.

Around the next symmetrical meander lobe, a floodplain traverse on the convex side at the bend axis (Fig. 4.22) indicates about 110 m of post-ash lateral migration (8.9 cm/yr). A cobble shelf at the bank is two to three meters wide. A dry slough appears to mark the boundary between the flooded pre-ash surface and the post-ash floodplain. The point bar here was traced downstream where the width of floodplain without ash narrows to 77 m (river km 150).

The river shows little evidence of post-ash lateral

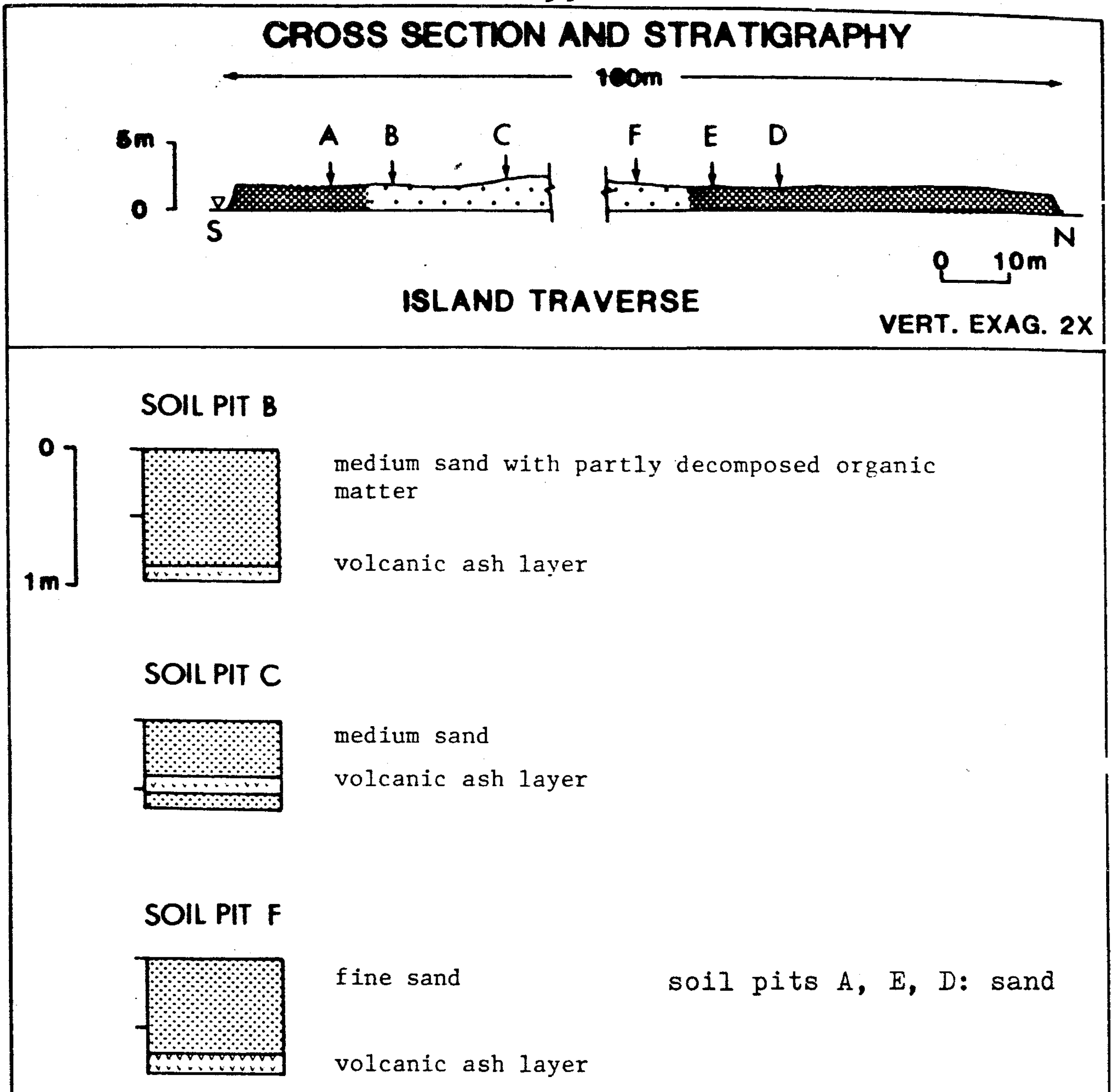


Figure 4.20 Geomorphic profile and stratigraphic sections from an island traverse at river km 137.8. This island has expanded outward from a core which has ash.

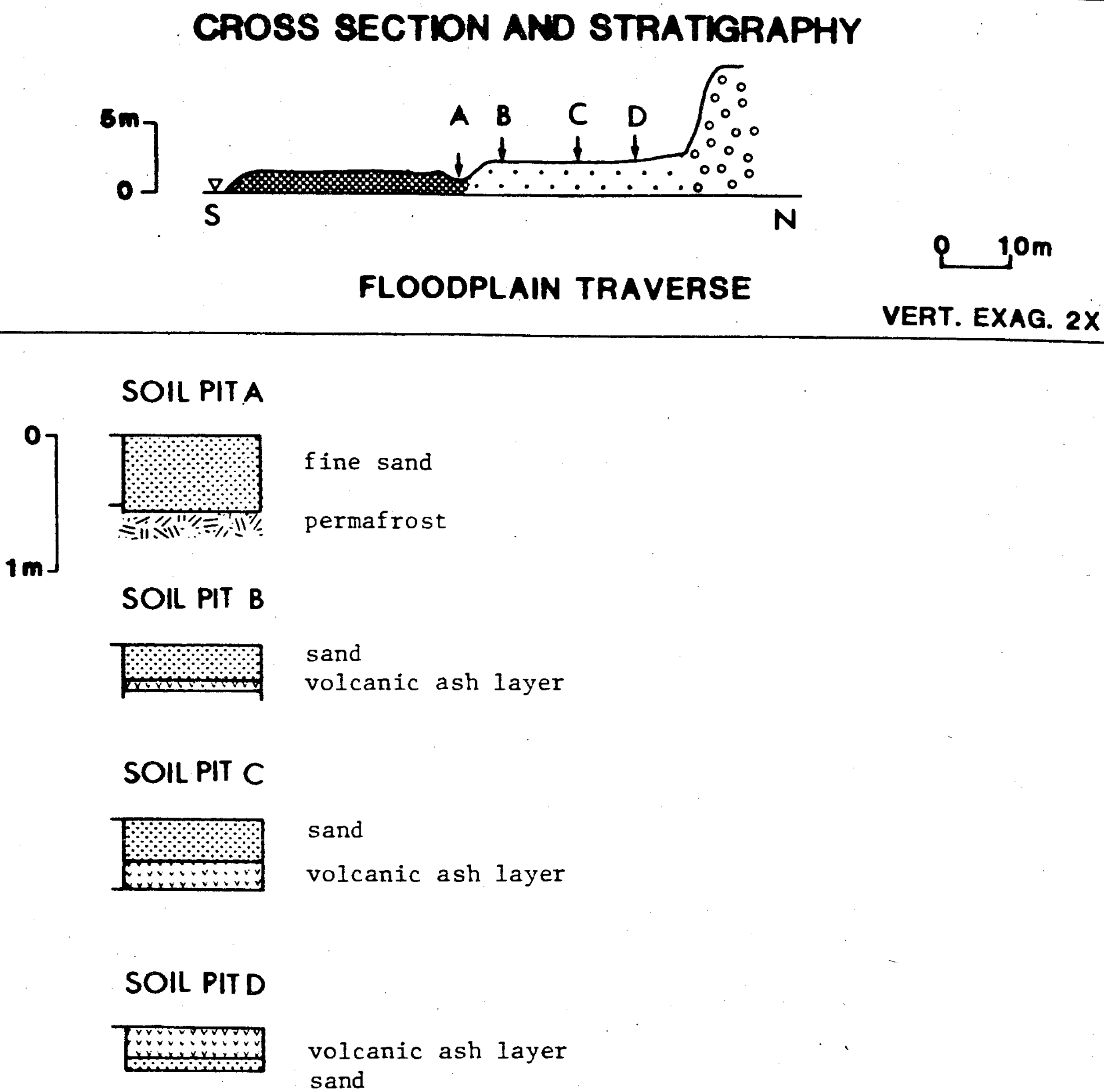


Figure 4.21 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 146.5, right bank. Pits "B" and "C" have sand covering the ash while pit "D" has ash at surface.

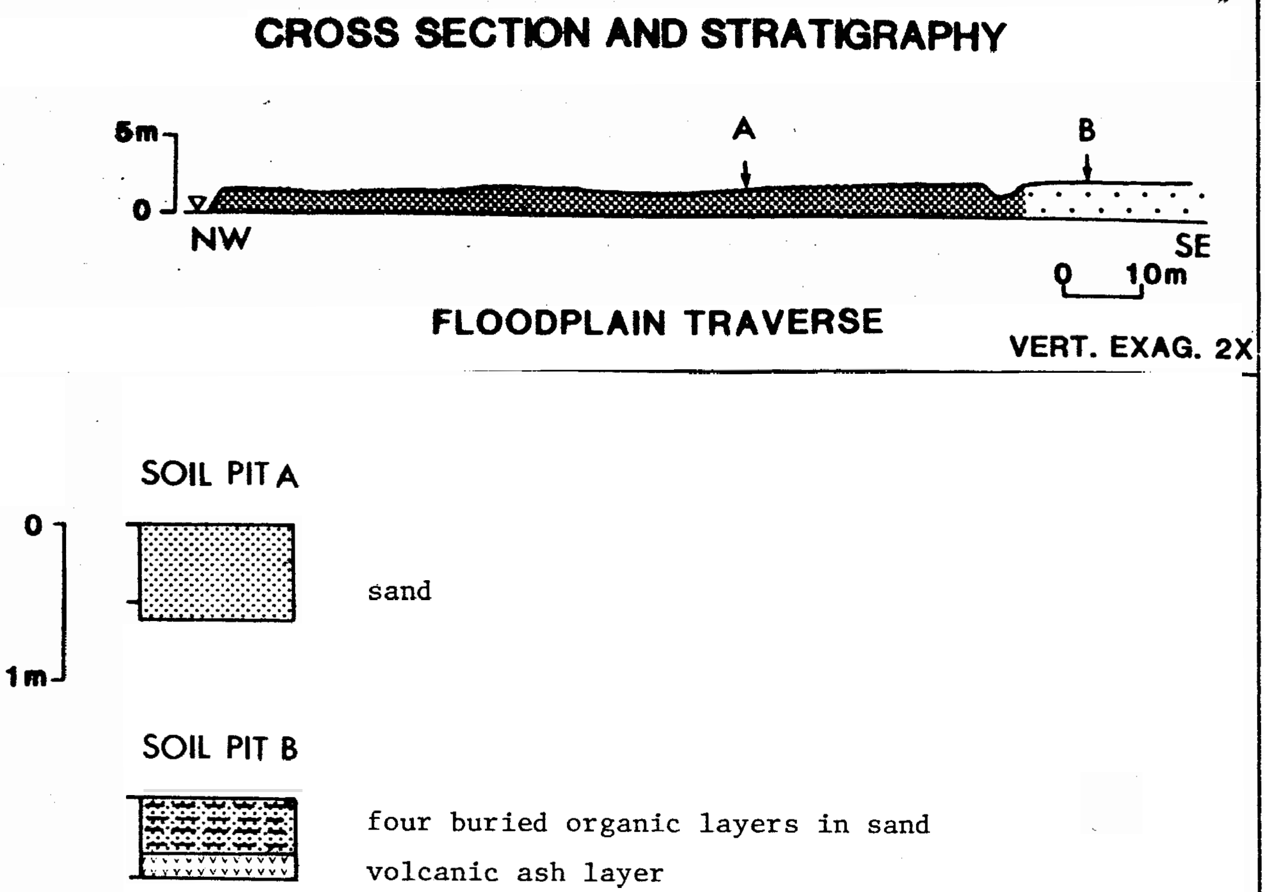


Figure 4.22 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 148.5, right bank. A narrow depression marks the boundary between floodplain with ash and floodplain lacking ash.

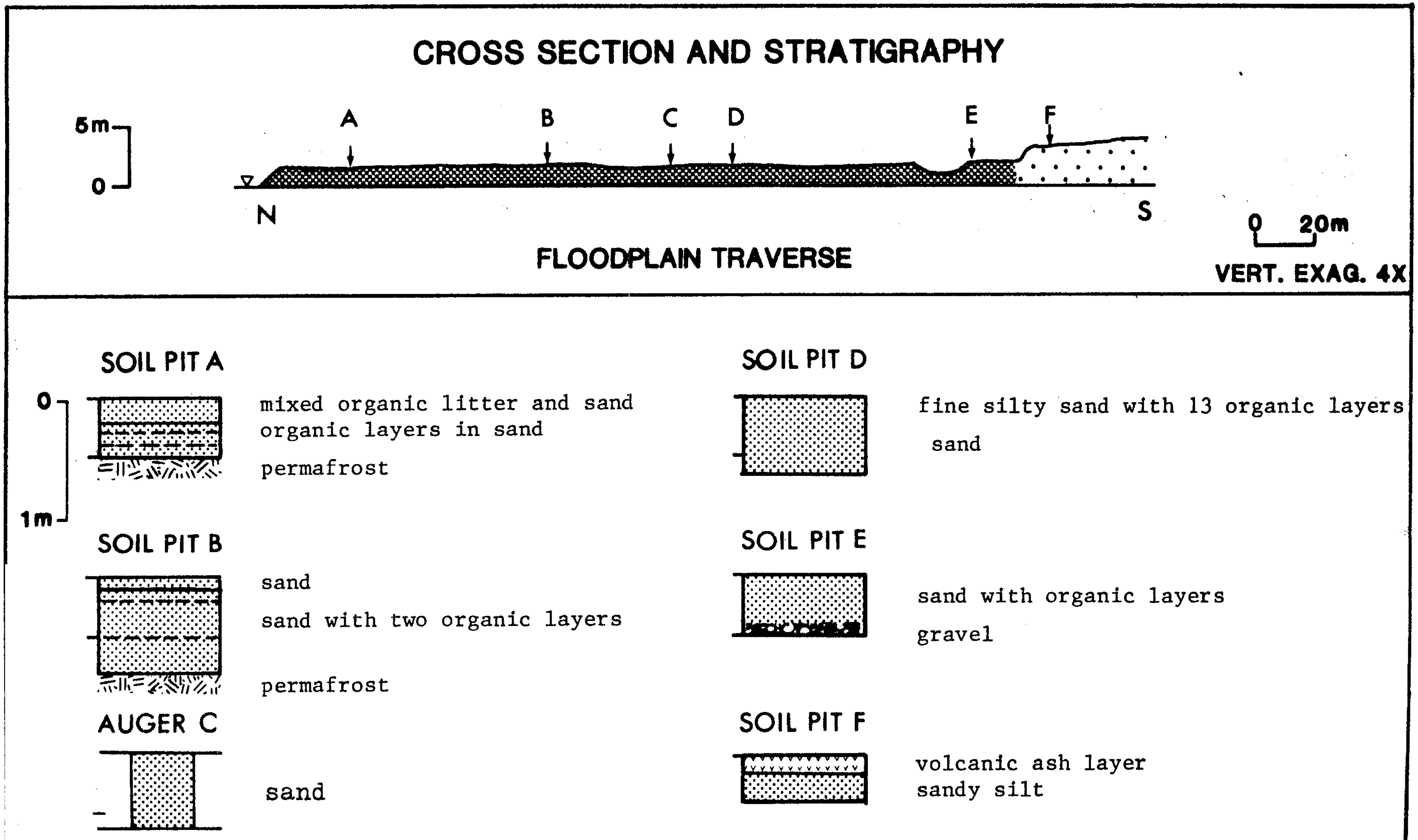


Figure 4.23 Geomorphic profile, stratigraphic sections and auger log from a floodplain traverse at river km 163, right bank. The floodplain lacking ash, a concave bench, is bounded by unflooded alluvium.

migration between river km 150.5 and 159 where the river is confined by McConnell ice stagnation deposits.

A traverse of a concave bench (Fig. 4.23) farther downstream (river km 163) suggests 250 m of lateral migration after the ash was laid down at a rate of 20 cm/yr. The boundary between the floodplain and terrace is marked by an abrupt change in slope with ash present on the slope and beneath the terrace.

Part of Eagle's Nest Bluff reach was restored to its presumed position at the time of ash deposition about 1230 yr BP (Fig. 4.24). The sketch map was constructed from the known and inferred limits of ash determined in the field. The following generalizations can be made about bend migrations of Yukon River during this interval. Migration tends to be down the valley and the age of the floodplain at any one place increases up the valley. Cutbanks therefore taper downstream. Knowing the width of floodplain without ash permits estimates of the loop migration rates for the last 1230 years. This rate can be extrapolated to estimate how long meanders have been present. The scrolled alluvial plain is about 1.5 km wide; that of ash free alluvium is about 200 m. The 200 m strip formed in 1230 years and the 1.5 km wide scrolled surface is therefore formed in 7500 years. This assumes that the rate applies to this longer timespan. The radiocarbon age determination in Hootalinqua reach indicates that lateral migration has been more rapid in the last 4700 years than the last 1200 years. The 7500 year estimate for the oldest

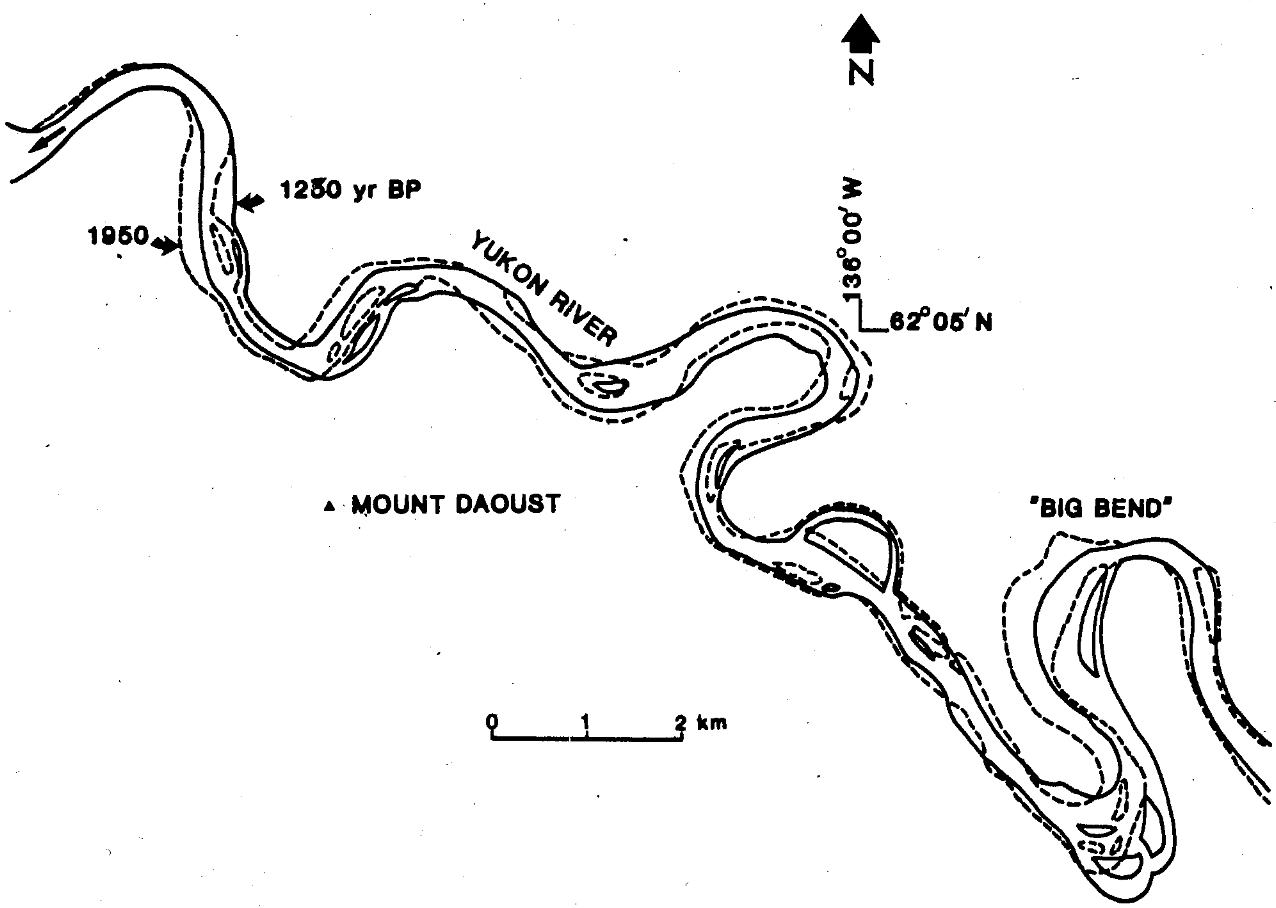


FIGURE 4.24

RESTORATION OF PART OF EAGLE'S NEST BLUFF – CARMACKS REACH

THE YUKON CHANNEL AT 1230 yr BP AND 1950 AD scrolled surface in Eagle's Nest Bluff reach may be a maximum age.

4.4.2 Post-ash Vertical Accretion of Eagle's Nest Bluff Reach

Post-ash vertical accretion on floodplains of different elevations above river level show that those in the 2 to 3 m range are flooded periodically. Alluvial surfaces above 4 m show no evidence of being flooded since ash deposition.

Post-ash deposits are of bedded sand and silt with or without buried organic layers (Fig. 4.26). Floodplains which are devoid of ash occur up to 3 m above river datum. These are comprised of basal gravel overlain abruptly by fining-upward bedded sand and silt. Organics are present in the upper half of sections.

The thickness of vertical accretion above the ash layer (Table 4.2) varies to a maximum of 0.9 m and averages 0.34 m.

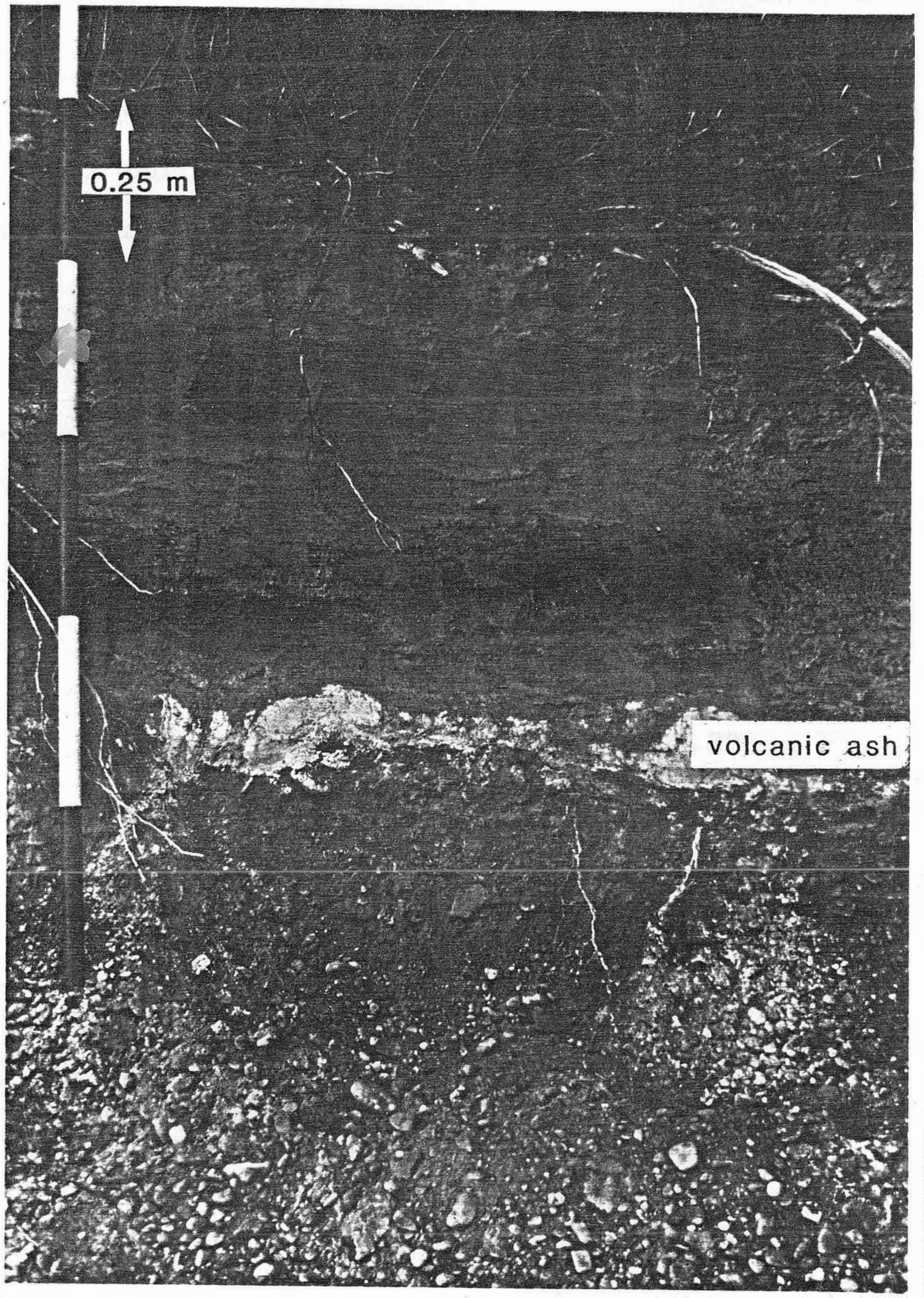


Figure 4.26 Riverbank exposure in Eagle's Nest Bluff reach at river km 129.1. Volcanic ash is reworked on top of gravel and overlain by laminated sands forming the 2.3 m floodplain. Sand covers the ash to a depth of 0.8 m at this site.

TABLE 4.2

Vertical post-ash accumulation on floodplains of different level for Eagle's Nest Bluff - Carmacks Reach

Downstream distance (km)	Base of ash (m)	Vertical accumulation (m)	Accretion rate (mm/yr)
104.7	1.82	0.25	0.20
104.7	2.4	0.20	0.16
105.6	1.8	0.36	0.29
106.2	1.75	0.17	0.14
106.25	1.8	0.36	0.29
106.8	1.25	0.7	0.57
106.8	1.55	0.5	0.41
106.8	1.6	0.55	0.45
106.8	2.16	0.30	0.24
107.5	2.0	0.30	0.24
108.0	1.7	0.12	0.10
111.2	0.95	0.50	0.41
113.2	2.35	0.00	0.00
113.2	1.45	0.20	0.16
113.9	0.8	0.15	0.12
116.2	1.3	0.40	0.33
116.8	0.8	0.90	0.73
117.3	1.3	0.40	0.33
117.3	1.15	0.15	0.12

Downstream distance (km)	Base of ash (m)	Vertical accumulation (m)	Accretion rate (mm/yr)
118.0	0.75	0.35	0.28
118.9	3.4	0.00	0.00
122.5	1.5	0.15	0.12
122.5	2.6	0.05	0.04
122.5	3.75	0.00	0.00
123.6	2.4	0.25	0.20
123.6	3.1	0.22	0.18
123.6	4.9	0.00	0.00
126.6	2.25	0.30	0.24
128.0	3.5	0.00	0.00
129.0	1.4	0.80	0.65
130.5	2.3	0.40	0.33
131.6	1.1	0.25	0.20
131.6	1.7	0.30	0.24
135.0	2.1	0.20	0.16
138.0	1.6	0.65	0.53
139.5	1.8	0.15	0.12
139.5	0.85	0.55	0.45
139.5	0.85	0.40	0.33
143.3	2.85	0.30	0.24
143.3	3.0	0.14	0.11
144.8	3.0	0.00	0.00

Downstream distance (km)	Base of ash (m)	Vertical accumulation (m)	Accretion rate (mm/yr)
145.9	1.6	0.40	0.33
147.3	1.5	0.20	0.16
149.0	2.1	0.80	0.65

4.4.3 Floodplain Accretion Diagram of Eagle's Nest Bluff Reach

A floodplain accretion diagram shows the relationship between the amount of vertical accumulation measured on the ash and height above the river for floodplains with buried ash (Fig. 4.27). This graph suggests more variation in the amount of material accreted on low floodplains than on high ones. This is expected because low floodplains are flooded more frequently than higher floodplains. However, although specific sites show an increase in accretion corresponding to a drop in ash height, the data taken as a whole shows poor correlation between ash height and accretion. This may be partly explained by the varying site of deposition; point bars and sloughs, concave and convex side of channel and width of floodplain. The limiting envelope was sketched through the maximum accretion for floodplains of different ash height may represent the highest accretion rate for the last millenium for floodplains which existed before 1230 yr BP. With time and similar hydrologic conditions the floodplains below the envelope will approach the maximum.

An average line was constructed by least squares regression. The equation of this line predicts medium term accretion rates for floodplains based on their height.

$$y = -0.003x + 0.36$$

where: y = vertical accretion (m)

x = height of floodplain (at base of ash)

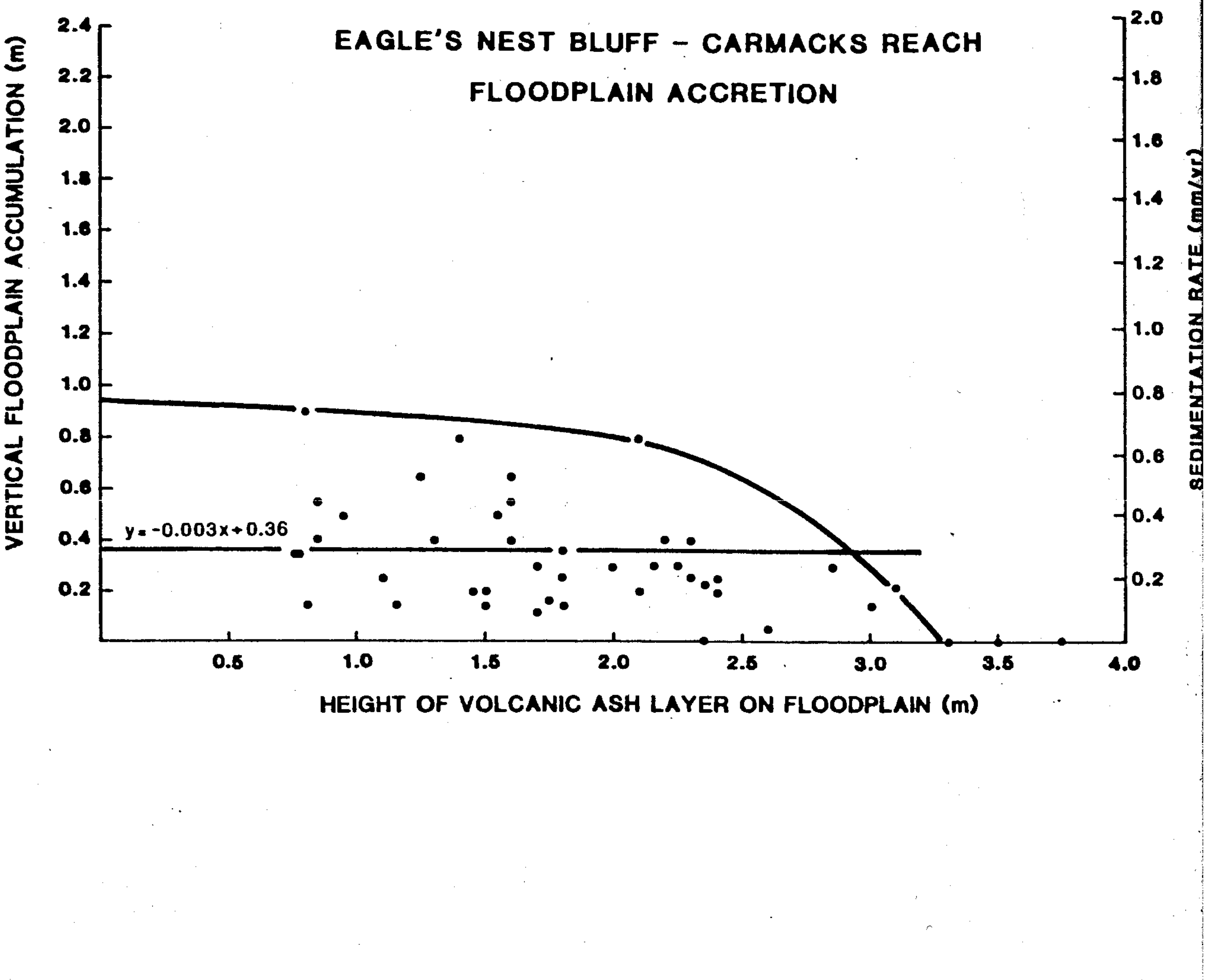


Figure 4.27 Eagle's Nest Bluff - Carmacks reach floodplain accretion.

4.4.4 Long Profile of Eagle's Nest Bluff Reach

The long (downriver) profile for Eagle's Nest Bluff reach shows the distribution of floodplains and terraces along the stream channel (Fig. 4.28 in pocket). Unpaired terrace segments, which represent scrolled meandering river deposits, are not linked on the diagram. Terrace segments without meandering planform or with low sinuosity channels and dune fields are inferred to have formed as outwash. Such segments are linked subjectively based on height.

Aspects of vertical accretion on floodplains of varying position and height can be inferred from the profile. The limit of aggradation is 3.25 m above river level and is parallel with the average river surface grade. The floodplain without ash, or those deposited in the last 1230 years, are 2.5 m below the highest flood level. The highest and oldest scrolled alluvial terraces are 8 m above river level. This shows that with time Yukon River has incised its bed leaving older meander scrolls as abandoned floodplains (terraces). The river has been reworking outwash and scrolled alluvium. The segmented lowest level of ash line is between 0.8 and 1.25 m above river level showing that the river has incised about 1 m since the ash fall.

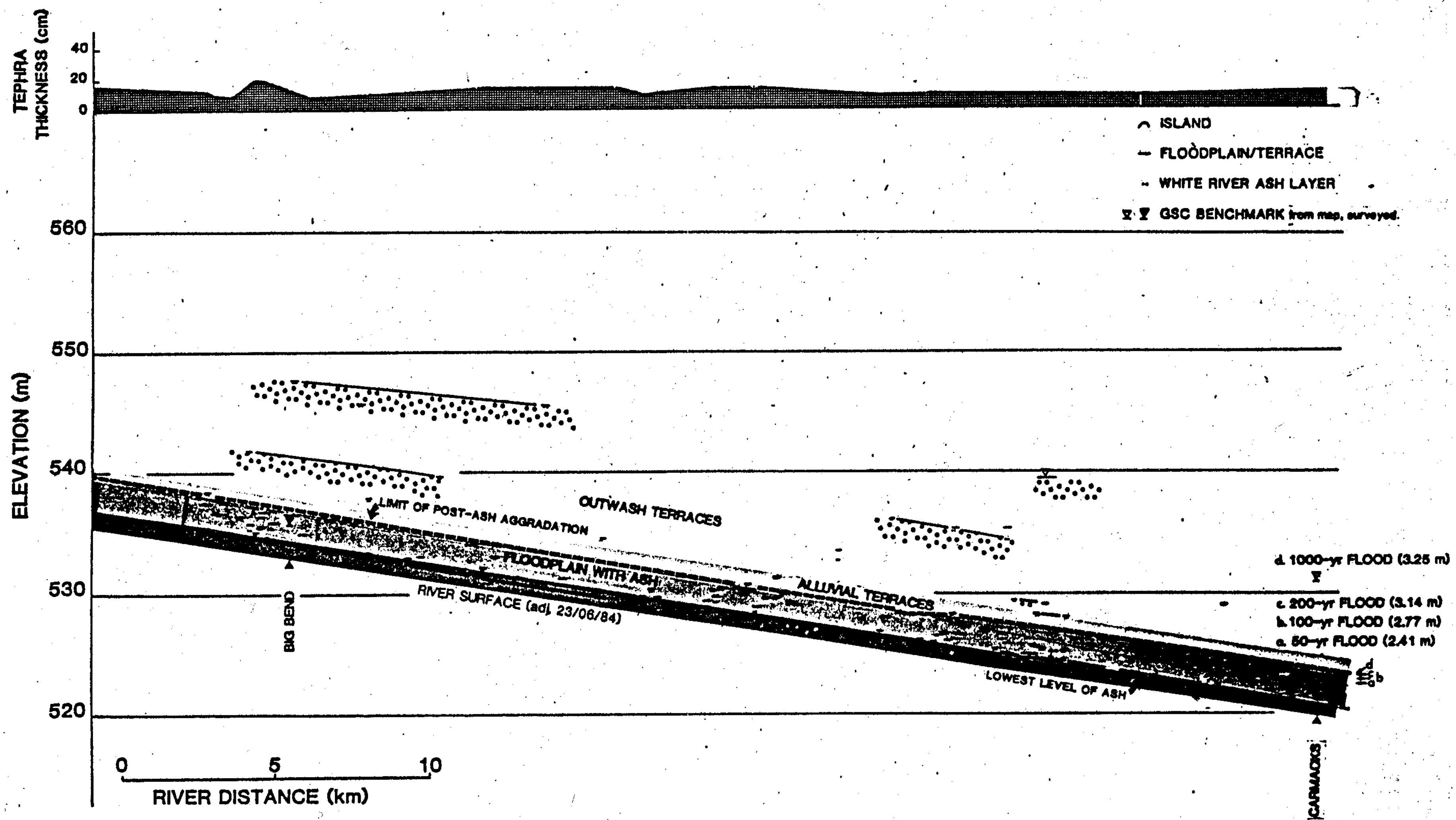


Figure 4.28. Long profile of Eagle's Nest Bluff-Carmacks reach showing White River Ash thickness, limit of post-ash aggradation, lowest level of ash, and levels of map units with position of ash layer. This is a reduced version of figure in pocket.

4.4.5 Concave Bench Accretion to the Floodplain

An example of concave bench formation (river km 111-112) is presented as a sequence of stages in the evolution of floodplain.

The stages in development of the concave bench are inferred from morphological features observed in the field and on airphotos. The White River Ash constrains the amount of concave bench formed over a fixed interval which is depicted (Fig. 4.29) as a pre-ash (stage 1) and present (stage 2) configuration of the channel and floodplain. The tail of the upstream point bar is also included in the diagram. A zone of deposition at the apex of the bend is present with a smaller channel on the concave side and a more active channel on the convex side. The minor channel eventually is abandoned within the post-ash period and remains as a low lying swale next to a former cutbank. Near the present concave bank water filled sloughs still traverse the lowest floodplain and are at least 2 m deep.

Other examples of concave bench evolution have been documented by Nanson and Page (1983) for a river in Australia.

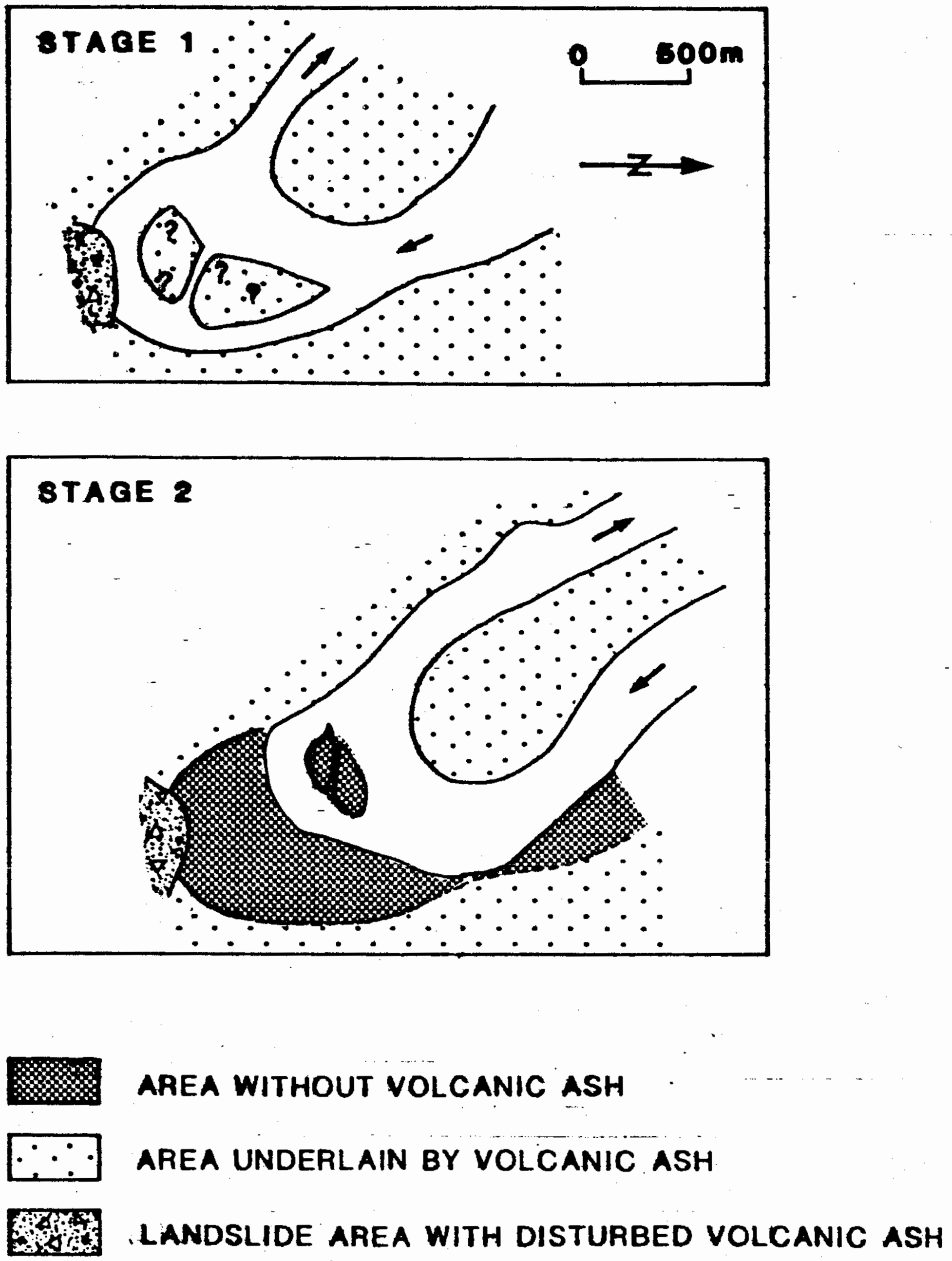


Figure 4.29 Development of a concave bench at "Big Bend"

4.5 Rink Rapids - Minto Reach

The Rink Rapids reach has an anastomosed planform (Fig. 4.3 in pocket) with abundant islands and low sinuosity. The surficial geology in this reach, at Five Finger Rapids, was mapped as part of dam site investigations (Owen, 1959c; Hardy Associates, 1980). Other mapping has been carried out by Klassen (in press). Bostock (1936 pp. 7-12) reported on broad aspects of the physiography and glaciation of the region.

4.5.1 Glacial History of Rink Rapids Reach

Excellent preservation of glaciofluvial features permit formulation of a tentative late glacial history for this reach based on airphoto interpretation and ground checking of materials and landforms.

Proglacial depositional forms extend beyond the limit of the last glacial advance northwest of Yukon Crossing. These landforms include a valley train, fans, and deltas. The highest terrace, which merges with the end moraine at Yukon Crossing and has a soil suggestive of McConnell age deposits, formed as the outwash plain at the maximum of the McConnell advance. This valley train has been mapped by height and surface features from Yukon Crossing to beyond the study reach and is informally called the "McConnell terrace". Part of the "McConnell terrace" and other outwash terraces were eroded as the ice withdrew from the valley. Younger outwash fills at successively lower elevations were deposited and subsequently channelled and terraced by meltwater streams. This left a series of terrace segments with a common depositional history in the valley (Fig. 4.30).

The highest and oldest terraces formed in closer proximity to ice than did the lower terraces. Channel scars on these terraces indicate their glacial influence. For example, a teardrop shaped remnant south of Yukon Crossing is remarkably similar to an outwash remnant described by Mollard and Janes (1984, p. 51) in Saskatchewan. Both features share a common genesis of channelling along a glacial spillway leaving a remnant surrounded by postglacial alluvium.

After McConnell glacial time, valley fills were incised leaving terraces well above the present river level.

Braided rivers probably formed because abundant sand and gravel were available to streams. Channel scars can be discerned on airphotos of the lower terraces. They are here referred to as outwash terraces but their relationship to a melting ice margin is not known. Deflation by wind left dune fields on the lower terraces which were stabilized before the White River Ash was erupted. Vegetation was established at this time and the river assumed the anastomosed channel character which persists today.

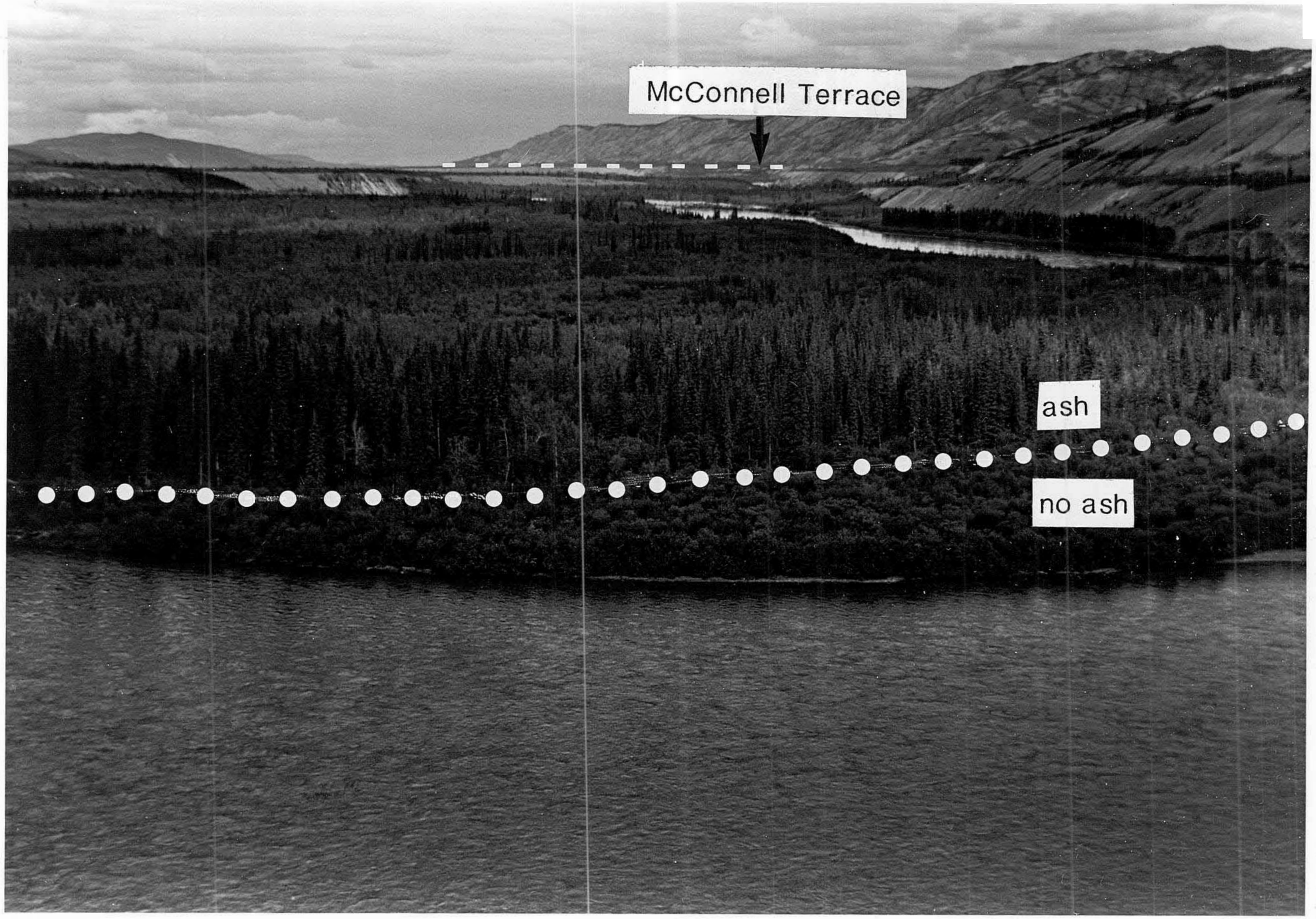


Figure 4.30 Downstream view of last meander lobe of Rink Rapids reach (river km 179.3). High-level glaciofluvial terraces from the McConnell glaciation form a series on the right hand side of the valley. Floodplain without ash in foreground is vegetated with alder and willow. Spruce covered floodplain contains the ash.

4.5.2 Major Geomorphic Map Units of Rink Rapids Reach

The geomorphic units are:

Channelled Terraces:

"Reid Terraces" (10-112 m)

"McConnell Terrace" (7-110 m)

High-level Glaciofluvial Terraces (36-86 m)

Glaciolacustrine Terrace (63-79 m)

Low-level Glaciofluvial Terraces (5-19 m)

Anastomosed Terraces and Floodplains:

Low-level Terraces and Floodplain with Volcanic Ash (2-5 m)

Floodplain without Volcanic Ash (0-3.8 m)

4.5.2.1 Channelled Terraces: "Reid Terraces"

The terrace extending in remnants downstream of McGregor Creek (river km 203) to below Minto roughly coincides with hummocky drift in Yukon River Valley and Von Wilczek Creek valley. This drift is presumed to be Reid age (Hughes pers. comm.). Its topography is more subdued than the fresh looking McConnell hummocky drift upvalley. The terrace remnants are informally named "Reid terraces" based on the proximity to presumed Reid drift and the presence of ventifacts, weathered stones and deeper soil profiles than McConnell age deposits. Similar criteria were used in McQuesten map area to differentiate deposits of different ages in Stewart River Valley (Tarnacai et al., 1985).

4.5.2.2 Channelled Terraces: "McConnell Terrace"

The largest and most extensive terrace in the Rink Rapids reach extends from near Yukon Crossing to Minto. It merges with the north sloping moraine ridge marking the McConnell limit (Hughes et al., 1969) (river km 196) (Fig. 4.30, 4.31, and 4.32). It is informally named the "McConnell terrace" and bears the same relationship to the McConnell ice limit at Yukon Crossing as the terrace traced from the McConnell glacial limit on the Stewart River to below McQuesten airstrip (Hughes, 1983 field work). The "McConnell terrace" in McQuesten map area is also covered with a veneer of loess overlying a brunisol developed in gravelly outwash. Ventifacts commonly observed in terraces above the McConnell terrace are absent from the "McConnell terrace" and younger terraces in both Yukon River valley and Stewart River valley.

4.5.2.3 Channelled Terraces: High-level Glaciofluvial Terraces (36-86 m)

Airphotos show that high terraces not mapped as Reid or McConnell terraces have channel patterns and dunes. Small meltwater channels merge with the highest of these surfaces south of the limit of mapping. The terraces occur near Tatchun

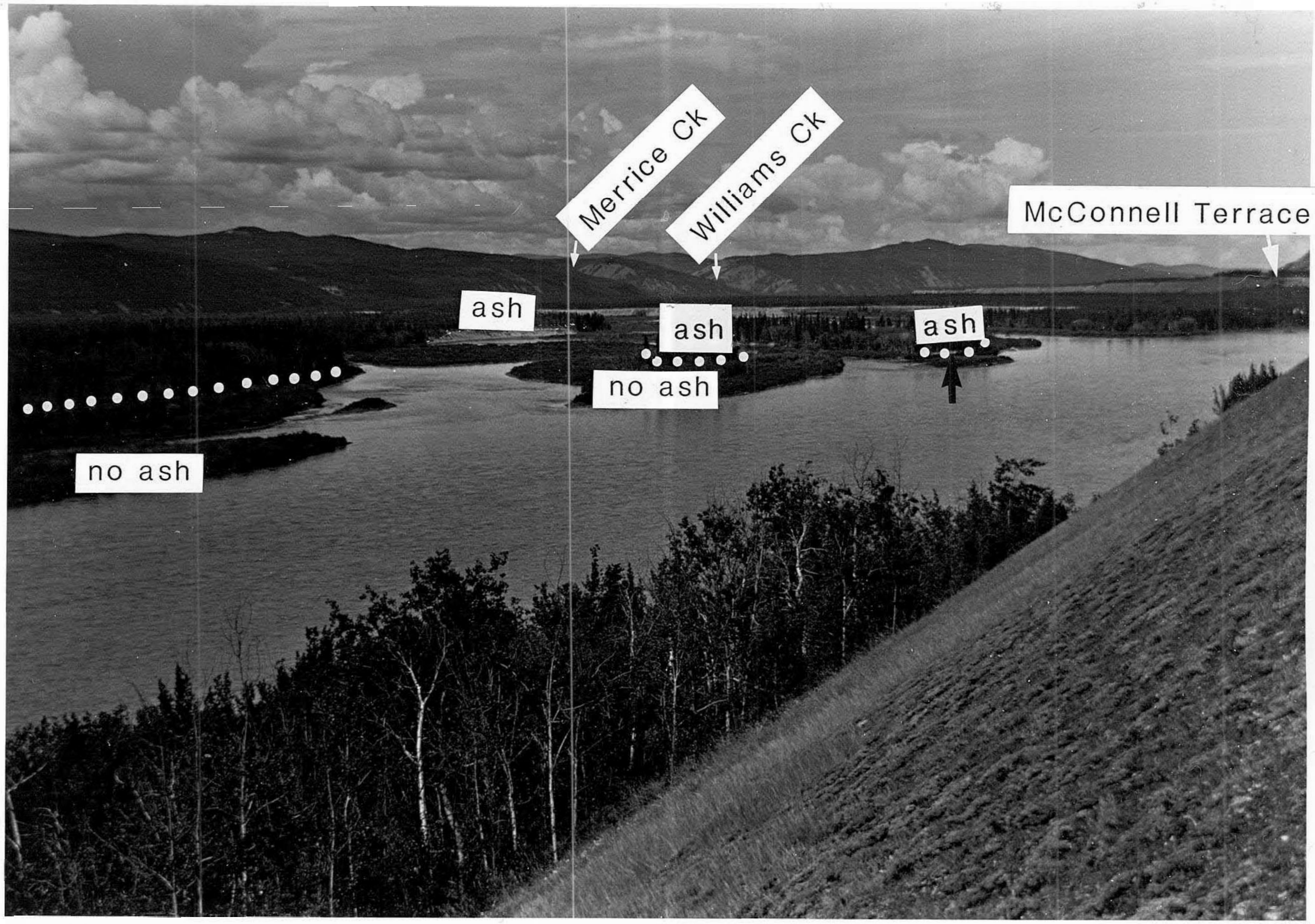


Figure 4.31 A downstream view of the Rink Rapids reach (river km 186.5) looking toward Yukon Crossing. The valleys of Merrice Creek and Williams Creek enter from the left. An anastomosed river pattern occurs in this area with vegetated islands, some of which contain ash.

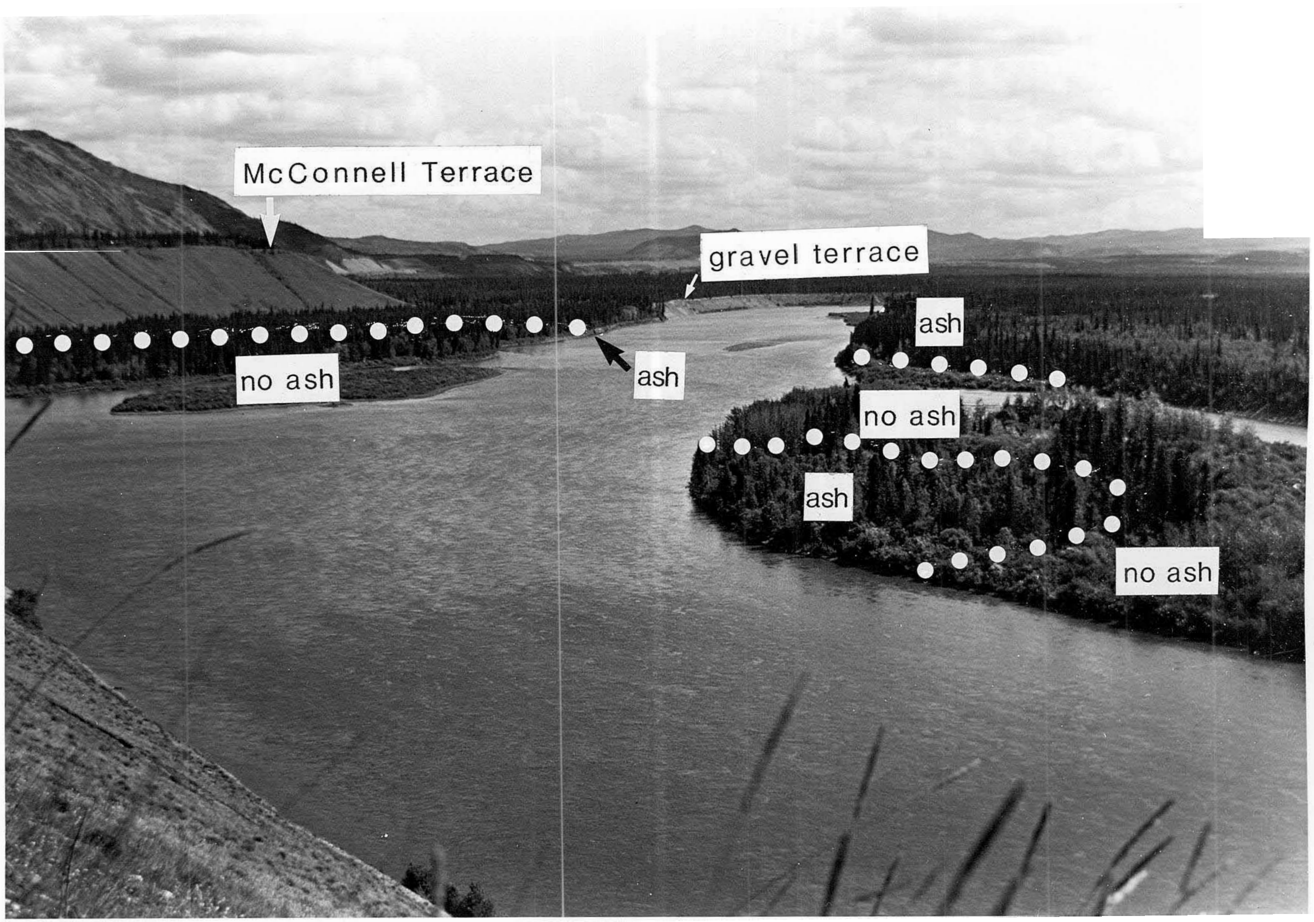


Figure 4.32 Upstream view from river km 199 in Rink Rapids reach showing multiple channels around islands and bars with varying stages of vegetation development. The high terrace on the left side of photo is the "McConnell terrace". A lower gravel terrace in mid-distance is recessional outwash with dune field modifying its surface. Ash is exposed continuously along the cutbank to the point indicated on photo.

River and Rink Rapids adjacent to the hummocky stagnant ice deposit in the centre of the valley (river km 177 to 191). Exposures are of poorly stratified and poorly sorted cobbly gravel. Large clasts range from 30 to 100 cm and are matrix supported. Volcanic ash 30 cm thick overlies loess which is about 50 cm thick above the gravel. Two gullies at river km 187 retain ash on surface slopes; these slopes have remained stable since ash was deposited. Ash is present on part of the terrace scarp but missing in other parts. The scarp with no ash slopes at 36°.

4.5.2.4 Channelled Terraces: Glaciolacustrine Terrace (63-79 m)

North of Tatchun River a smooth flat terrace contains stratified silt and clay overlying a pinkish till. Washed stratified gravels overlie the same laminated rhythmites on a road cut 53 m above the river. These deposits are interpreted to be the glaciolacustrine fill of a lake ponded by ice occupying Yukon River valley and drained by a large meltwater channel incised in the terrace.

4.5.2.5 Channelled Terraces: Low-level Glaciofluvial Terraces (5-19 m)

Gravel terraces below the "McConnell terrace" near the terminus of the last glaciation occupy the valley in sloping steps forming the river bank along much of the course (Fig.

4.32). Their surface is modified by dune fields and tributary fan deposits. The gravel is imbricated and crudely bedded and overlain by about a meter of sand, ash near the top and covered by eolian sand.

4.5.2.6 Anastomosed Terraces and Floodplain:

Low-level Terraces and Floodplain with Volcanic Ash (2-5 m)

The low valley flats (alluvial plain) straddle the river channel in modest proportions compared to outwash deposits notably in the Yukon Crossing area and upstream of McCabe Creek. Irregular minor channels open at their exits and closed upstream are present on this map unit, for example at river kilometer 206 and 215. They are in the process of being abandoned. Thirteen islands are partly underlain by this unit. Cutbanks of fetid layered silt and sand overlie gravel. The ash is buried by bedded sediment on island floodplains from 1.4 to 3.8 m above river datum. The gravel-sand contact of islands commonly falls in elevation downstream.

4.5.2.7 Anastomosed Terraces and Floodplain:

Floodplain without Volcanic Ash (0-3.8 m)

This map unit contains many islands, bars and accreted lateral bars. The anastomosed pattern of minor channels is present in these low lying deposits of Rink Rapids reach. The river bed is cobbly gravel. Cohesive cutbanks are of similar strata as the alluvial plain with ash. Rhythmically layered organic/sandy silt layers are common in the top meter. The organic layers are more closely spaced than scrolled floodplain and are fetid. Soil pits in these organic rich horizons encounter permafrost as shallow as 35 cm hindering depth to ash measurements.

4.6 Post-ash Channel Behaviour of Rink Rapids Reach

The Yukon River has not changed its anastomosed morphology in the last millenium. Rather it has modified islands and floodplain by erosion and deposition within the restricted valley flat bounded by high terraces. White River Ash distribution shows the low level of channel change. I infer from the map (Fig. 4.3 in pocket) that midchannel islands grew and diminished, that banks eroded between nodes, that lateral bars accreted and that outwash terraces eroded since ash fell. Examples of the river changes are illustrated from selected parts of the reach. A sequence of events for the generation of accreted floodplain is also discussed based on the 1230 year record.

The ash is exposed in banks 0.1 to 5 m above river level on ten midchannel islands. This is strong evidence for longevity of islands in anastomosed rivers.

4.6.1 Post-ash Lateral Migration of Rink Rapids Reach

Lateral floodplain accretion and midchannel island growth, seen in this reach, is illustrated with examples. Upstream of Yukon Crossing and at the terminus of the McConnell ice stagnation deposits (river km 187 to 193) Yukon River is split by many islands. The riverbanks are low-level glaciofluvial gravel terraces with dune fields and alluvium with and without ash. Volcanic ash underlies segments of four islands, from river km 187 to 192, showing that islands have migrated little since the ash was laid down. However, the aggregate width of islands lacking ash at river km 192 is 700 m and both banks have ash yielding a channel shift rate of 57 cm/yr. A north facing bank especially susceptible to slumping is being actively eroded here. It contains buried ash in a cohesive organic silt stratum. Rapid bank erosion is believed to have occurred as a result of thermal erosion. Thawing of permafrost releases water saturating the thawed sediment which leads to an unstable condition. This type of erosion is discussed by Walker and Arnborg (1966) and Outhet (1974).

Downstream of Yukon Crossing (river km 196.5) a 200 m wide post-ash floodplain is accreted to pre-ash floodplain (Fig. 4.33) with a slough at the boundary. Southwest of the slough ash is overlain by 25 cm of silt indicating that it has been flooded in post-ash time. Farther downstream (river km 200.8) accreted floodplain abuts a low-level glaciofluvial terrace. The floodplain without ash is 173 m wide and another slough marks the boundary (Fig. 4.34). The average lateral migration rate for these two examples is 15.2 cm/yr. A longitudinal island is underlain by volcanic ash at its downstream end. Channel migration is therefore restricted to the area of accreted floodplain and the present channel. Cutbanks with volcanic ash on both sides of this island indicate that the island was wider when ash was deposited than today.

Similar relations are seen just upstream of McCabe Creek. Islands divide the Yukon River between low-level glaciofluvial terraces. Volcanic ash is absent on the large island (river km 220.6) (Fig. 4.35) opposite a 250 m wide accreted floodplain. Two kilometers farther downstream accreted floodplain abuts floodplain with ash at a narrow slough (Fig. 4.36). The post-ash floodplain is 165 m wide here inferring a rate of 13.4 cm/yr. Because ash is exposed on the opposite bank of the river in an alluvial fan, migration has been toward the right bank.

A lenticular island occurs in midchannel between a 100 m high "Reid terrace" on the left bank and an 8 m low-level outwash terrace on the right bank at river kilometer 224.5. The central axis of this island (Fig. 4.37) is underlain by ash surrounded by lower ash-free areas ("wings"). The channel must be migrating away from the island centre and cutting terraces on each bank.

Another midchannel island with volcanic ash (river km 229) shows that lateral migration has widened the left channel and perhaps narrowed the right channel.

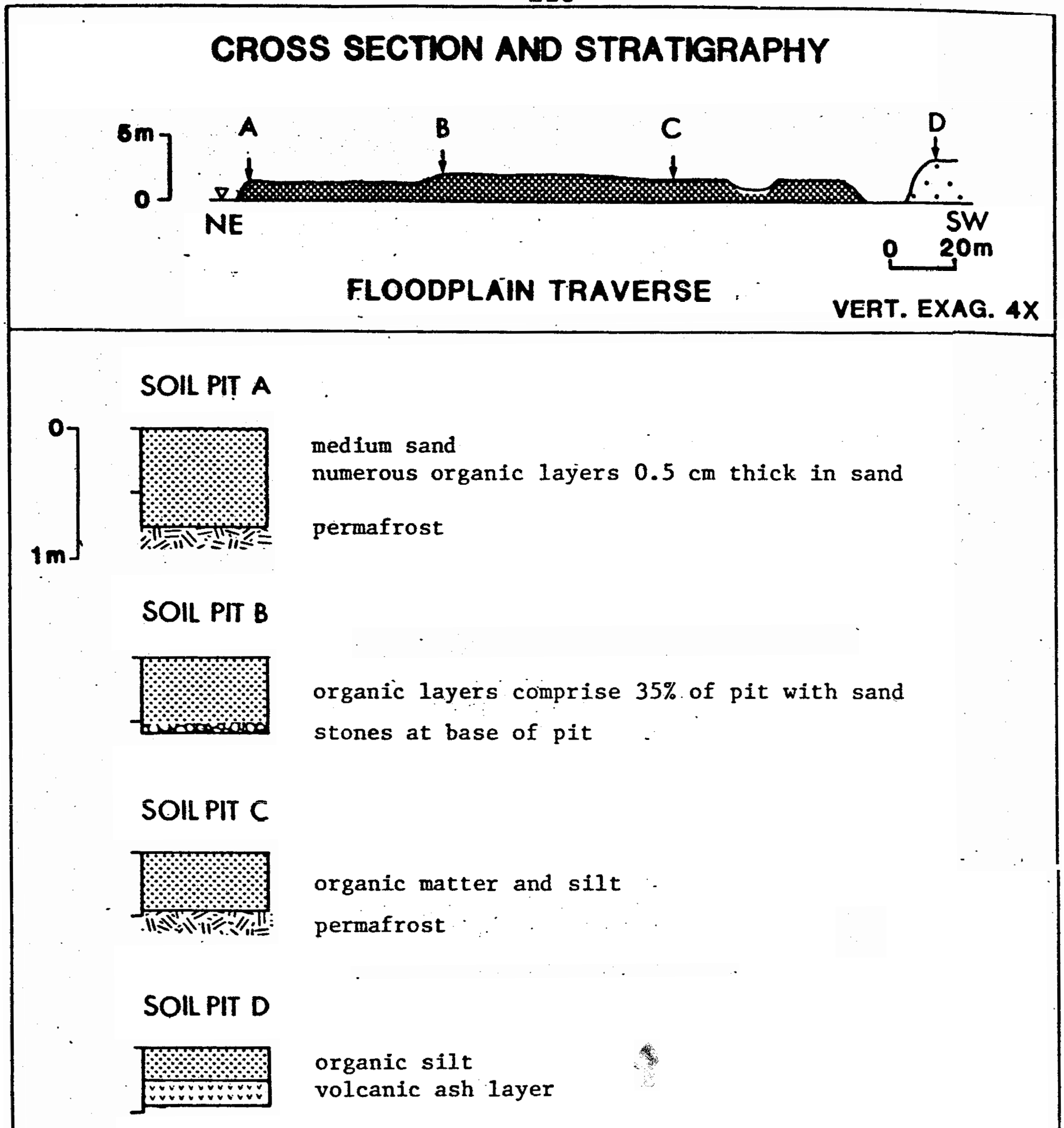


Figure 4.33 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 196.5, left bank. Floodplain without ash is separated from floodplain with ash by an active minor channel. Another minor channel is infilled with detritus.

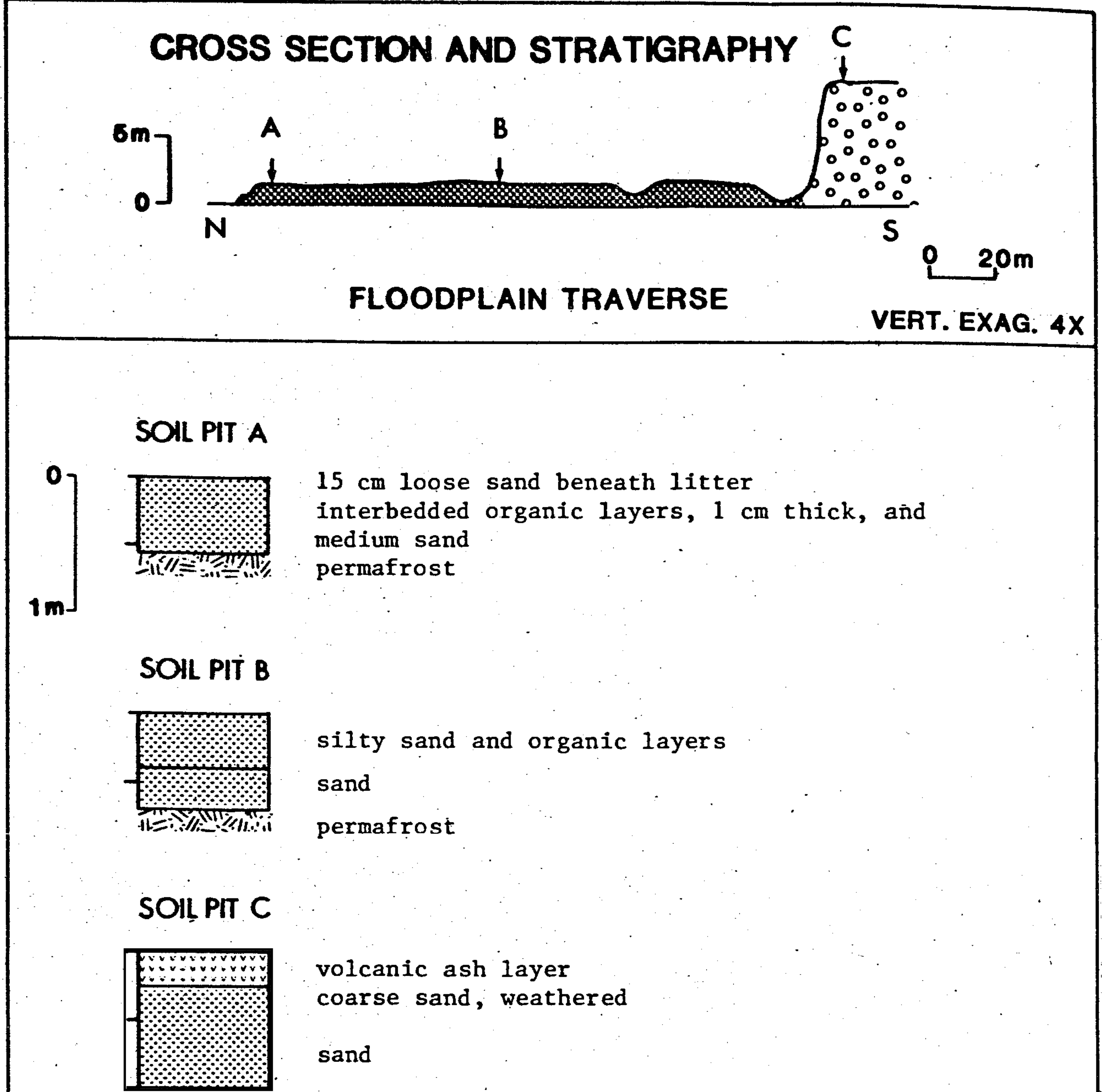


Figure 4.34 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 200.8, left bank. The floodplain lacking ash, an accreted lateral bar, occurs next to a former cutbank in gravel outwash.

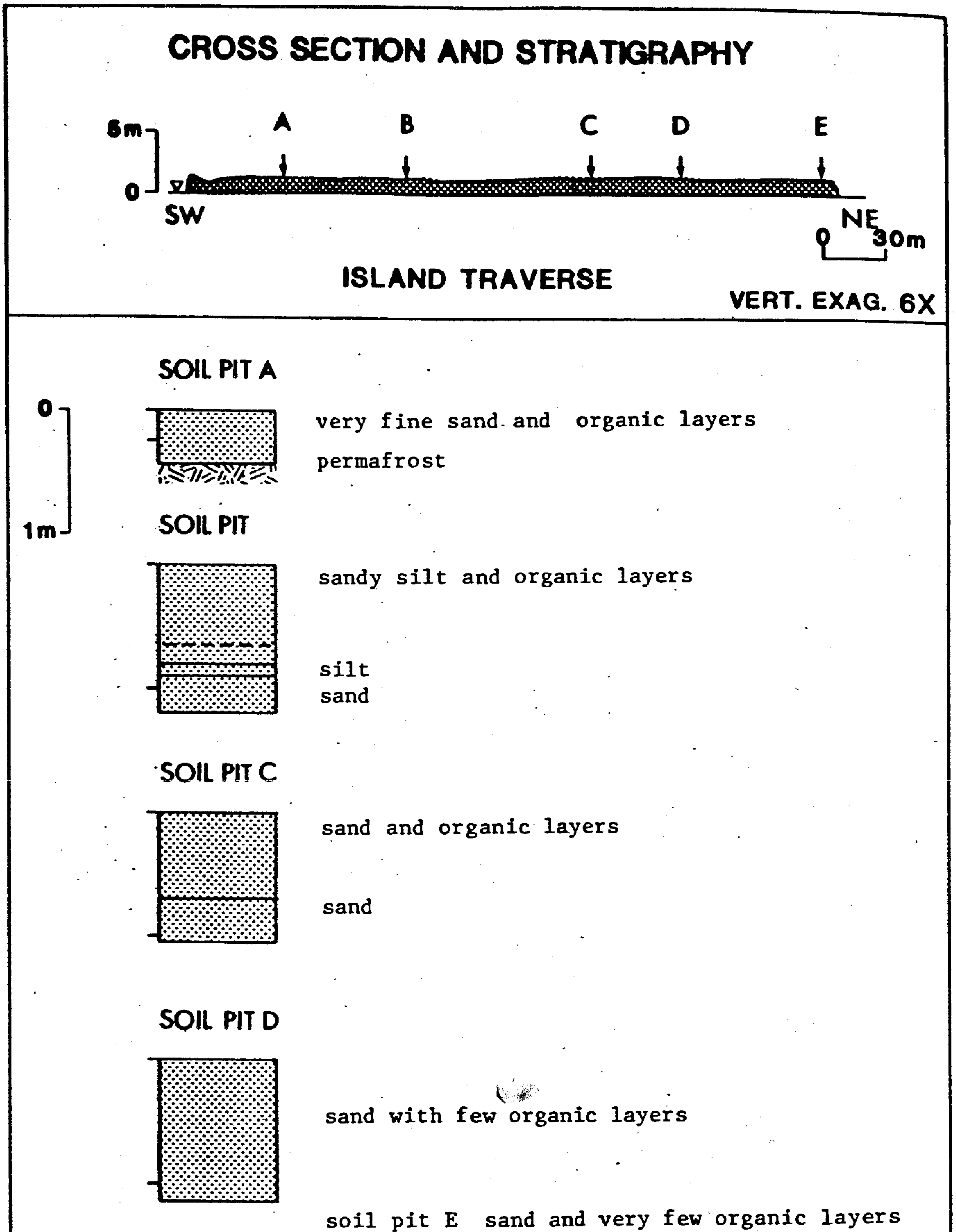


Figure 4.35 Geomorphic profile and stratigraphic sections from an island traverse at river km 220.6. This island, which lacks ash, has buried organic layers in the overbank deposits indicating repeated flooding.

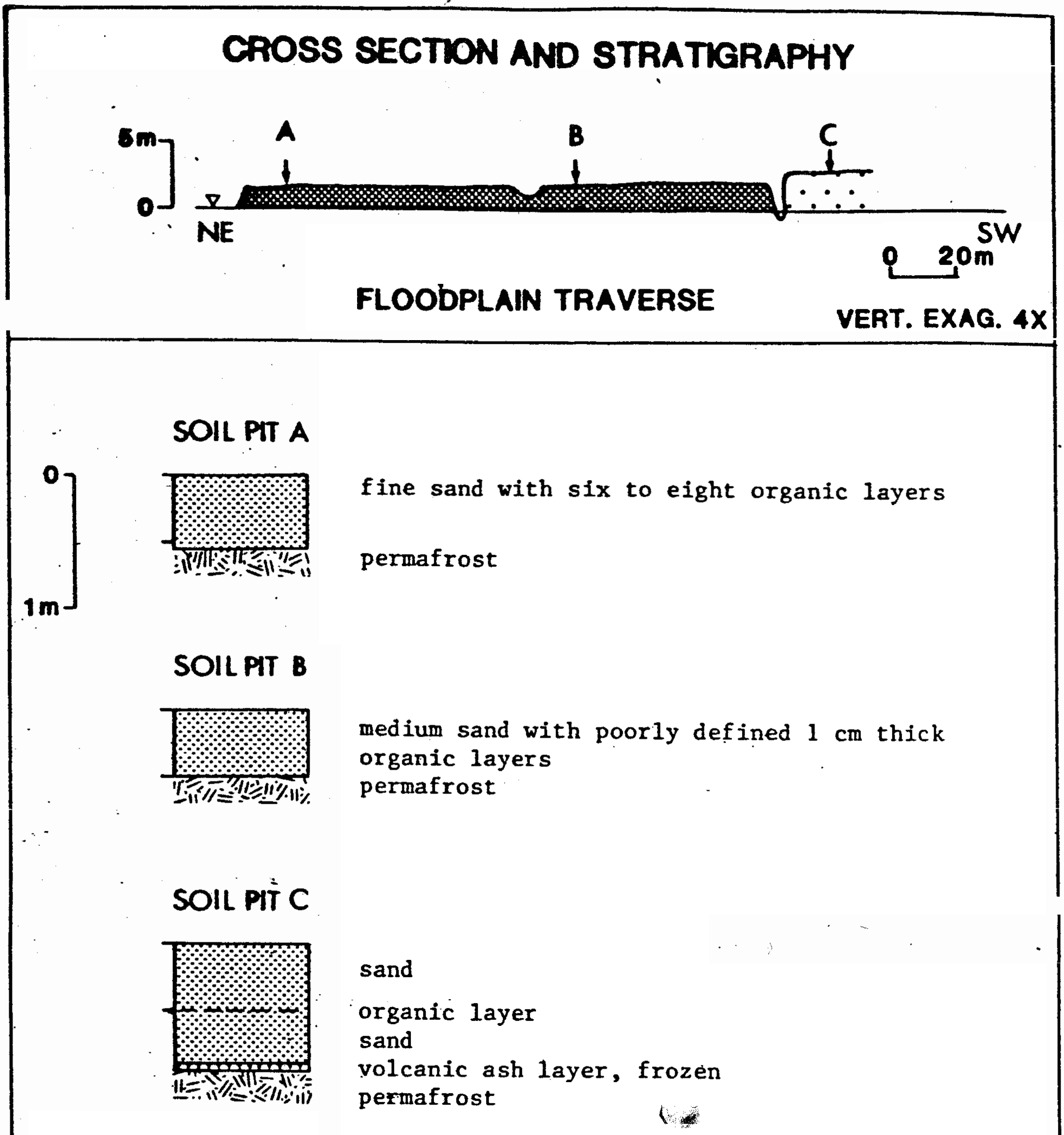


Figure 4.36 Geomorphic profile and stratigraphic sections of a floodplain traverse at river km 222.6, left bank. A lateral bar is in the final stages of accretion to the bank.

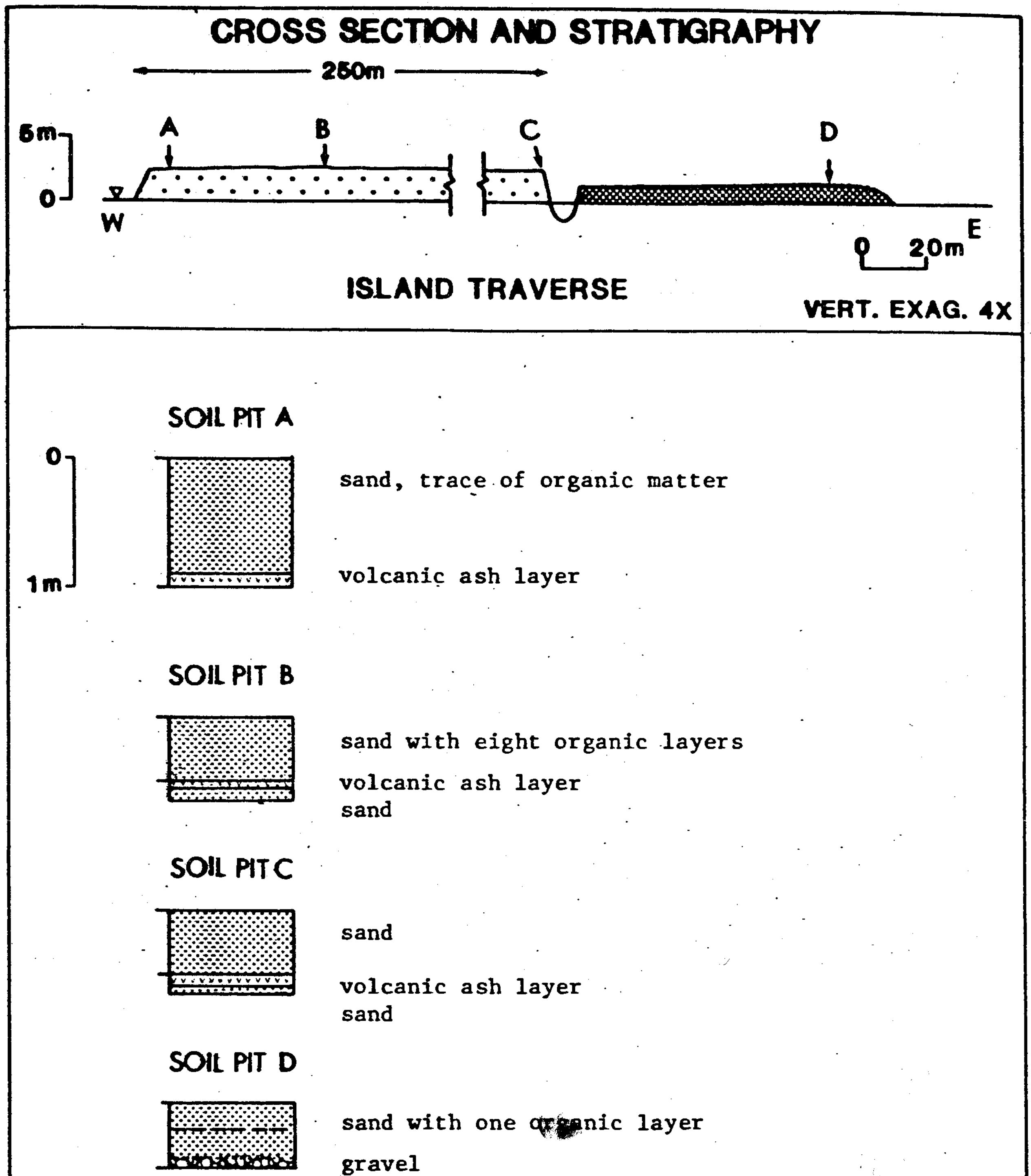


Figure 4.37 Geomorphic profile and stratigraphic sections from an island traverse at river km 224.5. The floodplain without ash forms one "wing" around a core with buried ash. Another "wing" is present to the left of this core (not shown).

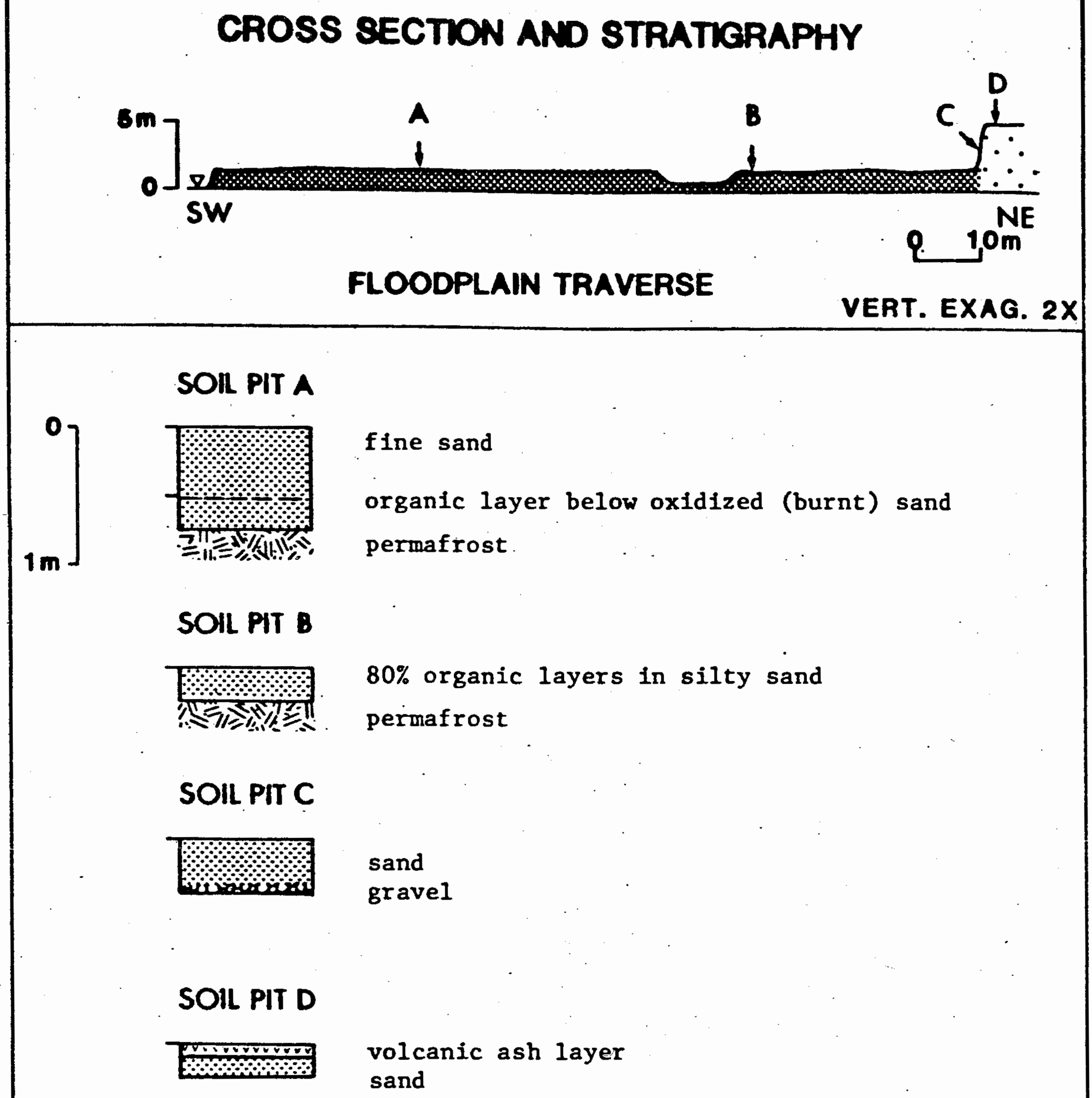


Figure 4.38 Geomorphic profile and stratigraphic sections from a floodplain traverse at river km 229.1, right bank. A floodplain with an abandonned minor channel is accreted to an unflooded terrace. Note a change in scale from previous figures.

Figure 4.39 A cleaned face on the bank of a large island in Rink Rapids reach (river km 190.4). A 20 cm thick ash layer is exposed in a 1.9 m floodplain at the downstream end of this island. The base of ash is 0.7 m above the river and it is covered by o.95 m of post-ash accumulation of laminated silty sand and organic layers.

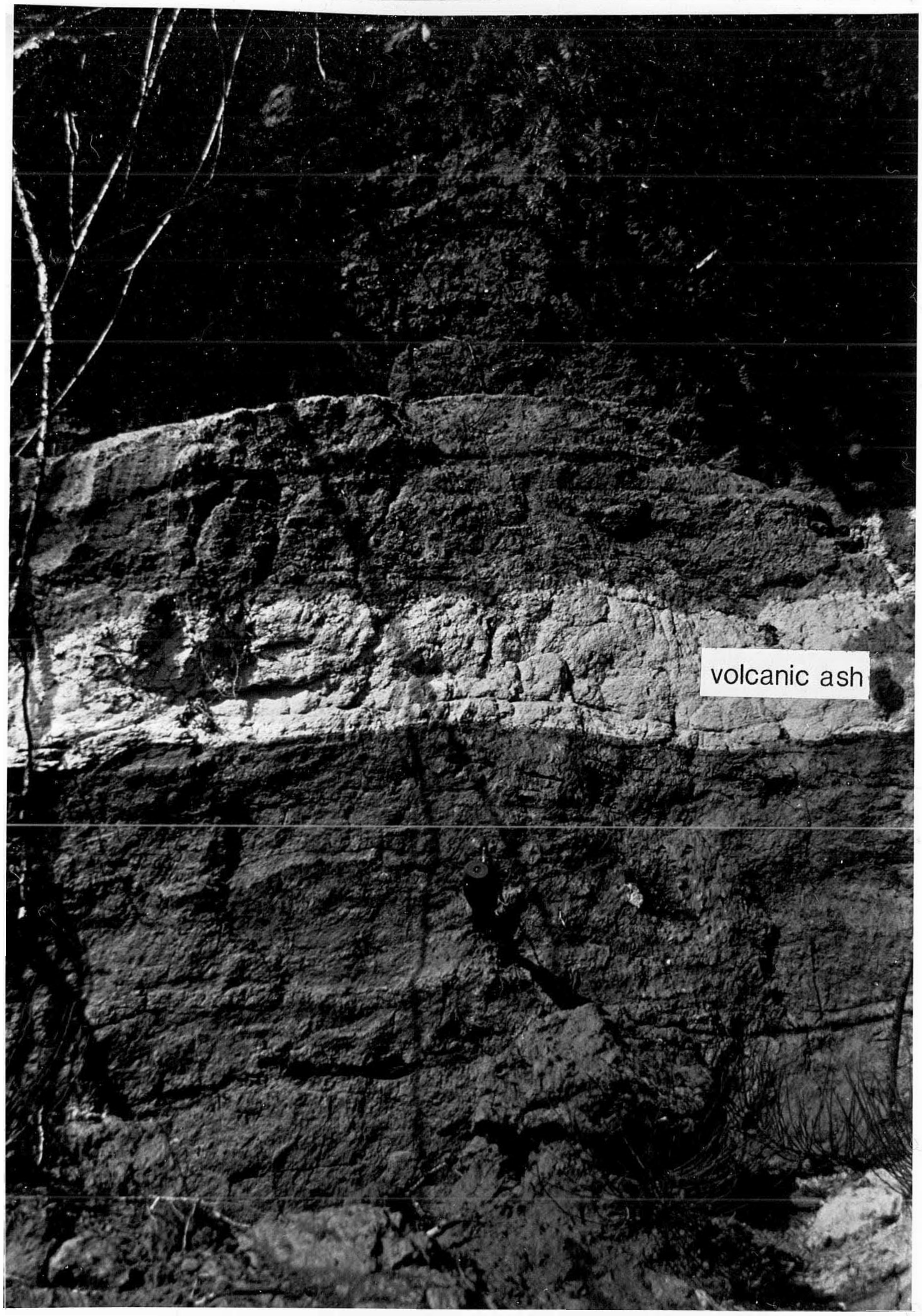


Figure 4.40 A cutbank in Rink Rapids reach (river km 197) showing ash, 20 cm thick, buried by 1.2 m of sand in a 3.4 m floodplain. There is a well-defined sharp contact below the ash and a more undulating contact above the ash.

The ash free surface on islands can extend upstream, downstream and outwards from the centre. Banks opposite the midchannel islands contain ash implying erosion after the ash was deposited. The amount of erosion is presumably close to the width of ash free islands.

4.6.2 Post-ash Vertical Accretion of Rink Rapids Reach

Sediment and organic layers have accumulated above the ash in the Rink Rapids reach floodplains. Deposition sites include the cores of some islands and floodplains adjacent to sloughs. Areas without depositon include low-level glaciofluvial terraces and low-level terraces of anastomosed morphology.

The accretion measured in soil pits and cutbanks (Table 4.3) averages 0.85 m and reaches a maximum of 2.2 m at river kilometer 212.3. This site is located on accreted floodplain. The average post-ash accretion rate is 0.07 cm/yr.

The ash layer is generally near the middle of 2.4 to 3.0 m cutbanks, but is locally within 10 cm of river level. Those above 3.8 m show no sign of having been flooded during post-ash time.

TABLE 4.3

Vertical post-ash accumulation on floodplains of different level for Rink Rapids - Minto Reach

Downstream distance (km)	Base of ash (m)	Accumulation (m)	Accretion rate (mm/yr)
179.4	0.55	0.45	0.37
179.9	4.4	0.3	0.24
183.7	2.4	0.5	0.41
184.2	1.7	0.7	0.57
190.4	0.75	0.7	0.57
191.45	1.6	0.5	0.41
191.45	0.5	1.7	1.38
191.45	0.1	1.2	0.98
193.4	1.5	0.75	0.61
194.35	1.7	0.5	0.41
194.9	3.0	0.6	0.49
196.7	2.75	0.25	0.20
196.7	2.0	1.2	0.98
198.25	1.14	0.85	0.69
198.25	0.3	1.15	0.93
198.25	2.17	0.43	0.35
201.0	1.5	1.15	0.93
201.0	1.33	0.97	0.79
201.6	2.7	0.40	0.33

Rapids Reach

Downstream distance (km)	Base of ash (m)	Accumulation (m)	Accretion rate (mm/yr)
202.6	1.25	1.5	1.22
204.0	2.7	0.42	0.34
204.7	2.0	0.54	0.44
207.0	2.0	0.95	0.77
209.3	1.2	1.25	1.02
209.8	1.05	1.4	1.14
211.0	1.0	1.5	1.22
212.3	0.20	2.2	1.79
219.5	0.80	0.46	0.37
219.5	1.8	0.3	0.24
221.5	2.35	0.3	0.24
222.5	1.63	0.90	0.73
224.35	1.75	0.50	0.41
227.5	3.7	0.05	0.04
227.8	1.5	0.35	0.28
228.5	1.37	1.5	1.22

4.6.3 Floodplain Accretion Diagram of Rink Rapids Reach

The floodplain accretion diagram (Fig. 4.41) for Rink Rapids reach shows scattered points. Variability in accretion increases as the volcanic ash elevation decreases. The lowest ash bed has the thickest accumulation above them and ash layer 4 m above river level lacks cover. The least squares regression line through the points shows the trend of sedimentation rate. The equation of this line predicts medium term accretion rates for floodplains based on their height.

$$y = -0.384x + 1.46$$

where: y = vertical accretion (m)

x = height of floodplain (at base of ash)

The maximum accretion for floodplains with respect to height is suggested by the envelope around the plotted points and the maximum accretion is about 2.4 m thick which gives an average accretion rate of 1.95 mm/yr. The highest flood in one thousand years appears to be about 3.6 m above river datum.

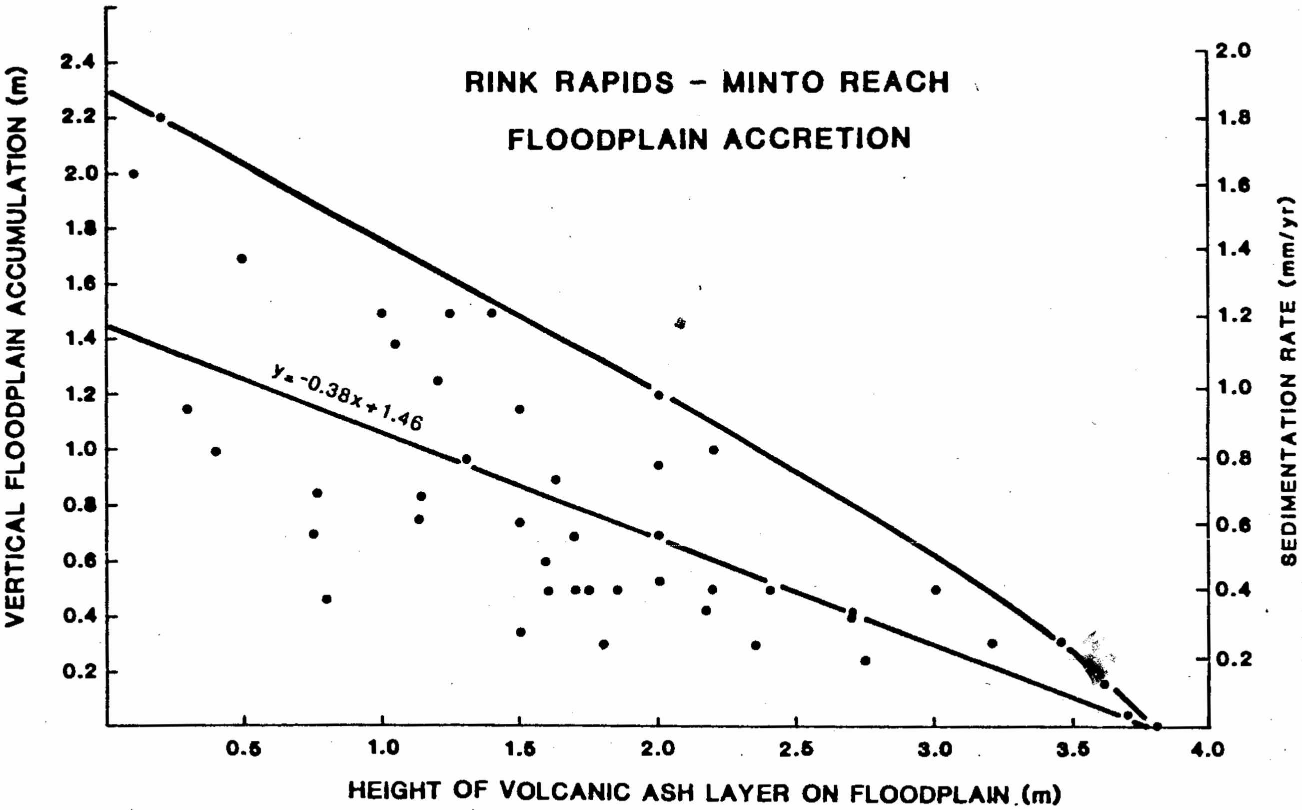


Figure 4.41 Rink Rapids - Minto reach floodplain accretion.

4.6.4 Long Profile of Rink Rapids Reach

The down river profile of Rink Rapids reach (Fig. 4.42 and 4.43 in pocket) summarizes downstream changes in terrace height, floodplain height, and ash height and permits correlation of terrace segments.

The long profile permits estimates of the generalized lowest level of the ash layer and implies the highest flood in 1000 years. The proximity of the ash to river datum, shown by the segmented line on profile, further implies that Yukon River has incised its bed by about 0.1 m during the last 1230 years. The highest flooded level is 4.0 m above river level and is parallel to the river surface slope. The highest alluvial terraces are about 3 m higher than the limit of post-ash aggradation. This suggests that in Rink Rapids reach the river is incising its bed at a much lower rate than Hootalinqua and Eagle's Nest Bluff reaches. The highest floodplain without ash is about 2.4 m above the river the same as the predicted maximum vertical accretion from the vertical accretion diagram (Fig. 4.41).

The "McConnell terrace" gradient is steeper than the present water surface. This may be because the "McConnell terrace" is an outwash terrace; such terraces are deposited on steeper slopes than anastomosed river deposits. Alternatively the "McConnell terrace" may have been tilted by isostatic recovery since deposition.

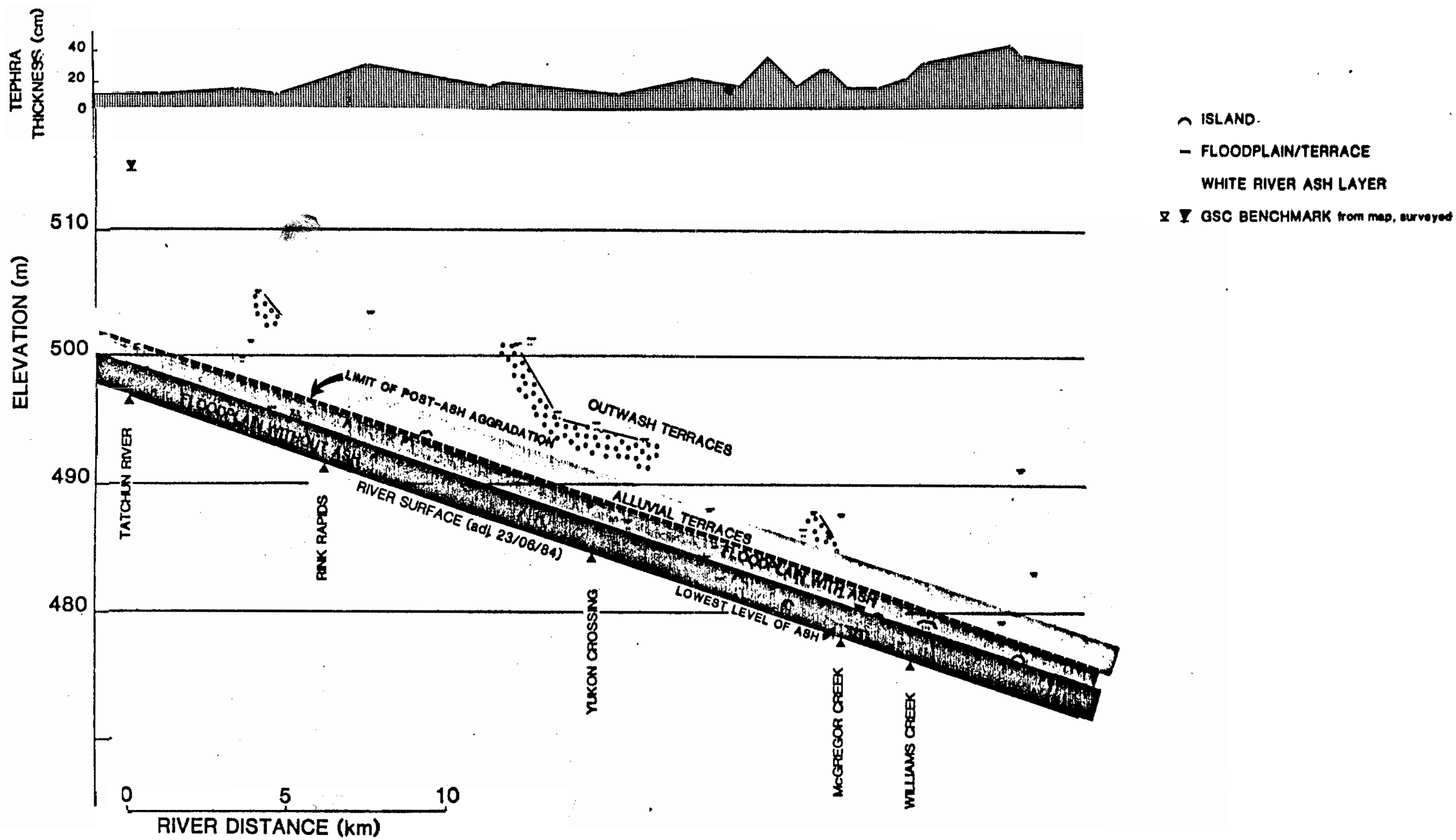


Figure 4.42. Long profile of Rink Rapids-Minto reach, south half showing White River Ash thickness, limit of post-ash aggradation, lowest level of ash, and levels of map units with position of ash layer. This is a reduced version of figure in pocket.

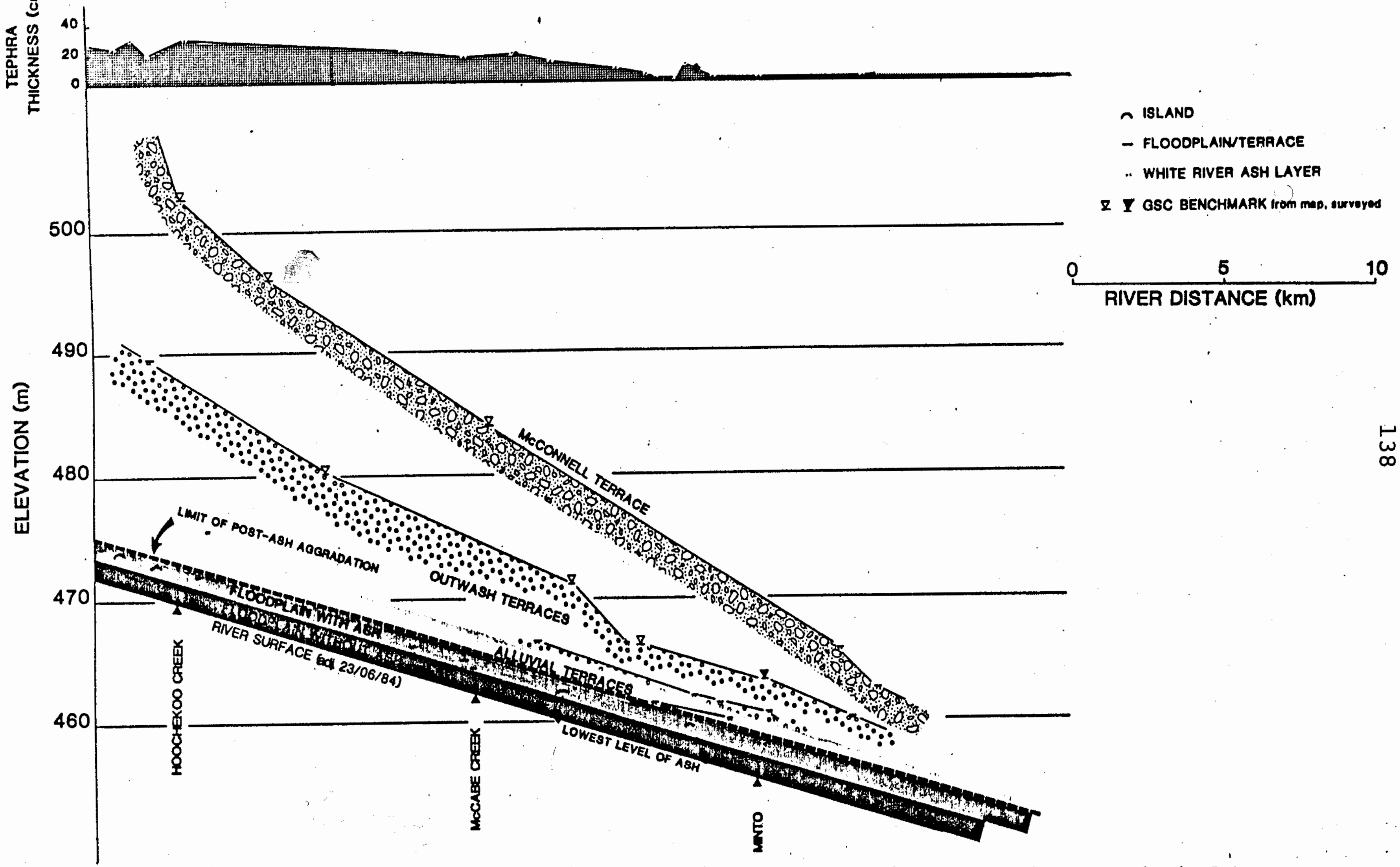
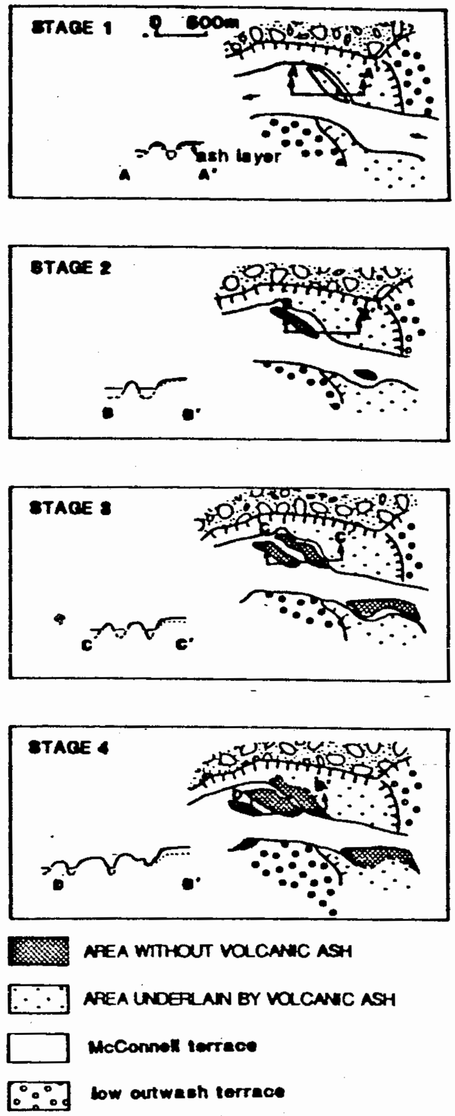


Figure 4.43. Long profile of Rink Rapids-Minto reach, north half showing White River Ash thickness, limit of post-ash aggradation, lowest level of ash, and levels of map units with position of ash layer. This is a reduced version of figure in pocket.

4.6.5 Lateral Bar Accretion to the Floodplain

Examples of post-ash lateral accretion are seen along Rink Rapid reach (river km 197, 201, 206, 212, 215, 220, and 222). They have similar landforms; lenticular floodplain abuts a terrace and projects downstream. A bar develops near the cutbank and as it expands more bars are deposited downstream. Each bar in succession is accreted to the floodplain as the channels between bars are filled in with sediment. For example, adjacent to the 75 m high "McConnell terrace" at river kilometer 197, lateral bar accretion is suggested (Fig. 4.44). Both the floodplain without ash and floodplain with ash drop in elevation in the downstream direction (Fig. 4.44). Two vegetated islands are located just downstream from the 150 m wide ash free accretion strip. The larger island is separated from the accreted floodplain by a narrow channel and wider channels are present between the islands. In addition the boundary between the ash floodplain and ash free floodplain is similar in shape to the narrow slough. It appears that 1230 years ago this boundary was a channel.

Four stages are postulated. The first stage inludes development of lenticular bars next to a gravel outwash terrace downstream from a constriction of the river. The head of the island nearest the constriction migrates toward the accreted floodplain narrowing the channel to a slough. During this stage gravel bars farther downstream grow and become vegetated. During the second stage deposition and erosion make the slough



DEVELOPMENT OF GRAVEL BAR NEXT TO ACTIVE FLOODPLAIN AT TIME OF ASH DEPOSITION

ATTACHMENT OF GRAVEL BAR TO FLOODPLAIN, GROWTH OF SECOND BAR
SMALL BAR GROWS ON LEFT BANK

INNER CHANNEL DIMINISHES AND FILLS WITH SEDIMENT AS A THIRD BAR GROWS DOWNSTREAM

LEFT BANK BAR EXPANDS AND ATTACHES TO BANK

CHANNELS BECOME ABANDONED AND ACCUMULATE SILT AND ORGANIC DEPOSITS, FOURTH BAR DEVELOPS

LEFT BANK BAR IS FULLY ACCRETED

Fig. 4.44. Example of evolution of floodplain in Rink Rapids reach (river km 197). Bars grow progressively downstream and minor channels become filled in accreting the bars to the floodplain.

sinuous. Accretion continues as the upstream islands begin to coalesce. In the third stage the slough is filled with sediment and blocked at its mouth; a shallow water filled slough is left between islands and accreted floodplain open at the downstream end. Finally the slough is filled with organic deposits and fine sediment and becomes an unbroken floodplain surface, wholly attached to the former cutbank.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

Of the three reaches examined, two have a meandering planform (Hootalinqua-Big Salmon reach and Eagle's Nest Bluff-Carmacks reach) while the other reach is anastomosed (Rink Rapids-Minto reach). The presence or absence of White River Ash on the floodplain provides a stratigraphic tool for estimating rates of channel migration, vertical accretion and incision as well as for mapping recent floodplain.

Hootalinqua-Big Salmon Reach

The Hootalinqua-Big Salmon reach has behaved as a meandering river for the last 4000 years to 6000 years. This time estimate is based on a radiocarbon date (GSC-3971 4770 ± 60 yrs BP) from a fining-upward alluvial plain 6.4 m above river level and extrapolated to the highest (oldest) scrolled alluvial plain which is 10 m above the river. This general sequence of events for the Yukon River is similar to that found for streams draining the east flank of the Rockies (Jackson et al., 1982).

During the last 1230 years, point bar deposits at or just downstream of bend apices have been the depositional norm. Direct lateral accretion as convex bends was the dominant process. Less common was midchannel accretion to floodplain involving island growth and bank erosion followed by channel abandonment by infilling. The river has deposited roughly 3.1

x 10^6 m^2 of floodplain area along a channel length of 44 km since ash eruption. The average rate of floodplain accretion is 56.4 m^2/km/yr. Based on an average depth of 1.5 m the volume of sand on this floodplain is 4.7 x 10^6 m^3. The increased area and volume represents lateral channel migration and vertical accretion to the floodplain after ash was laid down.

The floodplain deposits are a fining-upward succession with a lower gravel overlain by epsilon crossbedded sand. The stratigraphy and scrolled morphology reflect deposition from a meandering river.

Lateral migration rates vary within the reach, but generally increase downstream from a maximum rate of 0.8 m/yr at the bend at Walsh Creek to a low rate of 0.08 m/yr.

Accumulation of fluvial sediment above the ash is restricted to floodplains within 3.9 m (river datum). Above this the ash is overlain by organic litter, soil and eolian sediment. The 3.9 m level is thus interpreted to approximate the highest flood in 1000 years.

The maximum thickness of sediment above the ash on the floodplain is 1.0 m and the lowest ash is 0.4 m above river datum. This suggests a maximum accretion rate of 0.8 mm/yr on pre-ash floodplains and an incision rate of 0.33 mm/yr.

The height and stratigraphy of terraces confining the river appear to influence the river's planform. Where the river has cut moderate-level glaciolacustrine terraces, paraglacial fans and low-level outwash terraces meander lobes have developed.

These meander lobes are between 1 and 1.5 km wide. Where it cuts high-level outwash terraces the river is less sinuous and meander lobes smaller.

Eagle's Nest Bluff-Carmacks Reach

The Eagle's Nest Bluff-Carmacks Reach has a meandering pattern where it cuts low-level outwash and high-level ice-contact deposits.

Lateral migration in this reach over the last millenium has been accomplished by development of en echelon point bars downstream from bend apices along the convex side of the channel. Accretion around bends of high curvature (½600 m) is on the concave side with widening of the channel toward the convex bank. At bend radius of about 600 m there appears to be minimum migration.

Floodplain is accreted by successive infilling of sloughs outward from the floodplain margin as the main channel migrates downvalley cutting recessional outwash terraces. In this manner gravel channel lag is overlain by deposits of sand and silt with organic layers near the surface. Abandoned or rarely occupied sloughs occur as trough-shaped depressions.

Midchannel islands in straight parts of the reach have long axes underlain with buried ash. These islands are vegetated with spruce in both ash-free and ash-bearing surfaces. They appear to have almost doubled their size over the last millennium. Midchannel islands and bars located at or near bend apices are lenticular in shape and devoid of ash.

Deposition after White River Ash eruption occurred at, and downstream of, bend apices signifying downvalley meander lobe migration. The floodplain was constructed by deposition at point bars and growth of midchannel islands. For 68 km of channel length the floodplain area without ash is 3.8×10^6 m^2; on this basis the floodplain accretion rate was 45 m^2/km/yr. The estimated volume of sediment deposited above river datum is 5.7×10^6 m^3.

Two midchannel islands are partly underlain by buried ash indicating the relative permanence of these islands in particular and other islands in general.

Lateral channel shifts are greatest where the river is eroding low-level outwash terraces. The maximum inferred lateral migration rate is 0.4 m/yr. Lateral migration is the least, about 0.01 m/yr, where the river is confined by high-level ice-stagnation deposits.

Evidence of post-ash flooding of Eagle's Nest Bluff reach is seen to 3.1 m above river datum and lacking above 3.4 m; the highest flood in 1000 years is therefore about 3.4 m (river datum). The maximum thickness of sediment above ash is 0.9 m and the lowest ash is 0.8 m; incision may be about 0.8 m since ash eruption; an average rate of 0.65 mm/yr.

Rink Rapids-Minto Reach

The Rink Rapids-Minto Reach has an anastomosed channel pattern with many channels, islands and bars in a low sinuosity planform.

After White River Ash eruption the river has constructed islands and modified older ones. Former islands have been attached to the bank. Ash was seen on at least 13 of the 50 islands which indicates medium term island stability in this setting.

Lateral migration was by accreting lateral bars (islands) to low-level outwash terraces. Terrace erosion and midchannel island expansion also operated. The maximum lateral migration rate inferred from the width of ash free floodplain is 0.8 m/yr. For 50 km of river length the floodplain without ash occupies 8 x 10^6 m^2; a floodplain generation rate of 120 m^2/km/yr. The volume of sediment above river datum for this area is 12 x 10^6 m^3 assuming a depth of 1.5 m.

Evidence of post-ash flooding occurs up to 3.7 m, but above 4 m fluvial deposition above the ash is lacking. The highest flood in 1000 years presumably corresponds to 3.7 m.

The maximum thickness of sediment above ash is 2.2 m and the lowest level at which ash was observed is 0.1 m above river datum. This suggests accretion rates on pre-ash surfaces of 1.8 mm/yr and that little or no channel incision has occurred. Floodplain stratigraphy comprises a lower gravel overlain by sand with organic-rich silt.

Twelve hundred years ago the Yukon River in Rink Rapids reach probably had the same morphology as today, midchannel islands in a low sinuosity channel system. The change in morphology from a single channel meandering river to a multiple channel low-sinuosity planform farther downstream occurs near the ice margin on the McConnell advance at Yukon Crossing. Thick McConnell and Reid age outwash and rock benches controlled the planform and impeded lateral channel shifting. The floodplain width was therefore restricted promoting the preservation of an anastomosed river.

A summary of the reaches is tabulated (Table 5.1) for comparing rates determined in this study. In general, the area and volume of floodplain without White River Ash increases downstream. This corresponds to steeper gradient, higher discharge and number of islands per kilometer. Channel sinuosity decreases downstream. The height and clast size of confining terraces appears to control the floodplain width. Meandering river planforms with wide scrolled floodplains have developed in low-level outwash; in reaches with high-level outwash terraces the scrolled alluvium is narrower. Rock benches anchored the channel during the last millennium or more.

This research documents medium term changes in river planform and vertical accretion by using a recent tephra marker. There are no data of this timespan for other rivers. Short term rates for Yukon River and other northern rivers (Table 5.2) can be compared to the study results. Migration rates for a 250 year record of Beatton River, northern British Columbia in terms of channel widths per year are 0.024 channel/yr while Yukon River migrates 0.000041 to 0.0023 channel/yr. Opportunities for studying other Yukon Territory streams within the east lobe of White River Ash and the older north lobe are available. In British Columbia, Bridge River Ash, Edziza Ash and Mount Saint Helens Ash may prove useful in

Table 5.1

Reach	HOOTALINQUA	EAGLE'S NEST BLUFF	RINK RAPIDS
Position	upstream	middle	downstream
Morphology	meandering	meandering	anastomosed
Deposition	point bars and few midchannel islands	point bars and midchannel islands	midchannel islands and lateral bars
Length (km)	44	68	50
Slope	0.00047	0.00041	0.00087
Islands/km	0.23	0.54	1.00
Process	lateral migration and point bar accretion	lateral migration and point bar accretion	island and lateral bar accretion
Maximum lateral migration rate (m/yr)	0.8	0.4	0.8
Vertical accretion rate (mm/yr)	0.81	0.73	1.8
Highest flood (m)	3.9	3.4	4.0
Incision rate (mm/yr)	0.33	0.65	0.08

comparable unravelling of stream development.

The tephra markers may also be useful in studies of slope stability, gullying, eolian deposition rates and permafrost invasion rates.

This research helps fill a gap between the long and short term in the study of river evolution. It helps document the Quaternary sequence of events in the Yukon River valley where regional ice flow patterns and glacial margins are known.

Table 5.2

SHORT TERM CHANNEL CHANGES IN YUKON TERRITORY

River	Distance (m)	Timespan (years)	Migr. Rate (m/yr)	Reference
Yukon R.	0	20	0	N. Hydr. '75
Pelly River	0	20	0	N. Hydr. '75
Stewart R.	122	17	7.2	N. Hydr. '75
Stewart R.	183	23	8	N. Hydr. '75
Eagle R.	60	28	2.2	Crampton '79
Indian R.	64	61	1	Crampton '87
Fort Nelson R.			6.68	Hickin and Nanson '84

N. Hydr. = Northwest Hydraulic

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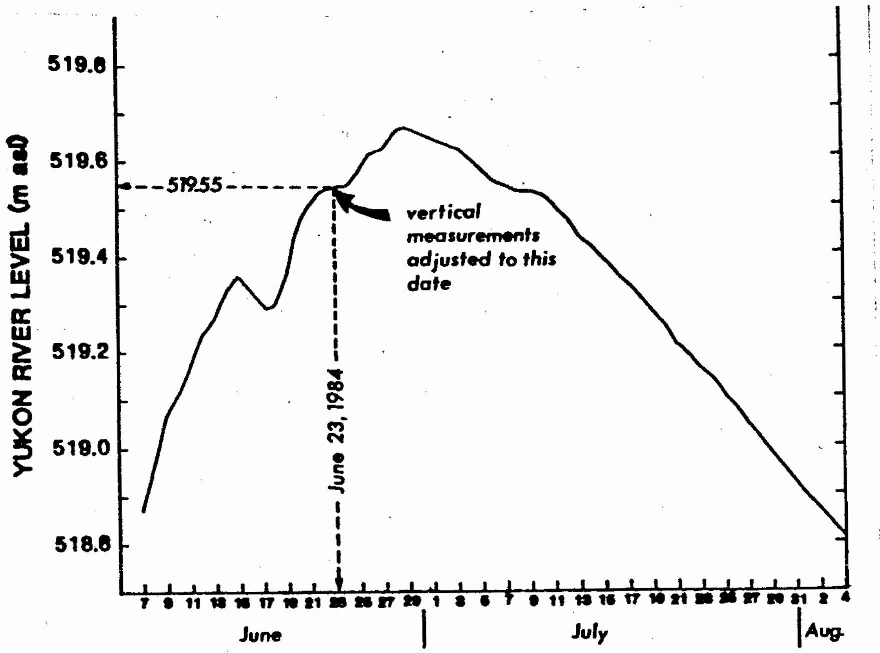
APPENDICES

APPENDIX I: HYDROGRAPH OF YUKON RIVER AT CARMACKS



Appendix II

DAILY MEAN RIVER ELEVATION AT CARMACKS STATION

DATE mo/day	GAUGE HT (m)	RIVER ELEV. (m)	ADJUSTMENT TO June 23, 1984 (m)
June 07	3.18	518.87	-0.60
08	3.28	518.97	-0.58
09	3.38	519.07	-0.48
10	3.43	519.12	-0.43
11	3.49	519.18	-0.37
12	3.55	519.24	-0.31
13	3.58	519.27	-0.28
14	3.64	519.33	-0.22
15	3.67	519.36	-0.19
16	3.64	519.33	-0.22
17	3.61	519.30	-0.25
18	3.61	519.30	-0.25
19	3.67	519.36	-0.19
20	3.77	519.46	-0.09
21	3.82	519.51	-0.04
22	3.85	519.54	-0.01
23	3.86	519.55	0.00
24	3.86	519.55	0.00
25	3.89	519.58	0.03
26	3.93	519.62	0.07
27	3.94	519.63	0.08
28	3.97	519.66	0.11
29	3.98	519.67	0.12
30	3.97	519.66	0.11

DAILY MEAN RIVER ELEVATION AT CARMACKS STATION

DATE mo/day	GAUGE HT (m)	RIVER ELEV. (m)	ADJUSTMENT TO June 23, 1984 (m)
July 01	3.96	519.65	0.10
02	3.95	519.64	0.09
03	3.94	519.63	0.08
04	3.92	519.61	0.06
05	3.89	519.58	0.03
06	3.87	519.56	0.01
07	3.86	519.55	0.00
08	3.85	519.54	-0.01
09	3.85	519.54	-0.01
10	3.84	519.53	-0.02
11	3.82	519.51	-0.04
12	3.79	519.48	-0.07
13	3.75	519.44	-0.11
14	3.73	519.42	-0.13
15	3.70	519.39	-0.16
16	3.67	519.36	-0.19
17	3.65	519.34	-0.21
18	3.62	519.31	-0.24
19	3.59	519.28	-0.27
20	3.56	519.25	-0.30
21	3.52	519.21	-0.34
22	3.50	519.19	-0.36
23	3.47	519.16	-0.39
24	3.45	519.14	-0.41
25	3.41	519.10	-0.45
26	3.39	519.08	-0.47
27	3.35	519.04	-0.51
28	3.32	519.01	-0.54
29	3.29	518.98	-0.57
30	3.26	518.95	-0.60
31	3.23	518.92	-0.63

DAILY MEAN RIVER ELEVATION AT CARMACKS STATION

DATE mo/day	GAUGE HT (m)	RIVER ELEV. (m)	ADJUSTMENT TO June 23, 1984 (m)
Aug 01	3.21	518.90	-0.65
02	3.18	518.87	-0.68
03	3.15	518.84	-0.71
04	3.12	518.81	-0.74
05	3.09	518.78	-0.77
06	3.07	518.76	-0.79
07	3.05	518.74	-0.81
08	3.05	518.74	-0.81
09	3.09	518.78	-0.77
10	3.12	518.81	-0.74

Source: Water Survey of Canada River Gauge Records for Yukon River at Carmacks, 1984.

APPENDIX III BENCH MARKS USED IN MAPPING

BM	km	Elev. (m)	River El. (m)	Date 1984	Adjustment 23.06.84
M14	3.2	588.151	583.95	24.07	584.36
M15	18.2	581.501	576.85	27.07	577.36
M16	28.0	573.622	571.28	30.07	571.88
M17	31.8	572.959	570.41	30.07	571.01
M18	41.5	573.525	568.28	01.08	568.93
M20	55.3	562.112	556.86	03.08	557.56
M21	63.0	559.957	553.96	03.08	554.66
M23	88.8	547.552	541.88	03.08	542.58
M25	107.4	535.538	532.71	03.08	533.41
M27	130.0	526.475	523.7	not loc.	523.7
74Y108	140.9	530.555	518.06	03.08	518.76
580E	179.0	514.709	496.71	03.07	496.63
M2	190.0	493.719	487.62	not loc.	487.62
594E	231.0	462.784	450.6	12.07	450.5
M28	243.0	450.285	449.0	not loc.	449.0

Source: Vertical Control Data, Geodetic Survey of Canada, Surveys and Mapping Branch, Energy, Mines and Resources, Ottawa, Canada, Quad. No. 61135, 62135, and 62136.

APPENDIX IV

AIRPHOTO LIST

105E Laberge

High Level Airphotos:
August 1980
A25577-79, 80, 106, 107, 108, 155, 156, 157
A25578-20, 21,22, 33, 34

Low Level Airphotos:
A11447-30, 31, 36, 37, 38, 39, 40, 41, 42, 43
A12178-69, 70, 71, 72, 73, 74
A12853-359, 360, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371

115I Carmacks

August 1980
A25578-57, 58, 59, 133, 134, 135, 146, 147, 148
A20059-138, 139, 140, 85, 86, 87
A20060-57, 58, 59
A20061-82, 83, 84, 85, 86
A20112-1, 2, 3, 4, 5, 6
1949
A11069-76, 77, 78, 79, 80
A11541-4, 5, 6, 7, 8, 9, 10