OVERBANK SEDIMENTATION PATTERNS ON THE MACKENZIE DELTA, N.W.T.

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by

CHERYL MARIE PEARCE, PH.D
London, Ontario, Canada

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LE PLAN VERT DU CANADA

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1.0 INTRODUCTION

Hydrocarbon development, upstream impoundment, and climate change could have major effects on the hydrology and overbank sedimentation patterns within the Mackenzie Delta, and ultimately on delta ecosystems. The NWT Programs Branch of Environment Canada has contracted research, through NOGAP Project C11.4 (Mackenzie Delta Sedimentation), Sub-project 11.4b (Overbank Sedimentation) to analyze sedimentation patterns and rates on the Mackenzie Delta.

Hydrocarbon development is anticipated in the Mackenzie Delta in an environment sensitive to changes in periodic flooding and disturbance of permafrost soils. Knowledge on sediment inputs to the delta, internal erosion/deposition balances, and discharge to the nearshore zone of the Beaufort Sea is still quite limited. The NWT Programs Branch is measuring sediment transport rates and loads, channel water levels, and flows within the Mackenzie Delta to quantify total delta sediment flux. The objective of this study was to produce estimates of mean areal overbank sedimentation rates for the Mackenzie Delta.

This report will:

1 summarize the results of previous sedimentation studies on the delta and new measurements collected in 1992 in the middle and outer delta;

2 explain the relationships between overbank deposition, delta landform, and vegetation;

3 evaluate methodologies for collecting data on overbank deposition;

4 estimate mean areal sedimentation rates for a middle delta study area;

5 present "overbank sedimentation maps" for all of the areas used in previous sedimentation studies;

6 recommend methods and new sampling sites on the delta to measure historical sedimentation rates and future overbank sedimentation patterns; and

7 propose a budget for additional sedimentation sampling in the middle and outer delta and analysis of the data.

2.0 BACKGROUND

Flooding, overbank sedimentation, and erosion exert a powerful control on Mackenzie Delta ecosystems. Whether or not a particular surface on the delta is flooded and receives new sediment is related to stage from ice breakup to freeze-up, the distance of the surface from Point Separation and major delta distributaries, and the elevation of the surface above a channel or lake. Sediment is delivered to and distributed through the delta in a very heterogeneous way, and sedimentation rates onto specific surfaces cannot be predicted solely from measurements of discharge and topography.

Past research on the Mackenzie Delta has provided information on the general patterns of flooding and overbank deposition in some areas of the Mackenzie Delta (see Cordes et al. 1984, Gill 1971, Hardy Associates 1982, Lewis 1988, Mackay 1963, Pearce 1986). Much of this data base was collected during BC Hydro-funded studies between 1980 and 1983 (summarized in Hirst et al. 1987 and reviewed by Carson & Associates 1991 and 1993).

Seven (7) study areas were used in the BC Hydro studies (Figure 1 in Appendix A) to represent geofluvial processes and plant communities in the High Subarctic (upper and middle delta) and Low Arctic (outer delta) climatic regions and flows from the Mackenzie or Peel/Rat River systems. Within each study area, baseline data were collected on flooding and sedimentation patterns, the plant and animal communities associated with different delta landform, and various physical and chemical phenomena. The data collected on the distribution and quantity of overbank sedimentation, flooding, and the interactions between flood-related phenomena and vegetation are of most interest to the NOGAP program.

2.1 Methods Used During the B C Hydro Studies

A stratified random sampling design was used to collect the baseline data on vegetation, flooding, and sedimentation. Each study area was examined using a combination of aerial and ground reconnaissance. In July 1980, transect lines (n = 123) 5-10 m in width (depending on the site) were cut across representative point bars, channel levees, lakeshores, and the delta plain from the water's edge to the highest point of land (see study area maps in Appendix B for transect locations).

Transect lines varied in length from about 10 m to more than 300 m. Elevation changes (to the nearest cm) along the transects were surveyed to permanent bench marks on the highest elevation on each line. Permanent vegetation sampling plots were established mid-way between the lower and upper boundaries of each plant community on the transect line. The size of the plots varied from 5 m^2 to 10 m^2 depending on the structure of the vegetation.

In extensive plant communities (e.g. white spruce stands on the delta plain and mature willow stands on point bars and channel levees), two and sometimes three sample plots were established. Sample plots were also established on mudflats to monitor plant colonization. The lower and upper boundaries of each plant community and the centre of each sample plot were surveyed to the bench mark (see, for example, Figure 7 in Appendix A).

Vegetation measurements included species composition, canopy cover, plant height, stem density, presence and survival of seedlings, and cover of litter. The plant communities were sampled at the height of the growing season in 1980 by Cordes et al. (1984). Forty-two (42) additional transect lines and plots were established in 1981 by Pearce between 1981 and 1983. Another 145 transects were surveyed across all landform types from water's edge to the highest point of land to quantify the relationships between vegetation and elevation. Some sedimentation measures were collected, as well (n = 45). The plant communities are described in detail in Cordes et al. 1984, Cordes and McLennan 1984a, Pearce 1986, and Pearce et al. 1988.

Depth and temperature of the active layer were measured every 1 or 2 m along the transect lines between 1980 and 1983. Soil samples were collected in 1980 and 1982 for physical and chemical analyses (texture using hydrometers, pH, major nutrients, cation exchange, etc.). The soil samples were collected randomly and at different depths from each plant community along selected transect lines. These analyses are presented in Cordes et al. 1984 and Pearce 1986.

Changes in water levels during the open water season were monitored and documented with stage recording cameras located on one channel and one lake within each study area (see *'s on figures in Appendix B). Breakup flooding patterns were analyzed and mapped by examination of photographs flown during or close to spring breakup and by aerial reconnaissance during breakup (Blachut et al. 1985).

Historical overbank deposition patterns were estimated in two ways:

1. by field examination of stratigraphic layers in trenches excavated within each plant community on different delta landform, and

2. by comparing the depth of sediment from plant initiation noda to the present surface with plant age. Annual sediment deposition in 1981, 1982, and 1983 was estimated in the following ways: i) direct measurement of new alluvium 2-3 weeks after breakup, ii) direct measurement of sediment depths over leaf litter deposited the previous autumn; iii) direct measurement of sediment around buried reference stakes (see Figure 2), and; iv)

direct measurement of erosional scarps on point bars and channel levees (see Figure 8b).

All sedimentation measurements were collected from sites adjacent to but off the transect lines and as close as possible to the sampling plots and lower and upper ecophase boundaries. Measurement sites were randomly-located except for the stakes. Stakes (n = 182) were put in at the lower boundaries of the mudflat, pioneer willow, mature willow, and alder-willow ecophases on selected transects (n = 48). New sediment deposited during summer storms or other phenomena that increased water levels was also measured. Sediment measures collected just after breakup were converted to "compacted" using a conversion factor of 0.63 given by Gill (1971) for silty soils. Six hundred and eighty-five (685) sediment samples were collected in 1982 and 1983 (364 from stakes, 321 from other methods). Of these, 448 were on channels, 182 were on lake sites, and 55 were on the delta plain.

An ecophysical classification system was developed for the delta based on the relationships among climate (the ***ecoregions***), landforms (the ***ecosections*** and ***ecosites***), vegetation (the ***ecophases***), and flood-related phenomena (Cordes et al. 1984) (Figure 3). The ecosites and ecophases in each of the study areas were mapped from aerial photographs using this classification system (e.g. Figures 4a and 4b). The area covered by each ecosite within each study area was measured with a planimeter (Table 1).

Because the classification units are biogeomorphic units that describe possibly unique sedimentation patterns and rates associated with each ecosite and ecophase (Table 2), this classification system could be used to analyze and map overbank sedimentation patterns over the entire delta surface, and future changes to these patterns, for input to a sediment flux model.

2.2 Flooding Patterns 1980-83

Flood peaks on East Channel at Inuvik have varied from 15.0 to almost 16.7 m (above an assumed datum) between 1981 and 1992 (Table 3). Breakup flooding occurs during the last week in May or first two weeks in June. Between 1980 and 1983, flood stage determined sedimentation to the middle and upper elevations of delta sites in the B C Hydro study areas (see stage hydrograph on Table 3). Both the spring flood and water levels at any time during the open water season determined sediment deposition onto lower elevations. Ice jams (particularly in the inner delta near East Channel in 1983) raised water levels during breakup above that predictable from discharge. Precipitation events, strong winds, and tides raised water levels during the open water season (see stage hydrograph on Table 3). In 1980 and 1981, only the lower to mid-elevations of channel levees and lakeshores were flooded. Approximately 95% of the delta surface was flooded during the 1982 breakup (Blachut et al. 1985); only elevated delta plain sites in the inner delta and parts of the west middle delta were not flooded (Pearce et al. 1988). (Presumably, similar patterns occurred during the 1961, 1972, and 1992 breakup floods, as well).

Thus, 1980 and 1981 can be considered "low" flood years, 1983 a "moderate" flood year, and 1982 a "high" flood year. However, the historical record is too short to determine the accuracy of these labels. What is not known is if 1982 represents a record high flood (i.e. the 1-in-100 event), or if it represents a flood that occurs more frequently (i.e. a 1-in-10 event).

2.3 Sedimentation Patterns 1980-83

The B C Hydro studies provided baseline data that were used to determine overbank deposition patterns and rates within the seven study areas. Annual <u>sedimentation rates</u> onto the different delta ecosites varied not only between flood years, but also within and between the study areas. However, general <u>sediment patterns</u> were evident.

Overbank sedimentation patterns were related to elevation above water bodies and to flood height in a particular year. For example, sites on the lower shorelines of lakes close to and connected directly to Middle Channel were flooded every year and received more sediment than shorelines on unconnected lakes 1 km from and 5 m above Middle Channel. The delta plain, elevated 4 to 10 m above low water, received very little sediment and then only during the higher breakup floods.

Overbank sedimentation patterns were also related to the distance of an ecosite from Point Separation and from major distributaries such as Middle, East, and Peel Channels. For example, a point bar on Middle Channel 10 km downstream from Point Separation received more sediment, on average, than a point bar on Taylor Channel 100 km from Point Separation.

Overbank sedimentation patterns were also related to landform. Channel landform (point bars 1a, channel levees 1b, 2b, and sandbars 1d) had the highest mean aggradation rates (3.5 to 6.06 cm/yr) and the delta plain (4) the lowest rates (<1 mm/yr). These aggradation patterns were similar among the study areas although actual rates differed, especially on channel sites (Figure 5). For example, average rates for point bars for all of the study areas was about 6 cm/yr (n=36,SD=1.47), but this varied from 2 cm/yr in the outer delta (Area 5) to 10 cm/yr in the inner delta (Area 2). Average aggradation for lakeshores was 1.6 cm/yr (n=40,SD=1.52), but this varied from <1 cm to 3 cm/yr on lakes close to main delta channels and 0 to 0.8 cm/yr on lakeshores far from these channels (Pearce 1986).

Overbank sedimentation rates were also determined by the landform and specific sites on the landform relative to elevation above and distance from delta channels and lakes. (Rates may also be determined by the stage of the spring breakup flood. Between 1981 and 1983, the actual amounts of sediment deposited into delta ecophases that were flooded every year were generally higher in 1982 than in either 1981 or 1983. However, high flood stage does not necessarily mean higher discharge and higher sediment loads. Overbank sedimentation has not been sampled for a long enough period to test this relationship.)

Sedimentation patterns and rates associated with particular ecosites and ecophases in the inner, middle, and outer delta are described in detail in Section 3.

2.4 Sedimentation and Vegetation

Hydrological processes and vegetation have reached a delicate balance on the Mackenzie Delta, a balance that represents both long-term and short-term flooding patterns. Most plants can survive inundation for days, weeks, and even months as long as the water is clear and contains dissolved oxygen. However, sediment deposition, which is directly related to flood height and flood duration, is a "physical" problem and, as such, exerts a great control on vegetation on most sites on the delta. Erosion and ice also control plant distribution on some sites. In turn, the dense root matrix of delta plants promotes landform stability by cohesion and the weight of the vegetation increases frictional resistance to shear (but these effects vary with successional stage). Some ecophases, most notably the horsetail and mature willow ecophases, form "sediment traps" that accumulate alluvium around plant stems.

Cordes et al. (1984), Gill (1971), Pearce (1986), Pearce and Cordes (1988), and Pearce et al. (1988) have documented the distribution of vegetation on the delta along ***topographic gradients*** related primarily to sedimentation. River horsetail (Equisetum fluviatile), common horsetail (Equisetum arvense), aquatic sedge (Carex aquatilis), felt-leaf willow (Salix alaxensis), arctic willow (Salix pulchra), Richardson's willow (Salix richardsonii), speckled alder (Alnus crispa), balsam poplar (Populus balsamifera), and white spruce (Picea glauca) are dominant species on the delta.

River horsetail has adapted to sites, such as lower mudflats on point bars and lakeshores, that are flooded for long periods every year and receive large amounts (5-10 cm/yr) of silty alluvium during flooding (Table 2). Horsetail grows in very dense emergent stands on many delta sites and forms a "sediment trap" during the growing season. The extensive rooting systems stabilize substrate that could be susceptible to erosion. Aquatic sedge, on the other hand, may be flooded for the entire growing season on some sites, but does not appear to be able to withstand as much sediment deposition (1-5 cm/yr). New sediment is deposited within tussocks of dead leaves that accumulate around the living sedge plants.

Felt-leaf willow (on channels) and arctic willow and Richardson's willow (on lakeshores) occupy the middle elevations of shorelines that are flooded at least every other year. The mature willow ecophases appear to mark the upper limits of low floods on the Mackenzie Delta (see, for example, Figure 6). Felt-leaf willow can withstand very large deposits of coarse-textured alluvium on point bars and channel levees throughout the delta (5-20+ cm/yr). These large deposits result, in part, from the sediment-trapping efficiency of dense stands of this willow. Gill (1971) also attributes the large amounts of sediment in this zone to snowdrifts that sometimes accumulate in front of mature willow communities providing a barrier to sediment transport beyond the point bar crest. The felt-leaf willow ecophases are susceptible to damage from ice on some channel sites, particularly in the inner delta near Middle Channel (Pearce 1986). However, the stems of this willow are quite pliable and appear to recover quickly from ice damage even if the stems are broken off. Arctic willow and Richardson's willow ecophases on lakeshores receive much less sediment than the felt-leaf ecophases (1-3 cm/yr and 0-0.5 cm/yr respectively), even though they can be flooded for long periods.

Balsam poplar occupies the leading edges of elevated point bar levees in the inner and middle delta and may receive up to 1-2 cm of sandy alluvium during moderate and high floods. Speckled alder characterizes elevated levees and lakeshores throughout the delta and parts of the delta plain in the inner and middle delta. The lower boundaries of the alder ecophases appear to mark the upper limit of average breakup flooding (see Figure 6). When the alder communities are flooded, they receive from 0.5 to 1 cm of new alluvium, but only every 2 to 6 years. White spruce forests and woodlands in the inner and middle delta occupy the most elevated sites on the delta plain. Spruce forests may be flooded every 10 years or so during the highest floods but receive only a few millimetres of fine-textured sediments. Spruce woodlands, most common in the west inner and middle delta in areas dominated by flows from Peel Channel and its distributaries, do not appear to be flooded at all under the present fluvial regime (and may not have been flooded for several hundred years). A ground cover of lichens and heaths, similar to tundra on upland sites adjacent to the Mackenzie Delta, characterizes the spruce woodlands.

Although both alder and spruce can survive some sediment deposition on an irregular basis (the author measured 5-10 cm in one spruce community after the 1982 breakup flood) and appear to require it for regeneration and maintenance on a site, they cannot survive repeated deposition (see Pearce et al. 1988).

Sediment deposition exerts a powerful control on plant succession, as well as distribution, on the Mackenzie Delta. As explained above, plant communities dominated by the horsetails, sedges and other emergent, willows, alder, poplar, and spruce are arranged in distinctive zones parallel to channels and lakes and at successively higher elevations. These zones are arranged along ***disturbance gradients*** as well as topographic gradients as the plant communities are in a state of constant "reorganization" or succession as sites are created or destroyed with sedimentation and erosion. As a site is elevated by aggradation, the dominant species are replaced by species that are less tolerant of sediment deposition. The plants respond to these processes according to individual species' tolerances to flood-related phenomena. The most common successions in the inner and middle delta are as follows (in order of elevation above water):

1 on channels - mudflats, horsetail, pioneer felt-leaf willow, mature felt-leaf willow, poplar (only on the leading edge of point bars), alder, and white spruce

2 on lakeshores - mudflats, horsetail, sedge, pioneer arctic willow, mature arctic willow, alder, and white spruce

3 on the delta plain - alder, white spruce forest (with herbs and shrubs), white spruce forest (with feathermoss), and white spruce woodland (with lichens and heaths).

Successional sequences on channels and lakes in the outer delta are similar, but poplar and white spruce are not found. There is no delta plain in the outer delta.

It is these successional patterns on different landform that are the basis for the ecophysical land classification system developed by Cordes et al. (1984) and described in a previous section.

3.0 OVERBANK SEDIMENTATION PATTERNS ON DELTA ECOSITES

Average aggradation rates for particular delta ecosites do not express the range of depositional environments on each ecosite that are related to elevation and to the vegetation. It is this detail that will be necessary for input into a sedimentation flux model for the Mackenzie Delta.

The following sections summarize information collected on overbank deposition for the different channel, lake, and delta plain ecosites and their associated ecophases in the inner, middle, and outer delta, using data collected in the B C Hydro study areas between 1981 and 1983. Details for specific transects can be found in Appendix C. Table 4 summarizes the sedimentation measurements from stakes on the transects sampled between 1981 and 1983 in ecophases on point bars, channel levees, lakeshores, lake deltas, lake shoals, and the delta plain. Table 4 also shows sedimentation patterns within the Alluvial Islands of Middle Channel (in the inner delta) estimated from willow ages and stem burial depths. Table 5 documents sedimentation measurements carried out in 1992 on selected transects in Areas 3 and 5 in August 1992. A study area just south of Inuvik, used by NHRI for lake sedimentation measurements, was sampled by the author in 1992 (Table 6), and will be used to test the sedimentation-vegetation relationships that resulted from the B C Hydro-funded studies.

3.1 Channel Ecosection

Point Bars (1a)

Point bars in the study areas cover, on average, only 6% (range 3 to 10%, see Table 1) of the delta surface, but they are the most active depositional and erosional sites studied in any detail on the delta. Point bars vary in size and shape depending on the width and configuration of the channel. Vegetation on the point bars is distributed along topographic and sedimentation gradients with scattered common horsetail and felt-leaf willow seedlings on the low-elevation mudflats, pioneer felt-leaf willow and common horsetail grading to mature felt-leaf willow on the middle elevations, and in the inner and middle delta, alder-willow, poplar (not everywhere), decadent willow, and white spruce on the bar crest (Figure 6).

The lower boundaries of the mature willow-horsetail, alder-willow, and spruce ecophases appear to mark the limits of "low", "moderate", and "high" floods respectively (e.g. Figure 6 for the inner delta), although high floods (e.g. 1982) have inundated some (but not all) spruce stands. In the outer delta, trees are absent; Richardson's willow ecophases with either horsetail or sedge in the understorey occupy point bar crests and are flooded at spring breakup except during the lowest flood peaks.

The willow ecophases comprise a "sediment trap" on many point bars. The willow just below and on bar crests can be very dense (see

Figure 8[b], for example). Much of the sediment carried by floodwater can be deposited in this zone rather than transported over the bar crest to other ecophases. As explained previously, Gill (1971) attributes this not only to the stem density of the willows, but also to snowbanks that accumulate just in front of and within the willow forming a temporary barrier to water flow during breakup.

Point bars in the inner delta (Figures 6 and 7) had the highest levees in the Mackenzie Delta, ranging from 8 to 10 m above fall low water, and steepness gradients of 1:3. Progradation rates of 0.6 to 0.75 m/yr were estimated by Cordes et al. (1984) based on the distances between the lower boundary of aged willow in the mature willow-horsetail ecophase and the lower boundary of aged willow in the pioneer willow-horsetail ecophase. Aggradation rates on inner delta point bars averaged **11.9 cm** (n=19,SD=14.2,SEM=202.3) in 1982 (a "high" flood year) but only **1.8 cm** (n=14,SD=2.7,SEM=7.4) in 1983 (a "moderate" flood year) (Table 4). However, most of the sediment received during breakup flooding was in the mudflat and pioneer willow ecophases (Table 4). Sediments deposited onto point bars in the inner delta were dominated by sands or silts at the lower elevations and silts at the upper elevations (see texture "boxes" on Figures 6 and 7).

Point bar crests in the middle delta ranged from 3 m to 6 m (above fall low water) and had steepness gradients of 1:6. Mean progradation rates of 0.5 to 0.8 m/yr have been estimated (Cordes et al. 1984). Mean aggradation rates for the entire point bar averaged **8.5 cm** (n=76,SD=7.1,SEM=50.4) in 1982 and **4.4 cm** (n=40,SD=4.6,SEM=21.1) in 1983 (Table 4). As in the inner delta, much of the overbank sedimentation was received at the mudflat and willow ecophases (Table 4). A horsetail ecophase was present on the slip-off slopes of many point bars in the middle delta, and this ecophase also received substantial amounts of new sediment during flooding. Sediment textures were dominated by silts (see Figures 8[a] and 9).

Point bars in the outer delta study area were much lower in elevation than point bars sampled in the middle and inner delta-only 1 to 1.75 m above fall low water (Figures 10[a] and [b]). Progradation rates have been estimated at 2.5 m/yr (Cordes et al. 1984), but this high rate was based on one point bar (Transect V-D). Pearce (1986) provides a rate of 0.4 m/yr for other point bars in the area. Aggradation rates of **5.3 cm** (n=11,SD=4.9,SEM=24.3) in 1982 and **2.4 cm** (n=10,SD=2.6,SEM=6.5) in 1983 for the entire point bar were estimated (Table 4). Again, mudflat and felt-leaf willow ecophases received most of the sediments (Table 4). Sediments were dominated by silts (Figure 10[a]). Most (but not all) surfaces of outer delta point bars appear to be flooded every year during spring breakup. Lower elevations may be reflooded many times over the open water season during high tides and the frequent storms (Pearce 1986). The lower elevations of point bars in the outer delta were subject to erosion, particularly between 1982 and 1983 when 44 cm were removed from the mudflats and 18 cm from the pioneer willow ecophase on one transect (T.V-F, Figure 10).

Channel Levees (1b,2b)

Channel levees on the Mackenzie Delta describe active depositional sites on low-elevation levees building across cut-off meanders, on cutbanks, and on distributary channels that connect channels to lakes, and levees on stable channels that aggrade at lower rates. Sedimentation and erosion rates on cutbanks were not measured during the B C Hydro studies. Levees on connecting channels and low-closure levees adjacent to lakes "captured" by channel shifts will be described within the Basin Ecosection.

Main Channel Levees (1b):

Main channel levees in the study areas occupy only 1-3% (but 9% in the Alluvial Islands). Aggradation rates on main channel levees averaged **7.4 cm** (n=16,SD=7.7,SEM=59.1) in 1982 and **2.5 cm** (n=19,SD=1.9,SEM=3.5) in 1983 in the middle delta (Table 4). Most main channel levees in the inner delta were very difficult to access because of saturated mudflats so that only a few measurements were collected (Table 4). In the inner and middle delta, sedimentation was highest within the mudflat and willow ecophases (Table 4). This ecosite was not present in the outer delta study area.

Low elevation levees adjacent to main delta channels can be high deposition environments. Levees adjacent to channel meanders can be cut through during high floods when the neck of land between the bases of a channel loop becomes very narrow. With continued erosion during subsequent floods, a new channel forms which bypasses the original meander loop. Most of the flow and transported alluvium goes through the new stretch of channel. Levees form on bedload plugs across the junctions of the cut-off meander loop and the new section of channel. As a levee builds across the inlet to a cut-off meander (Figure 11[a]), large amounts of alluvium are deposited onto the foreslope and crest of the aggrading levee. Thus, until the levee aggrades to a high elevation, it is also prograding into the channel and so is asymmetrical in cross-section with a long, gradual slope to the crest and a short steep slope down to the cut-off meander. In time, the long foreslope may be eroded to a short steep cutbank (Figure 11[b]).

Cut-off meander (or "oxbow") levees were not sampled in the middle or outer delta study areas. The distribution of vegetation on these levees in the inner delta (Figure 11[a] and [b]) was similar to that on the lower slopes of point bars, with mudflats grading into pioneer and mature willow-horsetail ecophases at successively higher elevations. It was difficult to collect sedimentation measures on some of these sites because the lower mudflats were very saturated and impossible to traverse. However, rates of **2.5 to 6 cm/yr** were estimated by excavating and aging willows within the pioneer willow ecophases. Aggradation rates of **11-15 cm/yr** were estimated by Cordes et al. (1984) for the mudflat ecophases.
Erosion during a series of summer storms in 1981 removed approximately $45m^3$-$135m^3$ of sediment from the lower elevations of a transect (T.II-G) on an oxbow levee on Peel Channel (see Figure 11[b]). However, sedimentation in 1982 and 1983 was infilling the site once again.

Some channels on the Mackenzie Delta occupy relatively constant positions (perhaps because of permafrost), and do not meander across the delta plain. Gill (1971) describes both "stable" channels (channels with no evidence of past or present lateral movement across the delta plain) and "static" channels (channels active in the past but now stable). Stable channels may have reverse flow if they are oriented perpendicular to the breakup flood (Gill 1971) and generally act as troughs through which alluvium is transported but not deposited in great amounts (Cordes et al. 1984). Stable channel ecosites in the middle delta study areas had paired, well-developed levees (see Figures 11[c] and [d]) which were generally lower in elevation than point bar levees and were aggrading at slower rates (**2-6 cm/yr**, Pearce 1986). Stable channel levees were characterized by dense bands of horsetail and sedge at the lower elevations (even into the water) on both sides of the channel which could filter out sediments. These emergent graded into willow-horsetail and alder-willow ecophases at the upper elevations of the levee. Although stable channel levees were not present in the outer delta study area, reconnaissance showed that water horsetail was absent on these levees, and pendant grass, sedge, and Richardson's willow-horsetail ecophases adjoined the channels.

__Distributary Channel Levees (2b):__

Distributary (or lake) channels deliver water and sediment from main delta channels to lakes, and levees are formed along these channels by overbank flooding and deposition of alluvium. Distributary channels, therefore, connect main delta channels and lakes. These channels have been placed within the Basin Ecosection in the ecological land classification, but are described here because their physical environments and the dominant plant communities more closely resemble those in ecosites 1a and 1b.

Distributary channel levees occupy 1-6% of the study areas (Table 1). Levee heights at the distributary channel inlets ranged from 6 m above fall low water in the inner delta, 3-4 m in the middle delta, and 1-1.5 m in the outer delta; however, levees were lower by 1-4 m at the lake outlets. Aggradation of distributary channel levees occurs primarily on the crest occupied by mature willow-horsetail ecophases (mean **3.5 cm/yr** [n=19, SD=0.68] reported by Cordes et al. 1984; **8 cm** in 1982 [n=5,SD=5.2], **5.5 cm** in 1983 [n=5,SD=1.9]) on sites closest to main delta channels [Pearce 1986], Table 4), as alluvium deposited onto the bottoms and sides of the channels is eroded and retransported during inflow to lakes and again at outflow from the lakes when water levels in main delta channels are lower than in the lakes. Most of the sediments deposited were silty in texture. Little lateral shifting occurs in distributary channels (Cordes et al. 1984, Gill 1971), and the banks are quite stable although asymmetrical in cross-section. Physical damage to channel levees from ice and debris carried by floodwater was significant at many channel inlets (Pearce 1986). Some shallow distributary channels became clogged with organic litter and flood debris and the channel bottom aggraded to form low closures during low summer water levels. These sections become further elevated to a point where that stretch of channel will be abandoned and connection severed between the main delta channel and the lake (Cordes et al. 1984).

Most of the distributary channels in the inner delta study areas were seasonal, with flow from main delta channels to lakes via the distributary only during breakup flooding. With drawdown, flow was out of the lakes through the rest of the open water season.

Figures 11[e]-[h] show profiles across distributary channel levees in the middle delta.

<u>Arcuate Depressions (1c)</u>

Arcuate depressions mark former positions of meandering channels. This ecosite was included within the point bar ecosite and will not be described separately here.

<u>Alluvial Sand Plain (1d)</u>

The alluvial sand plain ecosite includes the low, flat, sand bars and elevated sand plains in various stages of development within Middle Channel just north of Point Separation (the Alluvial Islands). (The formation of these islands may be similar to those formed in the outer delta at the outlets of main delta distributaries into the Beaufort Sea.) A combination of fluvial and aeolian processes has resulted in distinctive prograding and aggrading features. Some sites on the Alluvial Islands are elevated enough to support white spruce and poplar forests. However, most of the islands are low-lying sites that are flooded for long periods each summer, receive substantial amounts of new, usually sandy, sediment, and are continually shifting and migrating with erosion upstream and redeposition downstream. These unstable landform are occupied by pioneer communities of horsetail and willow.

Based on willow ages, sedimentation rates between 1980 and 1983 averaged **4 cm/yr** (n=95,SD=6.46,SEM=41.7) in the pioneer willow ecophases (Table 4, at end). Sedimentation into the mature willow and alder ecophases averaged **4.1 cm** (n=23,SD=3.01,SEM=9.1) and **0.6 cm** (n=11, SD=0.6,SEM=0,35) respectively during the same period.

3.2 Lake Ecosection

The physical effects of high sedimentation, strong currents, and ice damage which characterize channel sites are absent in most lake systems on the Mackenzie Delta. There are about 24,000 lakes in the Mackenzie Delta, most of them in the middle delta (Mackay 1963). Many lakes may have originated as bays at the prograding outer delta which became enclosed by prograding and aggrading distributary channel levees and middle channel bars where channels empty into the Beaufort Sea (Lewis 1988). As the delta prograded further into the Beaufort Sea, the lakes were left behind on the delta plain. Other lakes have formed from thermokarst processes on the delta plain, in cut-off or abandoned stretches of channels, and in depressions between point bar ridges (Mackay 1963).

Lakes on the Mackenzie Delta are quite shallow, 0.43 to 3.5 m deep for connected and low closure lakes to 4 m deep on average for high closure lakes (some oxbow lakes are 10+ m) (Cordes et al. 1984). Delta lakes may infill from sediments received during flooding and accumulations of plant litter, or enlarge by thermokarst erosion of lakeshore levees. Some lakes become connected to delta channels by lateral migration of a channel or headward erosion through previously-deposited sediments.

Delta lakes have been divided into two general types, connected lakes and closed lakes (Gill 1971, Mackay 1963). Cordes et al. (1984) have further classified delta lakes as Type A lakes (lakes directly connected to delta channels through a distributary channel or through other connected lakes by connecting channels), Type B lakes (unconnected or "closed" lakes, lakes with low-elevation levees completely surrounding the lake), and Type C lakes ("closed" lakes with high-elevation levees). Connected lakes are flooded every year directly through the distributary or connecting channels (and sometimes over lakeshore levees, as well), and water levels fluctuate with water levels in delta channels. Closed lakes must be flooded over lakeshore levees of differing elevations and so flooding depends on the height of the breakup flood. Water levels in these lakes do not fluctuate much after floodwater recede. Connected lakes can become closed with infilling of distributary and connecting channels; closed lakes can become connected with lateral migration of channels.

Sedimentation onto lake shorelines depends on whether the lake is connected or not, the elevations of the closure if the lake is unconnected, and the distance of the lake from major delta distributaries. Because the physical effects of strong currents and high sedimentation rates are generally reduced in lake systems, plant succession on shorelines is primarily related to the frequency and duration of flooding. However, sedimentation on actively aggrading and prograding sites (such as low closure levees and lake deltas) also controls plant colonization and establishment. It should be noted here that the most common willow on channels (felt-leaf willow) is found only on high-depositional sites, such as lake deltas, in lake systems. The most common willow on lakeshores is arctic willow in the inner and middle delta and Richardson's willow in the outer delta. These willows cannot withstand such large amounts of annual sediment deposition as the felt-leaf willow.

In some connected lakes close to the input channel, lake deltas have formed from sediments carried to the lake during spring breakup flooding and higher water in channels any time during the open water season (Cordes et al. 1984, Gill 1971, Mackay 1963). Sediments are also deposited onto these sites during flows out of a lake when lake levels are higher than channel levels. Lake deltas are most common in connected lakes in the middle delta (especially within and close to Area 4) close to main channels where there is throughflow to another lake. In the inner delta, lake deltas prograde into high elevation lakes from deposits transported there by seasonal distributaries which drain the lake after breakup flooding. Lake shoals have formed in many lakes in the middle delta as lakebeds become exposed with lower water levels or are built up with deposition and accumulations of organic debris (Cordes et al. 1984, Gill 1971, Pearce 1986).

The following sections will describe sedimentation patterns on lake deltas, lakeshores, lake shoals, and connecting channels in the inner, middle, and outer delta.

<u>Lake Deltas (2a)</u>

Lake deltas have formed from medium to coarse loam and sandy loam alluvium carried by distributary channels (described in the previous section) and deposited over finer-textured silts and clays on the flat bottoms of lakes where the channels first enter them. Lake deltas occupy only 0.1 to 2% of the study areas (Table 1). Deltas in the inner delta were not sampled by Pearce between 1981 and 1983. There are few connected lakes in the outer delta, and no deltas in the Area 5 study area.

Lake deltas in the middle delta have low relief, generally only a rise of 1 m in 35 to 100 m distance, and flooding is prolonged (as long as 2-3 months). Vegetation on lake deltas progresses from emergent such as pendant grass, horsetail, and sedge at the water's edge, through a pioneer willow-sedge zone, to mature willow-sedge at the upper elevations which sometimes grade into mature willow-horsetail communities on the distributary channel levees (Figures 12[a] and [b]). A mean aggradation rate of **1.34 cm/yr** (n=67,SD=.08, range 0.77 to 3.3 cm/yr) and progradation rates of 1-4.5 m/yr were measured on deltas in Areas 3, 4, and 7. Average sedimentation rates were **4.5 cm** in 1982 (n=26,SD=4.2,SEM=17.8) and only **0.9 cm** in 1983 (n=41,SD=1.1,SEM=1.1). Rates were highest in the pendant grass and willow ecophases (Table 4). Sediments were dominated by sands and silts (Figure 12). Sedimentation onto the lower elevations continued throughout the open water season during inflow from distributaries and outflow when lake levels were higher than channel levels.

Lakeshores (3a)

Delta lakeshores occupy 5.7 to 10.4% of the terrestrial surface in the inner and middle delta; basin shoals and lakebeds occupy another 22.9 to 42.7% (Cordes et al. 1984, Hirst et al. 1987) (Table 1). Lakes and their associated landform occupy extensive areas in the outer delta. An average annual aggradation rate of **1.61 cm/yr** (n=40, SD=1.5) was measured on connected and closed lake shorelines throughout the delta (Cordes et al. 1984, Pearce 1986) (Figure 5). In 1982 and 1983, overbank sediment rates onto lakeshores in the middle delta were **2.4 cm** (n=17,SD=1.9,SEM=3.7) and **1.7 cm** (n=21,SD=1.4,SEM=2.05) respectively (Table 4). (Too few measurements were collected in the inner and outer delta.) Shorelines on lakes which received some accumulations of sediment each year were wide and had gentle gradients. Annual deposition rates were highest on connected and low closure lakeshores close to main delta distributaries (0.66 to 3.37 cm/yr between 1980 and 1983) and lowest on high closure lakes far from these distributaries (no sedimentation was measured on these shorelines by Cordes et al. [1984] or Pearce [1986] between 1980 and 1983 because most of the high closure lakes studied were characterized by thermokarst shorelines).

(a) **Connected lakes**

None of the lakes sampled in the inner delta study areas were considered "true" connected lakes because they were connected to delta channels only during breakup flooding. With drawdown, waters drained from the lakes to the end of the open water season. In the middle and outer delta study areas, it was difficult to measure sedimentation on shorelines of connected lakes unless woody vegetation was present to provide a measure of deposition since plant initiation. On many shorelines, emergent vegetation, such as the horsetails and sedges, is very dense (see Figure 13) and the large amounts of leaf litter that accumulate around these plants trap sediment within the tussock making it unavailable for measurement. On mudflats, seasonal freezing and thawing displaced the sediment stakes. However, some direct annual measurements were taken, and plant initiation noda on willows (usually 2-6 yrs old) at low elevations were used to estimate sedimentation patterns on connected lake shorelines: **3-5 cm/yr** within the horsetail ecophases, **0.5-2.5 cm** within the sedge ecophases, and **1-5 cm** into the pioneer willow-sedge ecophases. Shorelines of connected lakes far from main delta distributaries are characterized by mature willow and alder ecophases right to and sometimes within the water. These lakeshores exhibited little, if any, active sedimentation between 1981 and 1983 and the banks were relatively steep.

Most of the lakes in the outer delta study area are closed rather than connected. However, shorelines on Lake 7 (the connected lake shown on the Area 5 map in Appendix B) were sampled. This lake is connected to Arvoknar Channel via "Penny" and "Franc" Channels. The shorelines of this lake were densely vegetated with sedge and Richardson's willow, and only on Transect V-B (see Figure 14) was there a small mudflat. Annual sedimentation in 1982 and 1983 was measured on the lower leaves and branches of sedge and willow because of the thick litter tussocks that covered the ground; thus the following measurements may be low. In both years, **2.5 cm** was deposited into the sedge-cottongrass ecophase, but only **2 mm** into the Richardson's willow ecophase. No sediments were observed beyond 20 m from the lake, and no new sediments were visible following the 1981 breakup flood.

(b) **Low closure lakes**

As main channels migrate laterally across the delta plain, they cut into lakes. These "captured" lakes then drain to their spill levels. With overbank deposition during breakup flooding, low levees form between the channel and the "captured" lake forming a low closure which is then only overtopped during flood peaks that exceed that elevation (see Figures 15 and 16 that show low closure lake levees in Area 3). Low closure levees adjacent or close to main channels can be high deposition environments when they are low enough to be flooded every year during breakup and summer storms. Average overbank sedimentation rates of **1-6 cm/yr** were measured using burial depths around aged willow stems.

Most of the lakes in the outer delta study area were unconnected, relatively small (often no more than ponds), and shallow within extensive inter-levee basins. Because most sites on the outer delta are flooded every year, the lakeshores of most of the closed lakes can be considered "low closure" (see Figure 17), although sedimentation over the closures appeared minimal between 1981 and 1983. Much of the sediment carried by floodwater may be filtered out by dense bands of willow adjacent to channels. Overbank sedimentation measurements on closed lake shorelines were difficult to complete because the sediments could have been deposited within the thick litter tussocks associated with the sedge and Richardson's willow ecophases.

(c) **High closure lakes**

Most of the high closure lakes studied during the 1980-1983 sampling period were characterized by steep, unvegetated, thermokarst shorelines, erosional rather than sedimentary environments. Some plants (such as horsetail and sedge) had colonized on "ledges" just below the lake surface formed not from sediment deposition but from slumping of soils from above. Erosion rates were not measured during the B C Hydro studies.

<u>Lake Shoals (3b)</u>

Lake shoals are a minor landform in the study areas (Table 1). Shoals are partly-emergent land in shallow water, and on the Mackenzie Delta are most common in the large, shallow, connected lakes of the middle delta. Most of the shoals in the middle delta study areas were small (about 10 m wide and 30 m long) and of a domed shape (exposed lakebottoms perhaps pushed up by hydrostatic or cryostatic pressure from below) or ridged shape (wave-formed) with elevations of less than 1.5 m (above FLW) (Pearce 1986). Shoals were flooded and reflooded for very long periods during the open water season (1-3 months). Mean sedimentation rates of **4.5 cm** (n = 10,SD = 4.7,SEM = 22.4) and **1.3 cm** (n = 26,SD = 2.5,SEM = 6.04) were measured in 1982 and 1983 respectively using the sediment stakes (Table 4). However, an average sedimentation rate of **<1 cm/yr** (mean **0.81 cm/yr**,SD = 0.21) was calculated using depths of alluvium around buried and aged willow stems. The sediments on shoals were fine-textured silts and silty clays. Only early successional plant communities occupied lake shoals: emergent communities dominated by pendant grass, sedge, and spike rush, and pioneer willow-sedge communities at the highest elevations (Figure 18).

Connecting Channels (3c)

Connecting channels are also a minor landform occupying <1% of the study areas (Table 1). Connecting channels join different lakes to each other on the Mackenzie Delta. Connecting channels, like connected lakes, are most common in the middle delta. Water levels in these channels fluctuate in unison with levels on main delta distributaries. Connecting channels are U-shaped in cross-section (Figure 19) and comparatively deep, especially between lakes of different sizes and depths (Cordes et al. 1984), as they act as troughs which transport water and alluvium through the channel to the lakes that they connect. These channels also have reversing flow so that any sediment that is deposited during inflow is entrained during outflow (Gill 1971). Because of this reversing flow, sedimentation onto levees is minimal relative to the long flooding durations--2-5 cm/yr on the lower elevations and only a few millimetres on the upper elevations (Table 4)--and aggradation rates are slow. Like distributary channels, connecting channels can become clogged with debris and act as low closures during low summer water levels.

The vegetation on connecting channel levees (see Figure 19) is controlled by the frequency and duration of flooding, similar to that on many lakeshores: narrow mudflats at the lowest elevations followed by sedge and willow-sedge ecophases and grading to alder and even white spruce on the levee crests and backslopes. Although connecting channels are relatively stable, the horsetail ecophase, characteristic of stable channels (1b), is absent because sediments deposited during breakup flooding and early drawdown are eroded quickly with reversing flow.

3.3 Delta Plain Ecosection (4,5)

The delta plain is a broad, relatively flat, stable surface at the highest elevations of the inner and middle delta. There is no delta plain in the outer delta. The processes that are responsible for the development of the delta plain are not well understood. Cordes et al. (1984) suggest that the delta plain may have evolved from inter-levee basins that formed between the levees of prograding distributary channels at the delta front and have infilled and been elevated above the present flooding regime either by gradual aggradation, by downcutting of channels, by major redistribution of Mackenzie River discharge or its tributaries upstream in the Mackenzie River Basin, by isostatic rebound following deglaciation, or by a combination of all of these phenomena.

The delta plain occupies 26 to 45% of the study areas in the inner and middle delta (Table 1). The high floods in 1982 inundated about 95% of the Mackenzie Delta, but some delta plain sites were unflooded, especially in the inner delta and in those parts of the middle delta dominated by flows from Peel Channel (see Pearce et al. 1988). White spruce forests dominate much of the mesic delta plain, although many sites in the middle delta near treeline are dominated by alder. White spruce/lichen woodlands and scattered black spruce and tamarack (in the inner and west middle delta only) occupy xeric and hydric sites respectively that are completely isolated from the present flooding regime of the delta (Pearce et al. 1988). Mosses, shrubs, and a variety of flowering herbs characterize stands that can be flooded during high breakup peaks. The substrate associated with these stands is composed of organic layers inter-bedded with mineral layers marking previous flood events. The ground vegetation in spruce stands not flooded by even the highest breakup peaks is quite different from spruce stands that do get flooded. Lichens and prostrate woody shrubs (such as crowberry and bearberry) under an open tree canopy characterize very elevated stands that do not appear to get flooded under the present fluvial regime (Figure 20a). The substrate is organic with permafrost 30 to 55 cm below the surface in summer and no evidence of alluvium deposition.

Spruce forests on the delta plain in the inner delta study areas did not receive new sediment during breakup flooding between 1980 and 1983 (Table 4). However, some sites near the East Channel study area (Area 1) appear to have been flooded in 1983 when ice dams on the channel backed up water onto parts of the delta plain. Some parts of the delta plain in the middle delta received **<1 cm** (SEM 0.3 and 0.006) during flooding in both 1982 and 1983 (Table 4).

Transect III-C (Figure 8a) was cut across a point bar and the delta plain in Area 3. The white spruce ecophase on the delta plain was flooded only in 1982 and 1992 between 1980 and 1992. At these times, floodwater rose to 1.0 to 1.4 m on individual trees on the highest elevations of the transect line. Sedimentation ranged from 0.5 to 2.0 mm in both 1982 and 1992 (average **1 mm**). However, white spruce on other parts of the delta plain in this area were not flooded in 1982. Sedimentation onto the delta plain in the inner delta between 1980 and 1983 was very similar to the patterns in Area 3, with only 0.5-1 mm being deposited if the site was flooded. Transect II-P (Figure 20b), surveyed by Cordes et al. in 1980, was cut across the mesic and hydric delta plain in Area 2. The vegetation on this transect was not flooded in 1972 or 1982 and the underlying substrate was completely organic.

3.4 1992 Sedimentation Measurements in Areas 3 and 5

Selected transects in Areas 3 (middle delta) and 5 (outer delta) were resampled in August 1992 to measure recent sedimentation and vegetation changes that may have occurred since 1983. The time was also used to remark the locations and benchmarks of some of the transects with bright pink flagging tape and to ascertain the fate of sediment stakes put in, in 1981. Measures of overbank sedimentation were estimated from burial of the fall 1991 leaf litter in the mature willow, decadent willow, alder, and spruce ecophases and from trenches and erosional scarps in the mudflat and pioneer willow ecophases. The sediment stakes that had not been buried or destroyed were not disturbed.

1992 appeared to be another "high" flood year on the Mackenzie Delta (see Table 3). Floodwaters reached 1.4 m on spruce trees on the delta plain in Area 3, and the spruce ecophases received a few mm of silty sediment (mean **0.18 cm**, n = 10,SD = 0.15,SEM = 0.02) (Table 5). All point bars in the study area were completely inundated and received <1 to 35 cm of new sediment (mean **6.1 cm**, n = 58,SD = 9.2,SEM = 84), most of which was deposited onto the mudflat and pioneer willow ecophases (Table 5). This is a little less than calculated for all middle delta point bars (using stakes) in 1982 (8.5 cm). Most of the sediment stakes on the lower elevations had not survived from 1990 (the last time this study area was sampled). Water levels in lakes were very high during the period of sampling in 1992, and only a few sedimentation measures were taken: 10 cm in sedge, 1 cm in mature willow-sedge, and <1 cm in the alder ecophases (mean **2.4 cm**, n = 5,SD = 0.15, SEM = 18.1) (Table 5).

Only one landform, a point bar (Transect V-F), could be sampled in Area 5 during the August 1992 sampling because of stormy weather and high water levels. On this point bar, sediment estimates were **8 cm**, **4 cm**, and **0.4 cm** for the pioneer willow, mature willow (felt-leaf), and mature willow (Richardson's) respectively (Table 5).

3.5 Summary of Sedimentation Patterns on Ecosites and Ecophases

The sedimentation rates for delta study areas are quite variable, not only between flood years and study areas but also within each ecosite and ecophase. As well, some of the sediment data is very sparse, particularly for 1981, for the outer delta, and for some ecosites. These problems will be discussed in Section 4.0. Nevertheless, general overbank sedimentation patterns on the Mackenzie Delta can be identified, particularly those associated with the <u>upper elevations</u> of all ecosites.

The mature willow, alder-willow, and spruce ecophases on channels, lakeshores, and the delta plain are not flooded every year. None of these ecophases were flooded during the "low" floods in 1980 and 1981. Only the lower to middle elevations in the mature willow ecophases were flooded in 1983, a "moderate" flood year on the delta, and deposition ranged from <1 mm to 3 cm (depending on the study area). All of the mature willow and alder-willow ecophases and many of the spruce ecophases in the middle delta were flooded during the "high" flood years of 1982 and 1992. However, deposition was minimal, from <1mm at the highest elevations to 1.5 cm at the lower elevations. The elevated spruce woodlands in the middle delta and spruce forests and woodlands in the inner delta were not flooded in 1982 (and probably not in 1992 either).

The low elevation ecophases (mudflats and pioneer willow on channels and horsetail, sedge, and willow-sedge on lakeshores) are flooded at all breakup stages and receive some new sediment each year. The ecophases on channels generally receive comparatively large amounts of new alluvium annually, but the rates were very variable. Not many samples were available for lakeshores, but sedimentation rates onto the lower elevations were considerably less than on channels and the amounts of sedimentation received each year did not vary as much from year to year.

The spruce forests appear to mark the height of "high" floods on the delta. "High" floods are infrequent but assure at least some regeneration of spruce because this species requires mineral soil for seed germination (see Pearce et al. 1988). Spruce woodlands have developed on very elevated sites on the delta plain that are not flooded under the present fluvial regime, but their lower boundaries may mark the "very high" or record floods on the delta. "Low" breakup floods determine the upper limits of sites that can be occupied by the pioneer ecophases: mudflat, emergent, and willow (but these ecophases are inundated during all floods). The lower alder-willow ecophases appear to mark the limits of "moderate" breakup floods. It may be that the "moderate" floods actually determine vegetation/sedimentation patterns on the Mackenzie Delta. This means that the ecophases that are not tolerant of regular sedimentation deposition (such as the upper alder and white spruce ecophases) can survive on elevated sites and the sediment-tolerant ecophases at the lower and middle elevations can be maintained.

4.0 ANALYSIS OF METHODS USED TO COLLECT SEDIMENTATION DATA

Standard methods for measuring annual sedimentation onto specific sites include coring and trenching to examine the structure, texture, and colour of the substrate at different levels; aging woody plants; measuring deposition depths onto autumn leaf litter layers; staking (either with or without a mesh bed or pan) to estimate burial depths; probing the freshly-deposited alluvium until resistance is met; and measuring the heights of erosional scarps produced during drawdown. All of these methods have been tried on the Mackenzie Delta with varying degrees of success. Some researchers in other areas have used marker layers of resin painted onto the pre-flood surface each year, but this method is much too expensive and time-consuming to use on the Mackenzie Delta.

Section 2.1 described the sampling design, sampling sites, and specific methods that were used to measure overbank sedimentation associated with different ecophases in the B C Hydro study areas between 1981 and 1983. Historical rates were estimated by examining stratigraphic layers in soil pits and by measuring burial depths around aged willow stems from plant initiation noda. Annual rates were measured directly by probing to the pre-flood surface 2-3 weeks after breakup, by excavating sediment stakes put in, in 1981, by measuring deposition onto the previous year's autumn leaf litter, and by measuring the heights of erosional scarps on mudflats. Long-term sedimentation rates in lakes were estimated by dating material from deep cores with cesium and lead. New measurements in 1992 in Areas 3 and 5 and a "test" area near Inuvik used soil pits and deposition onto leaf litter.

The following sections will evaluate each of these methods.

4.1 Cores and Trenches

Cores and trenches were used on the most elevated sites to look for mineral horizons within predominantly organic substrate to determine whether these sites are being flooded under the present fluvial regime. This method worked well for this purpose, but the frequency of flooding could not be determined without knowledge of flood peaks in a particular part of the delta. Records at Aklavik and Inuvik do not go back very far. However, mineral horizons in the upper soil layers on elevated sites were assumed to be from the 1961, 1972, and 1982 floods. Cores and trenches were also used on the unvegetated and sparsely vegetated mudflats in the hope that different flood events would be expressed in differences in texture, colour, and structure of the alluvium that occurs over time on these sites. Cores did not provide a reliable measure of annual sedimentation. Trenches were successful only occasionally, and then only on channel sites as the high water table on most mudflats filled the trenches before they could be examined.

Deep sediment cores were extracted from several lakes in each study area for Cs-137 analyses by Cordes and McLennan (1984b) to estimate historical lake sedimentation rates. This methodology could be very useful on elevated sites (reviewed in Carson & Associates 1991) but has not yet been tested on terrestrial surfaces.

4.2 Aging Woody Plants

Willows, and less frequently poplar and alder, colonize mudflats at the lower and middle elevations of most ecosites. These plants were used to provide an estimate of average annual sedimentation rates over the period of time that had elapsed from plant initiation to the date of measurement. For small plants, this was fairly easy to do by marking the present surface onto the plant stem, digging down to the plant base and extracting it, measuring the plant from the initiation point from which roots have grown to the surface mark, and then aging the plant by counting woody rings in stem tissue at the marked surface point. This method gives a measure of how much alluvium has been deposited around the plant since it started growing for calculating a mean annual accumulation rate for the site. This procedure was quite difficult for channel willows that were more than 10 years old because the initiation point could be a metre or more below the present surface and sometimes into permafrost. In some cases, the buried plant tissues had rotted. Nevertheless, this was one of the most reliable methods for determining mean annual sedimentation rates, keeping in mind that much of the deposition could have been from one big flood and accumulation rates on most sites decreased over time as the surface was elevated.

4.3 Leaf Litter Layers

Each autumn, leaves from deciduous plants are deposited in a layer on top of the soil surface. If the site is flooded the following spring, alluvium is deposited on top of the leaf litter providing a fast, easy, and reliable method for estimating sedimentation, *as long as there are enough leaves to produce a more-or-less continuous litter layer*. Figures 2 and 22 show the leaf litter layers, laid down in 1991 and in previous years, that appear as "marker beds" for the 1992 and earlier floods. This method worked very well in the mature willow, alder-willow, and spruce ecophases on the Mackenzie Delta as sediments had been deposited as a veneer 1 mm to several cm thick that could be peeled off and measured in situ. In the ecophases that received substantial amounts of new alluvium during flooding (e.g. the pioneer and mature willow ecophases), blocks of substrate were extracted with a square-toed shovel, taking care not to disturb the materials, and examined for leaf litter layers. At least 5-10 extractions/ecophase were necessary to include most of the variability. This method did not work in the sparsely vegetated ecophases (e.g. the mudflat and many pioneer willow ecophases) where the leaf drop was minimal, nor in emergent vegetation where the water table was very close to or at the surface and dense accumulations of attached leaf litter were present as tussocks around the living biomass.

4.4 Staking

Sediment stakes (1 cm diameter reebar 2 m in length) were pounded into the substrate (into permafrost if possible) at the lower and upper boundaries of different ecophases along the permanent transects established in the B C Hydro study areas in 1980 or 1981. Sediment stakes were also put in beside vegetation sampling plots (usually midway between the lower and upper ecophase boundary). After the breakup flood, the stakes were painted orange to the surface (see Figure 2b). The stakes were repainted yellow to the new surface the following year after breakup, and white the next year (1983). The stakes were extracted carefully in August 1983 and each paint length measured to estimate annual sediment deposition around the stake. The stakes were put back in after measurement but were not repainted. (Hardy Associates [1982] used a similar method in 1980, but put in the stakes in a 1 m square, each stake holding down a corner of a mesh screen. The depths of new sediment deposited on top of the mesh during flooding were measured the following year.)

Staking worked moderately well for lower and middle elevation sites where vegetation was too sparse to provide a continuous autumn leaf litter layer. However, on the lowest sites on channels, ice bent or completely removed the stakes during breakup, or new sediment covered the stakes completely. On a few sites, some stakes became so lodged into the substrate that they could not be removed without disturbing the accumulated sediments. On the lower shorelines of lakes, deltas, and shoals, freeze-thaw processes within the saturated substrate displaced the stakes in a random manner. Similar problems were experienced at the Hardy Associates stakes. An unassessed problem may have been the obstruction of the stake to flow which could have contributed to higher deposition around the stake. However, this same problem occurs around plant stems which are a natural part of the environment on the delta.

Unfortunately, many of the stakes on low elevation sites in Areas 3 and 5 did not survive the 1992 flood, and this may have happened in the other study areas, as well. Nevertheless, stakes provided a reliable alternative to measuring depths to leaf litter layers on sites with little vegetation.

4.5 Probing

Probing the substrate as soon as possible after the flood peak was an alternative method for measuring flood deposits onto delta surfaces. A long narrow probe (such as a length of 1 cm reebar) was pushed into the substrate gently until resistance was met. This "resistance" was usually the pre-flood surface upon which the uncompacted new alluvium had been deposited. A correction factor (0.63 for silty soils) was applied to the measures before comparison with other sediment data. Unfortunately, many delta sites were accessible only by helicopter at this time of year. Even with a helicopter, the mudflats were almost impossible to traverse. This method did not provide reliable measurements of overbank sedimentation.

4.6 Erosional Scarps

Erosional scarps are the "small cliffs" and "terraces" that result when falling water levels after the flood peak erode material from a sloping surface (see Figure 8b-mudflats on Transect III-C). In some cases, the material that was eroded was the recently-deposited alluvium, and the "cliff" measured the depth of this alluvium to the "terrace", the pre-flood surface. This method was used on some point bars and actively-aggrading low closure levees where other methods did not work, but its reliability was not tested for more widespread use.

4.7 Data Problems

Data problems were experienced related to the variability of the measurements between and within samples, a sampling bias towards point bars, and insufficient data for 1981, lakeshores, and the outer delta.

The individual sediment measures were very **variable**, not only within each ecosite but also within the same ecophases, no matter which of the above measurement techniques were used. However, these results were not a surprise. Variability in sedimentation patterns within the ecophases must be examined at both the "macro" scale and the "micro" scale. At the macro scale, sedimentation patterns were related to elevation above and distance from a channel or lake and the successional stage and structure of the vegetation. At the micro scale, sedimentation patterns were much less predictable as they were related to the topographic variability of the ground surface (including plant litter and other debris) combined with differences in plant density, plant height, stem size, etc. Sampling at this level is very difficult.

Another problem may be the **number of samples on point bars** compared to the other ecosites (for example, point bars n=256, lakeshores n=68, delta plain n=28) because this ecosite receives enough sediment to measure. Many of the transects used by Cordes et al. (1984), Gill (1971), and Hardy Associates (1982) were cut across point bars to the delta plain, and this procedure was followed by Pearce (1986) as well. Carson & Associates (1991) and Hirst et al. (1987) warn of using point bars to measure overbank sedimentation until the relationship between deposition and erosion on this ecosite has been determined. As well, the lower elevations of point bars may receive bed load rather than suspended load sediments that have not been separated in the deposition measurements.

In addition, the sediment data are very sparse for some years and for some ecosites. Very few measurements were collected in **1981** because the sediment stakes were not put in until after the 1981 spring flood (Pearce 1986). Some in situ measures were made, but only the mudflat, emergent, and lower willow ecophases were flooded in 1981, and these sites are particularly difficult for measuring sediment. Sediment data are also sparse for ecophases on **lakeshores** in all years and particularly in the inner delta. The transects sampled during the B C Hydro studies represented different kinds of lakes at different elevations and distances from main delta distributaries. However, there were few reliable measurement opportunities on lakeshore mudflats because of a lack of leaf litter layers that could be used as marker beds, the water table was near the surface on these sites, and frost heaving displaced sediment stakes that had been put in on some transects in 1981.

Sedimentation data are also sparse for some sites in the **outer delta**. Some ecosites are not common or even present in the outer delta study area (e.g. lake deltas and shoals, connected lakes, main channel levees). As well, the vegetation in this study area was dominated by sedge and Richardson's willow with a ground cover of large tussocks of litter that made the measurement of the small amounts of sediment received by these communities very difficult.

4.8 Test Area

The relationships between hydrology and vegetation on delta landform were not tested outside the B C Hydro study areas.
During sampling in Area 3 in 1992, it became apparent that the 1992 spring breakup had been high, as high if not higher in some places than that in 1982. White spruce ecophases on the delta plain had received 1-2 mm new sediment, and a flood height of 1 to 1.4 m above the ground surface was visible as very fine clay skins deposited onto tree trunks during flooding. As all of the ecophases in Area 3 appeared to have been flooded (perhaps for the first time since 1982), it was a "good" year to sample a location in the middle delta that had not been studied during the B C Hydro-funded research to determine if the sedimentation patterns would be similar.

The delta plain, a point bar, a shoreline on a connected lake, and a lake delta on Big Lake Channel and Big Lake immediately south of Inuvik across East Channel were sampled in August 1992 to analyze sedimentation patterns resulting from the 1992 breakup flood. This area was chosen because:

1 *it is close to Inuvik and the East Channel water level recording gauge that has been in operation for many years;*

2 *the area is in the middle delta and occupies a similar position in relation to East and Middle Channels as Area 3 (although levee heights are a little higher than in Area 3--about 5 m above fall low water on channels compared to 3.5-4 m [Pearce, unpublished data]);*

3 *the area is being used by NHRI to examine lake sedimentation patterns; (4) the area was used by Boyes (1991) for his M.Sc research and many of the ecophases were sampled by him; and (5) aerial photographs are available, including one set that appeared to have been taken during breakup in 1983.*

Table 6 summarizes the sedimentation measurements in the test area. The delta plain and a point bar near a GSC bench mark on Big Lake Channel were sampled for sedimentation (Figure 21). The highest elevations of the point bar and adjacent delta plain, both occupied by a white spruce ecophase, had been flooded in 1992. On the delta plain, clay skins on tree trunks were measured to 1.06 m above the ground surface and several millimetres (mean **0.04 cm**, n=5,SD=0.03,SEM=0.0009) of new **alluvium**, silty in texture, had been **deposited** onto the ground surface. Less than **1 mm to 2 mm** of alluvium had been deposited into **the** spruce ecophase on the point bar (n=5,SD=0.05,SEM=.003). Only a few millimetres were received at the upper elevations of the alder-willow ecophase (mean **0.2 cm**,SEM=.01), but up to 5 cm onto the lowest elevations (mean **3.8**, SEM=.08). Six to 7 cm (mean **4.7 cm**, SEM=6.7) of new sediment were measured lower on the point bar within the mature willow-horsetail ecophase. Examination of a trench dug in this ecophase revealed that this site had received 3 cm and 1 cm during previous flood events (1991 & 1990?). Sedimentation within the pioneer willow-horsetail ecophase was 15 to 20 cm (mean **17** cm,SEM=4.7) in 1992 (Figure 22). Sedimentation onto the lower mudflats could not be measured as the vegetation was not dense enough to produce a fall leaf litter layer.

Mean sedimentation on this point bar was **5.1 cm** (SEM=46.9) in 1992 (Table 6), very close to the rate of 6.1 cm (SEM=83.96) estimated for point bars in Area 3.

Figure 23 shows the shoreline of the second (and last) connected lake in a small connected lake system off Big Lake Channel that was sampled in 1992 for sedimentation patterns on lakeshores. The white spruce ecophases on the highest elevations of the lakeshore and on the delta plain had been flooded in 1992 (to 1.5 m on tree trunks) but had only received a veneer of very fine-textured alluvium **<1 mm** thick (Table 6). Less than **1 mm** of new alluvium was deposited within the alder-willow and willow-sedge ecophases at lower elevations, as well, and only **3 mm** into the sedge ecophase right at the lake's edge. However, alder-willow, willow-horsetail, and horsetail ecophases adjacent to the short distributary channel from Big Lake Channel to this lake all received 9 to 12 cm (mean **10.6 cm**,SEM=0.013) in 1992.

An actively-prograding and aggrading delta is forming where Big Lake Channel enters Big Lake. Sedimentation in 1992 ranged from **3 to 4 cm** in the mature willow horsetail ecophase, up to **20 cm** in the pioneer willow-horsetail ecophase, and up to **10 cm** onto the upper mudflats that were vegetated with small plants of sedge and horsetail (Table 6). These rates are quite a bit higher than for lake deltas sampled during the high flood in 1982 in Areas 3 and 4 (mean **6.9 cm** compared to 4.5 cm), but Big Lake Channel is a much larger and more active distributary channel than those in the B C Hydro study areas.

The sedimentation measurements from the Inuvik test area used the same methods that were used in Area 3 in 1992. The table below compares the results of these measurements:

	Mean Sedimentation (in cm)	
Ecosite/Ecophase	Area 3	Test Area
POINT BAR	6.1	5.1
Pioneer willow	19.8	16.8
Mature willow	5.3	4.7
Decadent willow or alder	0.2	0.2
LAKESHORE	2.4	0.1
Sedge	10.0[1]	0.3
Mature willow	1.3	0.05
Alder	0.3	0.04
DELTA PLAIN		
Spruce	0.18	0.04

[1] *This measurement was taken on the shoreline of a low closure lake beside Chicksi Channel and so cannot be compared with those on the second connected lake in the test area.*

Although there were some differences in 1992 sedimentation between the "test" area and the Area 3 study area, the differences are minor. What is interesting are the slightly higher deposition rates in Area 3 which is about 50 km north of the test area. However, the sites sampled in Area 3 were all on or very close to Chicksi Channel, a major distributary and a channel that is larger than Big Channel. Even though these measurements are not conclusive, based as they are on a very small sample size, and must be tested further, the evidence is convincing to propose a strong relationship between sedimentation and the delta vegetation (patterns of ecophases = patterns of sedimentation). This relationship will be used to produce an estimation of mean overbank sedimentation rates for some parts of the Mackenzie Delta.

5.0 ESTIMATION OF MEAN AREAL SEDIMENTATION RATES

One of the goals of the NOGAP program is to estimate mean overbank sedimentation over the entire Mackenzie Delta. Hirst et al. (1987) used minimum and maximum deposition rates on different delta landform (i.e. ecosites) as measured by Cordes et al. (1984) and Pearce (1986) and the areal measurements of ecosites (Table 1) for each study area to estimate the amount of overbank deposition occurring on the Mackenzie Delta. Sediment volume was converted to weight/km^2 using an average bulk density value of 1.5 (although they suggest that 1.2 or less might be more representative of the variation in sediment textures in the delta). Mean overbank deposition rates of 707 to 8,942 tonnes/km^2 for the inner delta (Area 2) to 16,348 to 26,568 tonnes/km^2 for the middle delta (Area 3), were estimated for all ecosites (excluding channel and lake beds). Based on average rates for all of the study areas of 6,418 to 15,295 tonnes/km^2, they calculated a range of 64,000,000 to 153,000,000 tonnes/year for the entire upper sub-aerial plain (approximately 10,000 km^2), representing "...51% to 122% of Lewis's [1986] estimate of the average annual suspended sediment load of 125,000,000 tonnes/year delivered to the delta by the Mackenzie River, Peel River, and Arctic Red River combined." (Hirst et al. 1987, p.5.15).

Hirst et al. (1987) cautioned that these measurements could be crude approximations only because:

1. *the data base on sedimentation was limited, especially for some landform;*
2. *many of the sedimentation measurements were done in 1982, a high flood year;*
3. *there was a sampling bias towards those landform where sedimentation could be measured (e.g. point bars);*
4. *ranges of sedimentation rates on the entire ecosite were used rather than ranges within the ecophases; and*
5. *the amount of sediment subsequently eroded was not included in the calculations. A revised version of Hirst et al.'s*

methods, incorporating solutions to some of the above problems, was used to provide a preliminary estimate of mean areal sedimentation rates onto ecosites in the middle delta using Area 3. These estimates were then extended to the entire delta.

5.1 Areal Sedimentation rates Using Min-Max and Mean RATES for Ecosites - "High" Flood Year

Table 7 shows the percentage of the Area 3 map area occupied by the various delta ecosites. These percentages were converted to m^2 based on a map area size of 4.5 km x 2.75 km (12.375 km^2). The ranges of sedimentation measurements given on Table 4 and 5 for a "high" flood year (e.g. 1982 and 1992), when all of the ecophases were flooded and received some new sediment, and the area occupied by each ecosite (Table 7), were used to calculate minimum and maximum sediment volumes in <u>one</u> "high" flood year (**Table 8**). (Author's criteria: "high" flood years <u>in the middle delta</u> flood all ecophases except the spruce-woodland ecophase; "moderate" flood years flood only to the lower alder-willow and decadent willow ecophases; and "low" flood years flood only to the mature willow ecophase.) Mean sediment rates for each ecosite (from Table 4) were also used to calculate sediment volume (**Table 8**). Sediment volumes were converted to weight using a bulk density of 1.2 as suggested by Hirst et al. (1987) (**Table 8**).

Using this method, point bars had the highest sedimentation rates in Area 3 in a "high" flood year, 30 to 53% of the total volume using min-max rates and 54% using mean values (point bar rates were 3 to 5 times higher than lakeshores and 2 to 12 times higher than the delta plain even though they occupy <10% of the study area).

5.2 Areal Sedimentation Rates Using Mean Rates For Ecophases - "High" Flood Year

Using minimum-maximum values for each ecosite may inflate the amount of sediments actually received. For example, on point bars the highest rate of 20 cm occurred on lower mudflats which occupy <1% of the study area. On the other hand, the lowest rates (<1 cm) occurred within the mature willow, decadent willow, and alder-willow ecophases which can occupy about 10% of the area. Sediment volume and weight for the ecosites were recalculated for a "high" flood year (i.e. all ecophases flooded) using the proportional area each ecophase occupied on each ecosite estimated from the Area 3 ecophase map enlarged 200% (see [3] High Flood Year on **Table 9** and Figure 24). The lower mudflats and willow ecophases on point bars and channel levees had the highest sediment rates in the "high" flood year with 58% and 23% of the total sediment volume respectively (**Table 9**). The delta plain with its relatively larger area in Area 3 (26.3%) received only 3% of the total sediment volume.

5.3 Areal Sedimentation Rates Using Mean Rates For Ecophases - "High", Moderate", "Low" Floods

Using only deposition rates for "high" flood years will also inflate the measurement of overbank sedimentation. Breakup peaks in "low" and "moderate" flood years do not inundate all ecophases. For example, only the mudflat, horsetail, and pioneer willow ecophases on point bars in Area 3 would be flooded in both "low" (estimated as 3 years out of 10, on average) and "moderate" (6 years out of 10, on average) flood years. These ecophases <u>plus</u> the mature willow ecophase would be flooded in moderate flood years. The area that each ecophase occupied on the ecosites, estimated by visual examination of the enlarged study area ecophase map (Figure 24), was used to calculate overbank sedimentation (volume and weight) for <u>one</u> "high" flood year (e.g. 1982), <u>one</u> "moderate" flood year (e.g. 1983), and <u>one</u> "low" flood year (e.g. 1981) (**Table 9**). The total amount of sediment deposited onto the ecosites in "high" flood years (226,080 tonnes) was almost four times higher than during "low" flood years (56,760 tonnes) and 2.4 times higher than in "moderate" flood years (94,170 tonnes), but "high" floods may occur only once every 10 years or so.

Total sediment accumulation on the ecosites in Area 3 for one "high" flood event, six "moderate" flood events, and three "low" flood events, was calculated to give an estimate of **946,300 tonnes** of sediment deposited onto this delta surface over a 10-year period (or **94,600 tonnes/year**), 80% of which could be deposited into the Channel System (57% to point bars alone), 19% to the Lake System, and 1% onto the delta plain (**Table 10**). This rate is 1/2 to 3/4 of Hirst et al.'s estimates for Area 3.

5.4 Areal Sedimentation Mackenzie Delta

Hirst et al. (1987) provide an estimate of 64,000,000 to 153,000,000 tonnes that could be deposited onto the Mackenzie Delta every year. Area 3 occupies 12.4 km^2 or about 0.1% of the upper delta (approximately 10,000 km^2, Hirst et al. 1987). An estimated sedimentation rate of 94,600 tonnes/year was calculated for Area 3 (or about 7,600 tonnes/km^2/year) using methods slightly different from those of Hirst et al. Extending this rate to the entire upper delta gives an estimate of 76,000,000 tonnes/year, about 60% of Lewis's (1988) and Carson & Associates' (1993) estimated annual suspended sediment load delivered to the delta head of about 125,000,000 tonnes/year.

6.0 MAPPING SEDIMENTATION PATTERNS ON THE DELTA

An important goal of the NOGAP studies will be to estimate mean areal sedimentation rates on the Mackenzie Delta for input into sediment flux models. A method was described in Section 5.0 for calculating these rates based on sediment measurements in one middle delta study area. These calculations are complex and cumbersome and, given the variability in the sedimentation measurements and the comparatively small number of samples that have been made, may result in erroneous values.

Maps of overbank sedimentation may be a more efficient way to document and analyze the patterns of deposition over the delta. During the B C Hydro studies, aerial photographs flown in August 1980 were used to map ecosites (landform) and ecophases (plant community successional stages) within each study area. Because ecosites and ecophases reflect possibly unique relationships between delta landform, vegetation, and the hydrological regime, these maps are a useful base upon which to visually document sedimentation patterns.

6.1 Mapping Sedimentation Patterns Using Delta Ecophases

As explained in the previous section, min-max sedimentation rates for each ecophase, rather than for the ecosite it is associated with, should be used to calculate mean annual sedimentation rates, although this procedure makes the estimation of total overbank sedimentation quite cumbersome. As well, some ecophases are flooded only during "moderate" or "high" floods. Table 4 documents average annual sedimentation into delta ecophases based largely on stake measurements. Even though sedimentation varied quite a bit between and within study areas and from one year to another, general patterns are evident. These patterns were simplified into the following categories for all study areas and for all break-up events:

1 High sedimentation environments (5+ cm/yr) **(RED)**

- flooded every year

• mudflats (svm) on point bars (1a) and main channel levees (1b)

• willow-horsetail (S-E) on point bars (1a), sandbars (1d), and low closure levees (1b)

- horsetail (Eq) on channels (1a,1b) and some lakeshores (3a)

- mudflats and pendant grass (Ar) on delta lobes (2a)

2 <u>Moderate sedimentation environments (1-4.99 cm/yr)</u> **(ORANGE)**

- flooded every year

- mudflats and emergent on some lakeshores (3a), deltas (2a), and shoals (3b)

- willow-horsetail on distributary channel levees (2b)

- willow-sedge (S-C) on lakeshores (3a)

3 <u>Low sedimentation environments (0.5-0.99 cm/yr)</u> **(GREEN)**

- flooded only during moderate and high floods except emergent

- emergent on some lakeshores (3a)

- willow-horsetail on elevated point bar and channel levees (1a,1b,2b)

- alder-willow (A-S) on some channel levees (1b,2b,3c), point bars (1a), and the sand plain (1d)

4 <u>Very low sedimentation environments (<0.5 cm/yr)</u> **(BLUE)**

- flooded only during moderate and high floods

- alder-willow on elevated channel levees (1b,2b,3c), high closure lakeshores (3a), and the delta plain (4)

- decadent willow (S) on point bars (1a)

- spruce (Pi) on all ecosites except 5

- Richardson's willow (Sr) on all ecosites in the outer delta

5 <u>No sedimentation under present fluvial regime</u> **(LIGHT YELLOW)**

- not flooded

- spruce on xeric and hydric delta plain (5)

These five sedimentation environments were then mapped onto each study area ecophase map (Figures 25-31) using the colours given above. (Author's notes: Not all sedimentation environments were present in every study area. As well, the ecophase map for Area 5 in the outer delta covered only a very small part of the study area and excluded ecosites and ecophases on point bars that receive more sediment than other ecosites. *This study area should be remapped.*) Each "colour" was then measured with a hand-held planimeter to estimate the area occupied by each sedimentation environment in each study area (Table 11).

Not surprisingly, the Alluvial Islands of Middle Channel (Area 8, Figure 25) are dominated by high sedimentation environments (40% of the terrestrial surface). All of the other study areas, even in the outer delta, are dominated by very low sedimentation regimes (50-80% of the terrestrial surfaces). Areas 2 and 7 in the west delta, dominated by flows from Peel Channel and its distributaries, have fairly large areas (10% and 35% respectively) that do not receive any sedimentation at all, even during the high breakup floods. High sedimentation environments that receive relatively large amounts of new sediment each year could occupy only 5-15% of the delta surface if the study areas are truly representative of fluvial regimes throughout the delta. The delta plain and elevated channel and lakeshore levees, with low to very low sedimentation regimes, could, <u>in total</u>, contribute a significant portion of the areal sedimentation because these sites occupy most of the terrestrial surfaces of the delta.

Using the methods explained in Section 5.0, an estimate was made of the volume and weight of overbank sediments in the Area 3 study area using the ecophase sedimentation classes. These estimates were extended to the entire upper delta. The mid-points of each of the sedimentation classes, except for the "low" class, were used for sediment rates.

Sedimentation by ECOPHASE

(total land area: 12,375,000 m^2 - 5,816,250 m^2 water = 6,558,750 m^2)

Area (m^2)	Rate	Volume (m^3)	Weight (tonnes)
787,000	.075 m	59,000	70,800
524,700	.03 m	15,700	18,800
655,875	.008 m	5,200	6,200
4,591,125	.001 m	4,600	5,500
Total/yr:		**84,500**	**101,300**

These sedimentation rates would estimate an annual overbank sedimentation rate for the delta of **82,000,000 tonnes/year**, quite close to the estimate calculated in Section 5.0 (76,000,000 tonnes/year) and 66% of the sediment delivered to the delta head. Thus, this method could be used to map overbank sedimentation patterns over the delta and to calculate annual areal sedimentation rates.

6.2 Mapping Sedimentation Patterns Using Delta Plant Communities

Mapping overbank sedimentation rates using the ecophases should provide the most accurate documentation of sedimentation patterns. However, the mapping is very time-consuming and requires a knowledge of the often subtle differences in sedimentation rates between ecophases dominated by the same plants. For example, horsetail on a channel [Eq/1a or Eq/1b] and horsetail on a lakeshore [Eq/3a] occupy slightly different sedimentation environments on the Mackenzie Delta, as do alder-willow on lakeshores, point bars, or the delta plain. Nonetheless, the relationship between a particular plant community and the amount of sedimentation it receives is quite strong. This relationship could be used to map overbank sedimentation patterns by mapping the dominant plant communities, a much easier task than mapping ecophases.

The sedimentation data on Table 4 plus the 1992 data given on Tables 5 and 6 were simplified further (Table 12) into sedimentation classes defined by the plant communities (Table 13). As a test, Area 2 (Figure 27 using ecophases) was remapped using these classes (Figure 32, using plant communities only), resulting in shifts of +/-5% for every class but the "no flooding" class and a cumulative error of 25% (Table 14). This error may be too high for input to a sediment flux model for the delta. This method was tested further in Area 3.

Figure 33 shows Area 3 remapped using plant communities rather than ecophases. Table 15 shows a cumulative difference of almost 80% in the area occupied by the 5 sedimentation environments when mapping sedimentation patterns by ecophase or by plant community (both from aerial photographs), primarily because of alder-willow on the delta plain. Using the methods explained in Section 5.0, an estimate was made of the volume and weight of overbank sediments in the Area 3 study area and extended to the entire upper delta. The mid-points of each of the sedimentation classes, except for the "low" class, were used for sediment rates.

Sedimentation by Plant Community

(total land area: 12,375,000 m^2 - 5,816,250 m^2 water = 6,558,750 m^2)

Area (m^2)	Rate	Volume (m^3)	Weight (tonnes)
1,180,575	.075 m	88,600	106,300
787,000	.03 m	23,600	28,300
2,623,500	.008 m	21,000	25,200
1,967,625	.001 m	2,000	2,400
Total/yr:		**135,200**	**162,200**

These rates would estimate overbank sedimentation to the upper delta to be 1.3×10^8 tonnes/year! One of the reasons for this obvious over-estimation is that in most years sediment is received only at the lower elevations. In addition, only a few sites receive the high rates of sedimentation. As well, the area covered by low sedimentation environments using plant communities as the "indicators" is too high because of the quite different sedimentation environments that can be occupied by alder (see Table 15). Thus, mapping overbank sedimentation patterns on the delta using plant communities is not recommended.

6.3 Mapping Areal Sedimentation Patterns Using Satellite Data

Current aerial photographs are not available for most of the Mackenzie Delta, and extrapolating measurements from seven small study areas to the entire delta surface may be unrealistic. It may be possible to use satellite data to map sedimentation environments if ecophases can be identified by the satellite sensors. Satellite data is available on a regular basis, weather permitting, covers large areas, and is still reasonably inexpensive when compared to acquiring current aerial photography. Because satellite data can be purchased in digital format, satellite data can be used with computers for automated mapping of features of interest and merged with other digital data.

Landsat Thematic Mapper (TM) data for August 1987 for an area approximating the Area 3 study area (Figure 34a) were classified using wavebands 2 (green), 4 (near-infrared), and 5 (mid-infrared). (Author's note: the satellite data were not geometrically corrected.) The classes were compared to aerial photographs and the ecophase and plant community maps (Figures 30 and 33). Unfortunately, the classes related to dominant plant communities and were assigned labels that designated specific plant community/sedimentation regimes and water (Figure 34[b]). The area (in % and km^2) of each plant community was calculated by the image analysis software and compared to the areas calculated using ecophases and plant communities on aerial photographs (Table 15). Again, there were large areal differences between the "ecophase" maps and the satellite "plant community" maps which would lead to the same erroneous estimates of overbank sedimentation described in Section 6.2.

SPOT satellite data is collected at a ground resolution of 10m^2 and so might provide more details on the delta vegetation units. However,if "plant communities" rather than "ecophases" are detected, the improved resolution may offer few advantages.

7.0 RECOMMENDATIONS

Although there is a fairly good data base on sedimentation rates for some parts of the Mackenzie Delta, this data base is far from complete and more measures must be taken before a reliable sediment flux model for the delta can be developed. There is very little sedimentation information for the outer delta, primarily because of the problems associated with extensive flooding during the summer field season and the buildup of dense leaf litter tussocks around the plants within which sediment is deposited but cannot be extracted for measurement. Indeed, the Area 5 study area may not be completely typical of the outer delta, especially the west outer delta on the other side of Shallow Bay and the prograding lobes right at the Beaufort Sea. Similar problems have also occurred in some ecophases on lakeshores in the inner and middle delta in addition to the problems of such very small amounts of sediment being deposited that are almost impossible to measure.

7.1 Suggested Areas For New Sediment Measurements

Carson & Associates (1993) have suggested new study areas, in addition to the B C Hydro areas, along B C Hydro's photo-transects C (middle delta) and D (outer delta) (Figure 35). On transect C, B C Hydro Areas 3 and 4 lie on the east and west side of Middle Channel respectively. Area 3 is dominated by flows from the Mackenzie River via East and Middle Channels and their distributaries; Area 4 is dominated by flows from the Peel and Rat Rivers via Peel and West Channels. A new study area between the B C Hydro areas would be an important addition. Two new sampling areas have been recommended (Carson & Associates 1993) near Crooked Channel and Napoiak Channel along transect C (* on Figure 36). These locations would be midway between sediment sampling sites on Middle Channel to the south and on Reindeer Channel and East Channel to the north.

The aerial photographs flown by B C Hydro along this transect, with the exception of study areas 3 and 4, were not located, and no new photography in this area was flown in 1992. If the B C Hydro photographs or new photography become available, it should be an easy task to select two new study sites (preferably the same size as the B C Hydro study areas) and to map them using the ecological classification system developed for the delta by Cordes et al. (1984). The maps can then be used to select representative sites for both historical and future sediment sampling and to map overbank sedimentation patterns similar to Figures 25-31 in Appendix A.

Transect D follows a generally northeast direction across the outer delta from the Big Fish River near the Richardson Mountains in the west across Shallow Bay and Middle Channel to the Beaufort Sea (Figure 35). This transect includes Area 5 on Ellice-Langley Island, the area used during the B C Hydro studies. Reconnaissance and limited sampling by the author between 1987 and 1992 showed that this area may not represent all environments in the outer delta. Carson & Associates (1991,-1993) have suggested new study sites along the transect line northeast of Shallow Bay and closer to the sediment sampling sites southwest of Richards Island and the proposed hydrocarbon developments between Niglintgak Island, Big Lake, and Taglu Island. The additional sites sampled by the author during ground checks of satellite images are shown on Figure 36 with *'s. Two of these sites lie northeast of Shallow Bay and the Area 5 study area, very close to the Beaufort Sea, and are dominated by extensive willow-horsetail and sedge-cottongrass communities. Both of these sites appeared to have been flooded every year.

If time and budgets permit, it would be interesting to sample some areas in the outer delta west of Shallow Bay. Many locations there were not flooded in 1990, even sites right on Mackenzie Bay, and may not be flooded very often because the vegetation was dominated by dwarf birch, labrador tea, cloudberry, bog cranberry, and lichens and mosses, an assemblage more characteristic of upland tundra with species that do not withstand sedimentation. Although off transect D and far from sediment sampling stations, one or two new study sites in this area could provide interesting information for this part of the outer Mackenzie Delta. Additional sampling on the outer alluvial islands (e.g. Pitt, Tent, Olivier) could also provide useful information on sedimentation because the vegetation here is surprisingly well-developed (sedge, pendant grass, cottongrass, willow) for sites so far out into the Beaufort Sea. Some sedimentation measures were made during reconnaissance in 1990 on these islands, and only a cm or two appeared to have been deposited during flooding.

There is limited recent aerial coverage of this part of the delta except for Area 5. Once photography becomes available, the new study areas can be mapped (following the ecological land classification system developed for the delta), sampled, and analyzed.

7.2 Sediment Measurement

New sampling should concentrate on (but not be restricted to) ecophases associated with those ecosites for which there is insufficient or unreliable data from the B C Hydro studies: lakeshores, main channel levees, distributary channel levees, and connecting channel levees. A three-tiered sampling program is recommended for sampling overbank sedimentation:

Short-term sedimentation rates (annual)

1 The deposition of new alluvium onto fall leaf litter layers will provide the most accurate, reliable, and efficient way to estimate annual sedimentation

rates within the pioneer willow, mature willow, alder-willow, decadent willow, poplar, and spruce ecophases on all delta landform except in some willow communities in the outer delta which may be flooded all summer and which may have a tussocky sedge understorey.

2 Staking will provide the best way to estimate annual sedimentation rates within the mudflat, sparsely-vegetated, emergent (sedge, horsetail, pendant grass), and willow-tussock sedge ecophases. However, stake displacement because of freeze-thaw processes within saturated sediments must be measured and accounted for.

<u>Medium-term sedimentation rates (10 years)</u>

3 Staking, if carefully planned, will provide a reliable, cost-effective method for measuring sedimentation rates over a 10 year or longer period into all lower and middle elevation ecophases.

4 During the B C Hydro studies, all of the transects were surveyed to the nearest cm with a B-2 automatic level to permanent benchmarks. During the surveys, distances from survey point to survey point were measured. The soil surface around the survey stakes and the tops of the stakes were also surveyed. These surveys were not used to measure aggradation rates because on most sites the amount of new sediment that accumulated between 1980 or 1981 and 1983 was not enough to provide a reliable difference in elevation in relation to the bench mark. Resurveying some or all of these transects could provide very reliable data on mean sedimentation rates to particular elevations over a 12 yr+ time period. This time period now includes 2 "high" floods, 3 or maybe 4 "low" floods, and a number of "moderate" floods. The survey data may be most useful for high-deposition mudflats and sparsely-vegetated sites where other methods have not always provided reliable or consistent sediment data.

<u>Long-term sedimentation rates (30 years)</u>

5 Deep cores extracted from elevated terrestrial sites and analyzed using Cs-137 as a time marker offers a very promising method for measuring historical sedimentation patterns on the delta (see Carson & Associates 1993). However, the judicious selection of sites for coring will be necessary (see Section 7.3). The cores will also provide samples for contaminant analysis.

7.3 Detailed Field Methods

Once the new study areas in the middle and outer delta have been selected and mapped using the ecological land classification system developed for the delta by Cordes et al. (1984), field sampling can begin. A stratified-random sampling design, similar to that used in the B C Hydro studies, is recommended to take advantage of the land classification system and to reduce costs.

<u>Transect lines and sediment sampling</u>

1 Carry out aerial and field reconnaissance to select representative ecosites. The number of ecosites to be sampled will depend on time and budget constraints, but at least two sites should be used for those ecosites where there is a good database (e.g. point bars, deltas, shoals) and four sites where the database is insufficient (e.g. lakeshores, channel levees). Selected ecosites should represent all of the possible ecophases for that ecosite class.

2 Select transect line locations similar to those used during the B C Hydro studies (i.e. normal to channels and lakes). Ideally, transect lines could

cross several ecosites (e.g. point bar to delta plain to lakeshore) as long as the boundaries separating the ecosites are detectable. The transects should then be cut, identified, and marked. Transect lines should be 1-2 m wide. All transect line locations and the ecophases must be located on the aerial photographs.

3 Install benchmark on delta plain. Survey transect line, if possible, from the water to the bench mark, including ecophase boundaries, sampling locations, topographic changes, etc. If surveying is not possible, measure distances from the water to each ecophase boundary, to sampling areas, and to the benchmark.

4 Locate and mark sediment sampling areas beside the transect line at the boundaries of each ecophase and midway between the lower and upper boundaries. Note vegetation.

5 Before the 1993 (or 1994) breakup flood, install a network of sediment stakes within each ecophase sampling area along each transect. Stakes will measure both short-term (i.e.annual) and medium-term (i.e. 10 years) sedimentation rates. 2-3 m long reebar 2 cm in diameter should be pounded into the sediments to and within the permafrost layer, if possible, in a grid pattern. At least 5 stakes should be used within each sampling area if time and budgets permit. Paint each stake from the ground surface to the top of the stake with several layers of waterproof bright-coloured paint. Give each stake a unique identifier.

6 In late summer, measure new sedi ments deposited onto the previous year's leaf litter layer along each transect line and as close as possible to the stake sampling sites. Leaf litter samples will be present only in some pioneer willow ecophases and in the mature shrub and tree ecophases, if they have been flooded. At least 10 measures per site must be made. Surface samples can be collected for texture and contaminant analyses.

7 Note and mark the approximate location of flood height on each transect line.

<u>Deep core Cs-137 analyses</u>

Deep coring will be used to measure longer-term sedimentation rates onto the delta surface using Cs-137 as a "marker" from the 1963 radioactive fallout. Budget constraints will necessitate a limited coring program in each of the new study areas. The coring should complement the short- and medium-term sampling program described above. Core samples can also be used for texture and contaminant analyses.

8 Select 2-3 coring sites per study area on the transects being used for overbank sedimentation measurements (total 8-12).

9 Ideally, the coring sites should represent sedimentation rates for a variety of ecosites and ecophases and for all breakup peaks. However, this will not be possible because of time and budget constraints. Therefore, coring sites should be located within the lower mature willow-horsetail ecophase on a point bar, the lower alder-willow ecophase on a lakeshore, and the lower white spruce ecophase on the delta plain in the middle delta study areas. In this way, all of the major delta ecosites will be sampled and most of the flood regimes. This is because the willow ecophase should produce sedimentation information from most flood heights, the alder ecophase from moderate and high flood heights, and the spruce ecophase from high and record flood heights. Coring will be more difficult in the outer delta. Coring sites should be located in the extensive

sedge ecophase on upper lakeshores (most floods) because sedimentation has been very difficult to measure in this vegetation type, in the mature upper willow-horsetail ecophase on a point bar (to measure moderate floods), and in the mature Richardson's willow or alder ecophase on any site (to measure high floods).

7.4 Calculating Sediment Volume And Weight

Measurements of sediment volume and weight for input into a sediment flux model for the Mackenzie Delta must consider:

1. sedimentation rates into ecophases rather than ecosites
2. flood peak in relation to ecophases
3. areal extent of ecophases over delta
4. bulk density of different sediments
5. erosion rates on different ecosites and ecophases.

Table 8 showed the inflated mean areal sedimentation volumes and weights that may result from using minimum-maximum sedimentation rates for each ecosite rather than using rates for each ecophase on a particular ecosite type (Table 9). There is a good start to a database on sedimentation rates within different delta ecophases, but certainly more information is needed, particularly for those ecophases in lake systems and in all ecophases in the outer delta.

Table 9 also showed the differences in sedimentation rates within delta ecophases during "high", "moderate", and "low" flood events which must be considered in a sediment flux model for the delta. Flood peaks for different years in different parts of the delta may be able to be derived from stage measurements at Arctic Red River, Inuvik, and Aklavik for the inner and middle delta, but there is a lack of reliable information for the outer delta. Certain ecophases seem to mark "low", "moderate", and "high" floods (and perhaps "record" floods): the lowest elevations of the mature willow-horsetail, alder-willow, white spruce forest, and white spruce woodland ecophases respectively in the inner and middle delta; mature willow-horsetail, Richardson's willow-sedge, and alder in the outer delta). These ecophases can define the sediment model under a particular flooding regime.

Accurate areal measurements of all delta ecophases will be difficult to accomplish. Seven study areas on the Mackenzie Delta have been mapped in detail using ecosites and ecophases as the mapping units. However, each study area encompasses only 12 to 15km^2 (each less than 1% of the delta) and may not truly represent the spatial patterns of all ecophases throughout the delta, particularly in the vast outer delta. Nevertheless, these maps have been an excellent *starting point* for developing a methodology to estimate overbank deposition rates for the delta.

Mapping overbank sedimentation patterns based on five "sedimentation classes" (high, moderate, low, very low, and none) and then estimating the % area each class occupies of the terrestrial surface is a much easier task and seemed to provide a useful estimate of sediment rates for the middle delta. Maps like this were prepared for the B C Hydro study areas and should be completed for the new sampling areas, as well. With these additional maps, it should be possible to calculate overbank sedimentation rates for the inner delta, the middle delta, and the outer delta, and ultimately areal sedimentation for the entire Mackenzie Delta. It is possible that high resolution SPOT satellite data could be used to map delta ecophases to use as a surrogate for actual sedimentation measurements, particularly if this data can be combined with topographic data, but this has not yet been tested.

There is one problem, however, in using aerial photographs and satellite data--the very small areal extent of many of the ecophases at the lower and sometimes middle elevations. Many of the ecophases are difficult to see, let alone measure, on the photographs. These eco phases are often the ones that receive much of the sediment each year.

A bulk density of 1.2 was used to calculate all sediment weights. It appears that bulk density of overbank deposits on the Mackenzie Delta has not yet been measured for different sites, and this density may not be appropriate for all ecophases. Bulk density should be determined for the sediments depòsited onto major delta ecosites.

Some of the sediments deposited during the flood peak and, on lower elevations, throughout the open water season, are eroded during drawdown and storms and put in transport once again. This is a particular problem on point bars, low elevation channel levees, and some lakeshores. However, with the exception of some cutbank studies on Middle Channel, the quantities of these eroded sediments and where they end up have not been measured for different ecosites and ecophases on the Mackenzie Delta.

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APPENDIX A
(Tables and Figures Referred to in Text)

Figures

TABLE 1: Area[1] Occupied by Ecosites in the Mackenzie Delta Study Areas

Ecosite	Area 1[2]	Area 2	Area 3	Area 4	Area 7	Area 5	Area 8
Channel Systems:							
Point bars 1a	6.4%	6.1%	9.6%	5.1%	8.8%	0.5%	3.1%
Levees 1b	2.5%	2.8%	3.0%	1.5%	0.4%	-	9.3%
Arcuate depressions 1c	0.7%	0.1%	0.3%	0.2%	0.7%	-	-
Bars/sand plain	-	-	-	-	-	-	33.3%
Channel beds	8.4%	10.8%	13.7%	6.4%	4.7%	1.1%	54.3%
TOTAL	18.0%	19.8%	26.6%	13.2%	14.6%	1.6%	100.0%
Lake Systems:							
Lake deltas 2a	0.3%	0.1%	0.9%	4.2%	0.1%	-	-
Distributary channels 2b	3.1%	6.4%	1.6%	2.7%	4.9%	0.6%	-
Lakeshores 3a	9.9%	5.7%	10.4%	8.4%	7.0%	72.8%	-
Lake shoals 3b	0.1%	0.2%	1.0%	0.9%	0.1%	-	-
Connecting channels 3c	0.5%	0.4%	0.2%	0.4%	0.7%	-	-
Lake beds	23.1%	27.6%	33.0%	43.7%	31.3%	24.1%	-
TOTAL	37.0%	40.4%	47.1%	60.3%	43.4%	97.5%[3]	-
Delta Plain Systems:							
Mesic	45.0%	37.1%	26.3%	29.7%	21.4%	-	-
Hydric/Xeric	-	2.7%	-	-	21.0%	-	-
TOTAL	45.0%	39.8%	26.3%	29.7%	42.4%	-	-

[1] % of map area
[2] Areas 1,2,8 inner delta; Areas 3,4,7 middle delta; Area 5 outer delta
[3] Pingos cover 2% of Area 5

(Source: Cordes et al. 1984, Hirst et al. 1987)

Table 2: Characteristics of the major plant community types (Ecophases) in the hig subarctic coastal plain (Blachut et. al., 1985; Pearce and Cordes, 1985;Pearce, 1986 synthesized in Hirst et sl.(1987). (from Boyes, 1991)

Plant Community	Location	Flood Frequency (/10 years)	Flood Duration (days/yr)	Sedimentation Rate (cm/yr)	Colonization Method	Active Layer Depth (cm)	Age (years)
<u>Emergent</u>							
Horsetail, Sedge, Pendent Grass	Point bars arcuate depressions basin deltas distributary channels basin shores basin shoals connecting channels	high (10)	high (15-85)	moderate to high (0.5-20)	rhizomes, fragmentation, adventitious roots	60-150	?
<u>Shrubs</u>							
Arctic Willow	arcuate depressions basin deltas basin shores basin shoals connecting channels	low to moderate (2-6)	low (0-28)	low to moderate (0-6.5)	seeds, stump suckers	60-175	17-60
Feltleaf Willow	point bars alluvial sand plains distributary channels	low to moderate (2-6)	low (0-40)	moderate to high (0-20)	seeds, stump suckers	60-200	1-50
Alder	point bars alluvial sand plain distributary channels basin shores basin shoals connecting channels	low to moderate (2-6)	low (0-2)	low (0-2.5)	seeds, stump suckers	64-112	20-60
<u>Trees</u>							
Balsam Poplar	point bars alluvial sand plain distributary channels	low (1-2)	low (0-2)	low to very low (0-0.5)	seeds	79-140	50-200
White Spruce Forest	point bars distributary channels basin shores delta plain	low (0-2)	low (0-2)	very low (0-0.2)	seeds	17-114	150-400
White Spruce/ Lichen Woodland	delta plain	very low (0)	very low (0)	none	seeds	15-55	250-475

TABLE 3: Breakup Flood Peaks and Dates, East Channel at Inuvik

Year	Stage[1]	Date
1981	15.080 m	May 23
1982	16.696 m	June 3
1983	16.202 m	June 6
1987	15.703 m	June 3
1988	15.404 m	May 29
1989	16.127 m	May 31
1991	15.526 m	May 24
1992	16.680 m	June 5

[1] maximum instantaneous except for 1982 which is mean daily stage

Source: Water Survey of Canada, Inuvik, N.W.T.

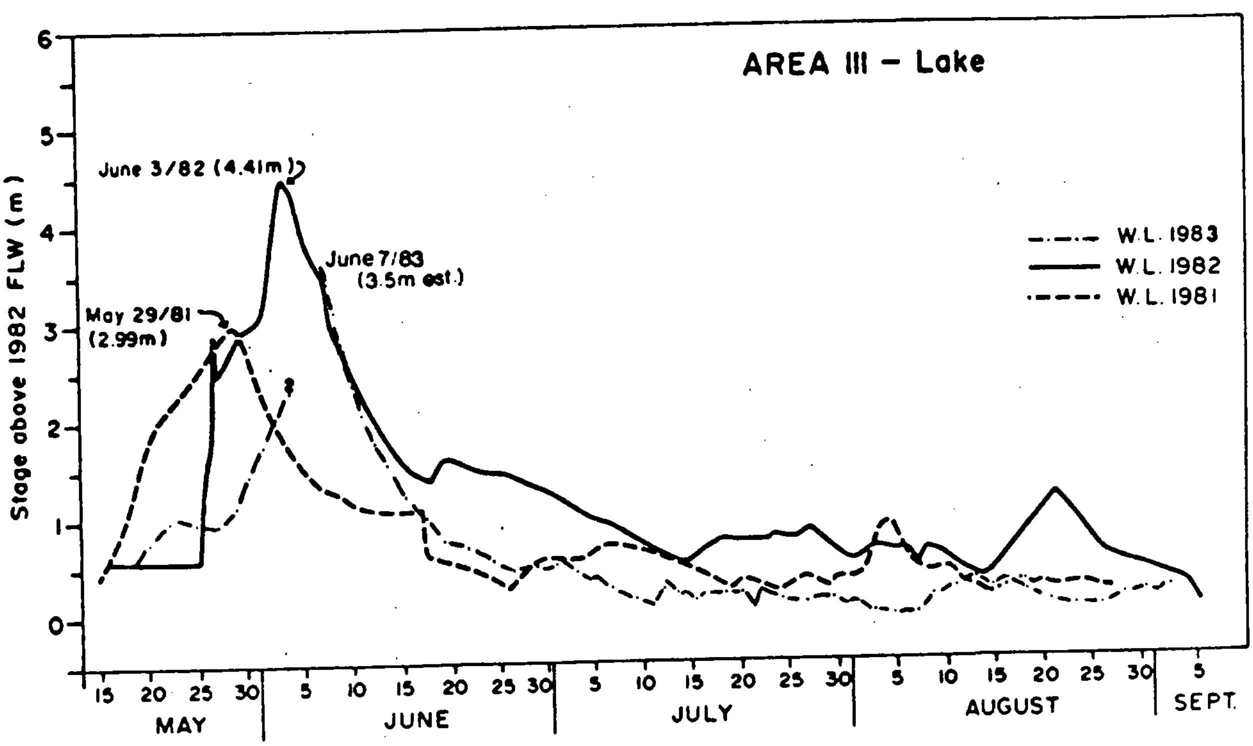


TABLE 4: Mean Sedimentation in 1981, 1982, and 1983, by Ecophase Inner, Middle, and Outer Mackenzie Delta (based on stake measurements)

	1981 ("Low"[1][2])	1982 ("High") (cm/yr)	1983 ("Moderate")
POINT BAR (1A):			
Inner Delta			
Mudflats	?	15.3 (n=9, SD=7.6)	2.5 (n=2)
Pioneer Willow	15	60.0 (n=1)	4.7 (n=3, SD=4.9)
Mature Willow	0	9.5 (n=3, SD=6.1)	0.5 (n=2)
Alder	0	1.0 (n=2)	1.3 (n=4, SD=1.4)
Poplar	0	1.0 (n=2)	0 (n=1)
Spruce	0	0.5 (n=2)	0 (n=1)
Mean Point Bar:	?	11.9 (n=19, SD=14.2)	1.8 (n=14, SD=2.7)
Middle Delta			
Horsetail	?	9.5 (n=6, SD=4.6)	6.0 (n=2)
Mudflats	20	15.7 (n=20, SD=5.9)	8.1 (n=9, SD=5.3)
Pioneer Willow	7	12.0 (n=14, SD=4.9)	6.7 (n=10, SD=4.6)
Mature Willow	0	6.0 (n=16, SD=3.4)	2.6 (n=10, SD=2.3)
Decadent Willow	0	0.6 (n=9, SD=0.6)	0.7 (n=3, SD=0.6)
Alder	0	0.8 (n=10, SD=0.9)	0.1 (n=3, SD=0.17)
Poplar	0	0.1 (n=1)	0.3 (n=3, SD=0.2)
Mean Point Bar:	?	8.5 (n=76, SD=7.1)	4.4 (n=40, SD=4.6)
Outer Delta			
Mudflats	4	13.0 (n=2)	4.0 (n=3, SD=3.5)
Pioneer Willow	1	7.0 (n=2)	1.5 (n=2)
Mature Willow (Sa)	0	4.0 (n=3, SD=4.1)	3.5 (n=2)
Mature Willow (Sr)	0	0.3 (n=3, SD=0.15)	0.01 (n=2)
Alder	0	0.01 (n=1)	0 (n=1)
Mean Point Bar:	1	5.34 (n=11, SD=4.9)	2.4 (n=10, SD=2.6)

TABLE 4 contd.

	1981 ("Low"[1][2])	1982 ("High") (cm/yr)	1983 ("Moderate")
MAIN CHANNEL LEVEE (1B):			
Inner Delta			
Mudflats	10	?	?
Pioneer Willow	?	13.0 (n=1)	6.0 (n=7, SD=5.6)
Mature Willow	?	10.0 (n=1)	1.7 (n=3, SD=0.6)
Middle Delta			
Mudflats	?	17.0 (n=2)	3.5 (n=2)
Horsetail	?	11.0 (n=4, SD=6.8)	2.9 (n=8, SD=1.4)
Pioneer Willow	2	6.3 (n=3, SD=1.5)	3.3 (n=3, SD=3.2)
Mature Willow	0	10.0 (n=2)	2.0 (n=2)
Alder	0	0.15 (n=2)	0.8 (n=4, SD=1.1)
Mean Levee:	?	7.4 (n=16, SD=7.7)	2.5 (n=19, SD=1.9)
LAKE DELTA (2A):			
Middle Delta			
Mudflats	?	1.5 (n=7, SD=1.7)	0.8 (n=8, SD=0.9)
Pendant Grass	?	6.6 (n=12, SD=4.6)	0.75 (n=13, SD=0.8)
Sedge	?	0.3 (n=2)	1.5 (n=9, SD=1.5)
Willow w/horsetail	0	5.8 (n=3, SD=4.6)	2.5 (n=1)
Willow w/sedge	0	7.0 (n=1)	2.3 (n=4, SD=1.3)
Mean Delta:	?	4.5 (n=26, SD=4.2)	0.9 (n=41, SD=1.1)
DISTRIBUTARY CHANNEL LEVEE (2B):			
Middle Delta			
Horsetail/sedge	?	10.7 (n=3, SD=5.1)	6.5 (n=2)
Mature Willow	0	4.0 (n=2)	4.8 (n=3, SD=1.8)
Mean Levee:	?	8.0 (n=5, SD=5.2)	5.5 (n=5, SD=1.9)
Outer Delta			
Pendant Grass	?	?	?
Sedge	?	2.0 (n=1)	2.0 (n=1)
Mature Willow (Sa)	?	?	0.35 (n=3, SD=0.05)

TABLE 4 contd.

	1981	1982	1983
LAKESHORE (3A):			
Middle Delta			
Horsetail	?	1.8 (n=5, SD=1.8)	2.0 (n=2)
Sedge	?	2.1 (n=7, SD=1.8)	1.4 (n=11, SD=1.2)
Mudflats	0.5	?	3.0 (n=2)
Pioneer Willow	?	3.0 (n=1)	1.5 (n=1)
Mature Willow	1.0	3.6 (n=4, SD=2.5)	2.5 (n=3, SD=2.2)
Alder	0	0.1 (n=1)	0.1 (n=1)
Mean Lakeshore:	?	2.4 (n=17, SD=1.9)	1.7 (n=21, SD=1.4)
Outer Delta			
Pendant Grass	?	?	?
Sedge	?	2.5 (n=1)	2.5 (n=1)
Willow (Sa)	0	0.5 (n=2)	0.2 (n=2)
LAKE SHOALS (3B):			
Middle Delta			
Mudflats	?	4.5 (n=10, SD=4.7)	1.8 (n=15, SD=2.9)
Pendant Grass	?	2.6 (n=2)	0.4 (n=4, SD=0.5)
Sedge	?	3.0 (n=1)	2.0 (n=2)
Pioneer Willow	?	0.3 (n=3, SD=0.2)	0.06 (n=5, SD=0.09)
Mean Shoals:	?	4.5 (n=10, SD=4.7)	1.3 (n=26, SD=2.5)
CONNECTING CHANNEL LEVEES (3c):			
Middle Delta			
Mudflats	?	5.3 (n=3, SD=1.5)	?
Pioneer Willow	?	?	?
Mature Willow	0	0.2 (n=1)	?
Alder	0	0.1 (n=2)	?
DELTA PLAIN (4,5):			
Inner Delta			
Spruce 4	0	0 (n=5)	0 (n=5)
Spruce 5	0	0	0
Middle Delta			
Spruce 4	0	0.4 (n=8, SD=0.6)	0 (n=5)
Spruce 5	0	0	0

TABLE 4 contd.

		1981	1982	1983
ALLUVIAL ISLANDS - AREA 8 (1D)[3]:				
Horsetail	-	6 cm (n=2)		
Pioneer willow	-	4 cm (n=45,SD=6.46		
Mature willow	-	4 cm (n=23,SD=3.0)		
Alder	-	0.6 cm (n=11,SD=0.6)		

[1] "Low", "moderate", "high" relate to author's criteria for flood peaks in study areas.

[2] Stakes were not put in until after the flood peak in 1981. Sedimentation measures for 1981 are from Hardy & Associates (1982), Cordes et al. (1984), and direct sampling.

[3] Measured in 1982 and 1983 from plant initiation depths.

Source: Pearce 1986 and unpublished data, Cordes et al. 1984, and Hardy Associates 1982.

TABLE 5: Sedimentation Measurements[1] in Area 3, Middle Delta, and Area 5, Outer Delta, 1992

	Sample Size	Mean (cm)	Standard Deviation
AREA 3			
POINT BAR			
Mudflats	3	31.7	2.9
Pioneer willow (lower)	5	19.8	3.6
Pioneer willow (upper)	5	8.2	4.0
Mature willow (lower)	9	5.3	2.8
Mature willow (upper)	6	0.4	0.1
Poplar	7	1.9	1.6
Decadent willow	12	0.2	0.2
Mean Point Bar	58	6.1	9.2
LAKESHORE			
Sedge	1	10.0	-
Mature willow-sedge	1	1.3	-
Alder	3	0.3	0.2
Mean Lakeshore	5	2.4	4.3
DELTA PLAIN			
Spruce	10	0.18	0.15
AREA 5			
POINT BARS			
Pioneer willow	2	8.0	-
Mature willow (Sa)	2	4.0	-
Mature willow (Sr)	2	0.4	-
Mean Point Bar	6	4.1	-

(1) Estimated from burial depths of autumn 1991 leaf litter

Source: Pearce, unpublished data

TABLE 6: Sedimentation Measurements[1] in "Test" Area, Big Channel, Middle Delta near Inuvik, 1992

	Sample Size	Mean (cm)	Standard Deviation
POINT BAR			
Pioneer willow	5	16.8	2.2
Mature willow	5	4.7	2.6
Alder (lower)	4	3.8	0.3
Alder (upper)	3	0.2	0.1
Spruce	5	0.1	0.05
Mean Point Bar	22	5.1	6.9
LAKESHORE			
Sedge	4	0.3	0.08
Willow with sedge	5	0.05	0.02
Alder	6	0.04	0.05
Spruce	4	0.01	0.005
Mean Lakeshore	19	0.1	0.12
DELTA PLAIN			
Spruce	5	0.04	0.03
DISTRIBUTARY CHANNEL			
Horsetail	1	10.0	-
Mature willow	3	12.3	2.5
Alder	3	9.5	0.5
Mean Distributary Channel	6	10.6	2.0
LAKE DELTA			
Sedge	5	6.6	2.7
Pioneer willow	3	14.8	4.5
Mature willow	4	3.5	0.6
Mean Lake Delta	12	6.9	11.9

[1]Estimated from burial depths of autumn 1991 leaf litter

Source: Pearce, unpublished data

TABLE 7: Area Occupied by Ecosites in Area 3

Ecosite	% of Area	m^2
Total area	100.0	12,375,000
Point bars 1a	9.6	1,188,000
Arcuate depressions 1c	0.3	37,125
Main Channel Levees 1b	3.0	371,250
Lake deltas 2a	0.9	111,375
Distributary channels 2b	1.6	198,000
Lakeshores 3a	10.4	1,287,000
Lake shoals 3b	1.0	123,750
Connecting channels 3c	0.2	24,750
Delta plain 4	26.3	3,254,625
Water	53.3	6,595,875

Source: Cordes et al. 1984

TABLE 8: Areal Sedimentation, Area 3, Mackenzie Delta, Using Minimum-Maximum and Mean Rates for Ecosites, "High" Flood Year[1] [2]

SEDIMENTATION RATE (m/yr)	VOLUME (m^3)	WEIGHT (Tonnes)
Point Bars 1a and Arcuate Depressions 1c (1,225,125 m^2):		
.005 - .2 m/yr (min-max)	6,100 - 245,000	7,300 - 294,000
.09 m/yr (mean)	110,300	132,400
Stable Channel 1b and Distributary 2b Levees (569,250 m^2):		
.008 - .17 m/yr (min-max)	4,500 - 96,700	5,400 - 116,000
.075 m/yr (mean)	42,700	51,200
Lakeshores 3a (1,287,000 m^2):		
.001 - .065 m/yr (min-max)	1,300 - 83,700	1,600 - 100,400
.02 m/yr (mean)	25,700	30,800
Lake Deltas 2a and Shoals 3b (235,125 m^2):		
.002 - .065 m/yr (min-max)	500 - 15,300	600 - 18,400
.045 (mean)	10,600	12,700
Connecting Channels 3c (24,750 m^2):		
0 - .05 m/yr (min-max)	0 - 1,200	0 - 1,400
.02 m/yr (mean)	500	600
Delta Plain 4 (3,254,625 m^2):		
.001 - .005 m/yr (min-max)	3,300 - 16,300	4,000 - 19,600
.004 (mean)	13,000	15,600
TOTALS (one "high" year) -		
min-max:	20,800 - 458,200	25,000 - 549,800
mean:	202,800	243,300

[1] See text for author's criterion for "high" flood.
[2] All volume and weight values rounded to nearest hundred.

TABLE 9: Mean Sediment Volume and Weight[1] by Ecosite and Ecophase for Low, Moderate, and High Flood Years, Area 3, Mackenzie Delta

Sedimentation Rate (m/yr)		Volume (m^3)	Weight (Tonnes)
POINT BARS (1,225,125 m^2):			
(1) Low Flood Year (e.g. 1981)			
Lower mudflats .2 m/yr	(98,010)[2]	19,600	23,500
Upper mudflats .05 m/yr	(85,759)	4,300	5,200
Pioneer willow .07 m/yr	(122,513)	8,600	10,300
Total Low:		32,500	39,000
(2) Moderate Flood Year (e.g. 1983)			
Lower mudflats .2 m/yr	(98,010)	19,600	23,500
Upper mudflats .08 m/yr	(85,759)	6,700	8,000
Pioneer willow .07 m/yr	(122,513)	8,600	10,300
Mature willow .02 m/yr	(306,281)	6,100	7,300
Total Moderate:		41,000	49,100
(3) High Flood Year (e.g. 1982)			
Lower mudflats .2 m/yr	(98,010)	19,600	23,500
Upper mudflats .15 m/yr	(85,759)	12,900	15,500
Pioneer willow .12 m/yr	(122,513)	14,700	17,600
Mature willow .06 m/yr	(306,281)	18,400	22,100
Decadent willow/alder .07 m/yr	(612,563)	42,900	51,500
Total High:		108,500	130,200
CHANNEL LEVEES (569,250 m^2)[3]:			
(1) Low Flood Year			
Mudflats .03 m/yr	(142,313)	4,300	5,200
Willow .01 m/yr	(213,469)	2,100	2,500
Total Low:		6,400	7,700
(2) Moderate Flood Year			
Mudflats .05 m/yr	(142,313)	7,100	8,500
Willow .03 m/yr	(426,938)	12,800	15,400
Total Moderate:		19,900	23,900

TABLE 10: Estimated Total Areal Sedimentation[1] in 10-Year Period[2], Area 3 (12,375,000 m^2), Mackenzie Delta

Ecosite	Volume (m^3)	Weight (Tonnes)
Point bars	452,000	541,800
Channel levees	182,700	219,400
Lakeshores	119,500	128,900
Lake deltas and shoals	40,700	48,400
Connecting channel levees	1,550	1,900
Delta Plain	4,900	5,900
Total:	801,400	946,300
Mean Annual:	80,100	94,600

[1]Volume and weight rounded off to nearest hundred.
[2]Includes ONE "high" flood year, SIX "moderate" flood years, and THREE "low" flood years (see text for author's criteria).

TABLE 11: Areal Extent of Overbank Sedimentation by Rate, Mackenzie Delta Study Areas (based on ecophases interpreted from aerial photographs)

		% of Terrestrial Surface
INNER DELTA		
Area 8 - Alluvial Islands		
High (5+cm/yr)	-	40%
Moderate (1-4.99 cm/yr)	-	5%
Low (0.5-0.99 cm/yr)	-	55%
Very low (<0.5 cm/yr)	-	0%
None	-	0%
Area 1		
High	-	12%
Moderate	-	8%
Low	-	15%
Very low	-	65%
None	-	0%
Area 2		
High	-	10%
Moderate	-	0%
Low	-	20%
Very low	-	60%
None	-	10%
MIDDLE DELTA		
Area 7		
High	-	10%
Moderate	-	10%
Low	-	0%
Very low	-	45%
None	-	35%
Area 4		
High	-	5%
Moderate	-	10%
Low	-	5%
Very low	-	80%
None	-	0%

TABLE 11 contd.

		% of Terrestrial Surface
Area 3		
High	-	12%
Moderate	-	8%
Low	-	10%
Very low	-	70%
None	-	0%
OUTER DELTA		
Area 5		
High	-	0%[1]
Moderate	-	35%
Low	-	0%
Very low	-	65%
None	-	0%[2]

(1) High sedimentation point bars are not in area shown on Figure 31

(2) Pingos in the outer delta do not receive sedimentation but are not in the area shown on Figure 31

TABLE 12: Average Sedimentation Rates by Plant Community (all areas, all ecosites, all years, all methods)

<u>Mudflats and Herbs:</u>		
Sparsely vegetated mudflats (svm)	-	6.0 cm/yr (n=145,SD=5.23)
Horsetail (Eq)	-	5.0 cm/yr (n=46,SD=4.6)
Sedge (C)	-	2.6 cm/yr (n=57,SD=1.7)
Pendant grass (Ar)	-	2.0 cm/yr (n=51,SD=2.6)
<u>Shrubs:</u>		
Pioneer willow-horsetail (S-E)	-	10.2 cm/yr (n=101,SD=17.8)
Mature willow-horsetail (S-E)	-	5.0 cm/yr (n=109,SD=3.3)
Mature willow-sedge (S-C)	-	2.0 cm/yr (n=24,SD=1.8)
Decadent willow (S)	-	0.6 cm/yr (n=24,SD=0.25)
Alder-willow (A-S)	-	0.5 cm/yr (n=57,SD=0.5)
Mature willow-horsetail and Mature willow-sedge (Sr-E/C)	-	0.2 cm/yr (n=6,SD=0.05)
Alder in outer delta (A)	-	0.1 cm/yr (n=2)
<u>Trees:</u>		
Poplar (Po)	-	0.3 cm/yr (n=14,SD=0.5)
White spruce (Pi4)	-	0.2 cm/yr (n=67,SD=0.24)
White spruce (Pi5)	-	0
Black spruce-tamarack (Pi5)	-	0

Source: Cordes et al. 1984, Pearce 1986

TABLE 13: Sedimentation Classes Using Plant Communities

High annual sedimentation (5 cm+) (RED)[1]:

- flooded every year

mudflats (svm)
horsetail (Eq)
pioneer willow-horsetail (S-E)
mature willow-horsetail (S-E)

Moderate annual sedimentation (1-4.99 cm) (ORANGE):

- flooded every year

pendant grass (Ar)
sedge (C)
willow-sedge (S-C)

Low annual sedimentation (0.5-0.99 cm) (GREEN):

- flooded every 3-5 years

alder-willow (A-S)
poplar (Po)
decadent willow (S)

Very low annual sedimentation (<0.5 cm) (BLUE):

- flooded every 5-10+ years

mature willow-horsetail (Sr-E)
mature willow-sedge in outer delta (Sr-C)
alder in outer delta (A)
spruce (Pi4)

No annual sedimentation (LIGHT YELLOW):

spruce (Pi5)

[1]Colour on Figures 25-32

Source: Cordes et al. 1984, Pearce 1986

TABLE 14: Comparison of Areal Measures of Sedimentation in **Area 2** Using Ecophases or Plant Communities

Sedimentation Environment	Ecophase	Plant Community	Difference
High (5+ cm/yr)	10%	15%	+5%
Moderate (1-4.99 cm/yr)	0%	5%	+5%
Low (0.5-0.99 cm/yr)	20%	15%	-5%
Very Low (<0.5 cm/yr)	60%	55%	-5%
None	10%	10%	0

TABLE 15: Comparison of Areal Measures of Overbank Sedimentation in **Area 3** Using Ecophases or Plant Communities from Aerial Photographs and Plant Communities from Landsat TM Satellite Data

(a)

Sedimentation Environment	Aerial Photos: Ecophase	Aerial Photos: Plant Community	Difference
High (5+ cm/yr)	12%	18%	+ 6%
Moderate (1-4.99 cm/yr)	8%	12%	+ 4%
Low (0.5-0.99 cm/yr)	10%	40%(1)	+30%
Very low (<0.5 cm/yr)	70%(1)	30%(2)	-40%
None	0%	0%	0%

(1) Many alder-willow (A-S) ecophases (e.g. on the delta plain) were included in the very low category. These ecophases shift to the low category when mapping plant communities.
(2) Includes only the spruce communities.

(b)

Sedimentation Environment	Satellite Data	Difference Ecophase	Difference Community
High (5+ cm/yr)	19.6%	+7.6%	+1.6%
Moderate (1-4.99 cm/yr)	0[1]	-8.0%	-12%
Low (0.5-0.99 cm/yr)	49.1%	+39%	+9%
Very low (<0.5 cm/yr)	31.3%[2]	-39%	+1.3%

[1]Could not be detected on the Landsat TM data as vegetation zones are too narrow.
[2]Includes only the spruce communities.

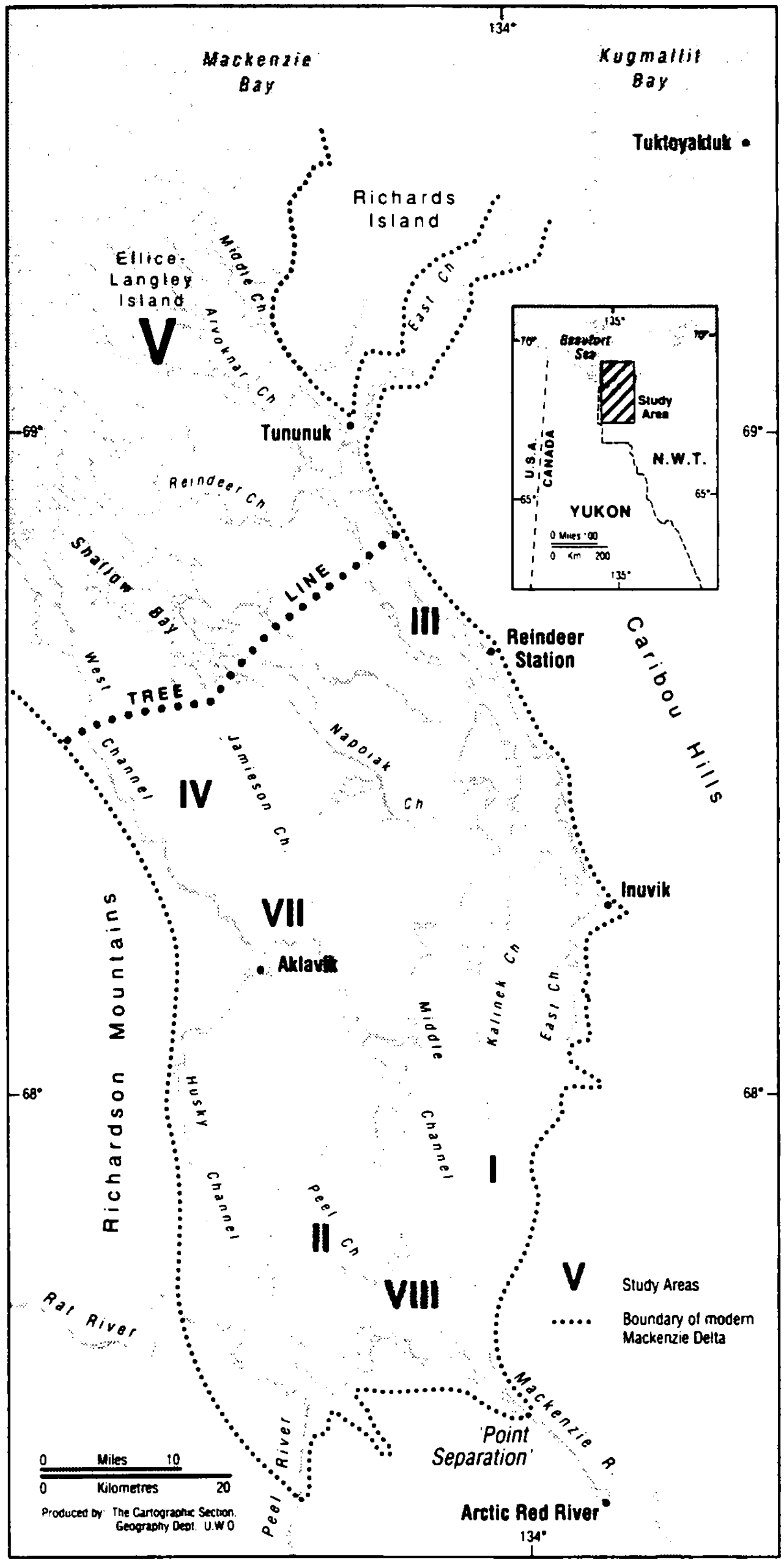


Figure 1: Mackenzie Delta study areas

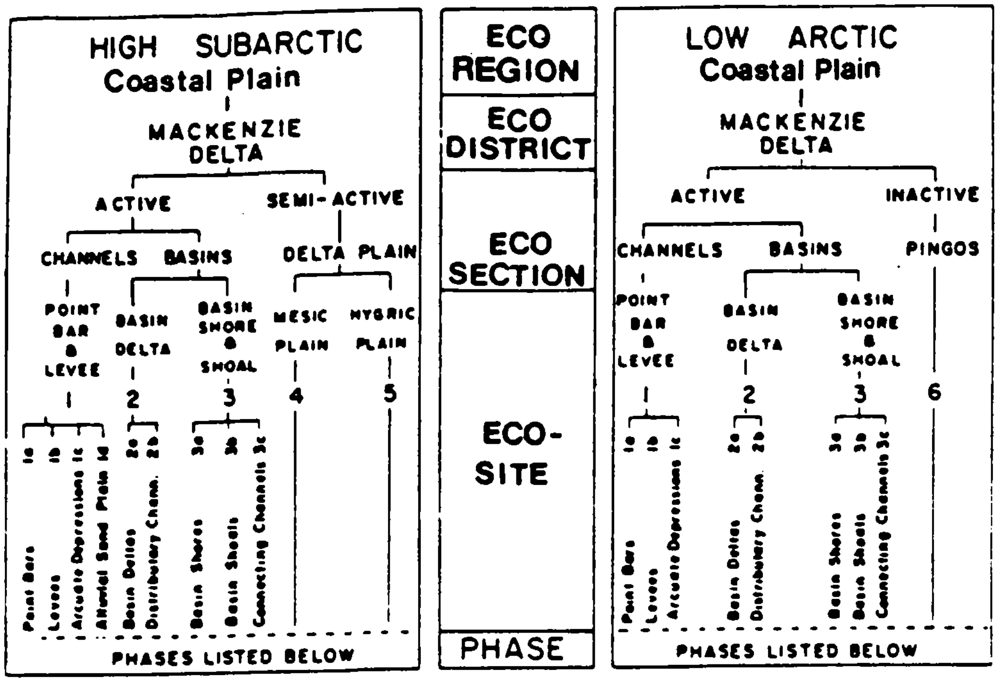
b

a

Figure 2(a): Using leaf litter layers to measure annual sediment deposition

Figure 2(b): Using survey stakes to measure annual sediment deposition

Figure 3: **ECOLOGICAL LAND CLASSIFICATION SYSTEM FOR THE MACKENZIE DELTA**



POINT BARS 1a	LEVEES 1b	ARCUATE DEPRESSION 1c	ALLUVIAL SAND PLAIN 1d	BASIN DELTAS 2a	DISTRIBUTARY CHANNELS 2b
svm Eq/E S-E S A-S Po Pi	cb svm Eq/E C S-C S-E S A-S Po Pi	C S-C	svm svs S-E S A-S Po	svm Eq Ar C S-C	cb svm Eq/E C S-E S A-S Po Pi

	BASIN SHORES 3a	BASIN SHOALS 3b	CONNECTING CHANNELS 3c	MESIC PLAIN 4	HYGRIC PLAIN 5
	svm Eq C S-C S A-S	svm Eq Ar C S-C	svm Eq C S-C S A-S	A-S Pi	Pi

LEGEND

cb cutbank complex
svm sparsely vegetated mudflat
svs sparsely vegetated sandflat
Eq/E Equisetum
Ar Arctophila
C Carex
S-C Salix - Carex
S-E Salix - Equisetum (arvense)
S Salix
A-S Alnus - Salix
Po Populus
Pi Picea

POINT BARS 1a	LEVEES 1b	ARCUATE DEPRESSION 1c	BASIN DELTAS 2a	DISTRIBUTARY CHANNELS 2b
svm Ar S-E Sr-E Sr-As	cb S-E Sr-E Sr-C Sr-As	C-Er C-Ag Sr-C	Not found in study area	C-Er S-E Sr-E Sr-C Sr-As

BASIN SHORES 3a	BASIN SHOALS 3b	CONNECTING CHANNELS 3c	PINGOS 6	
svm Ar C-Er C-Ag Sr-C Sr-E Sr-As A	not found in study area		Sr-As A	

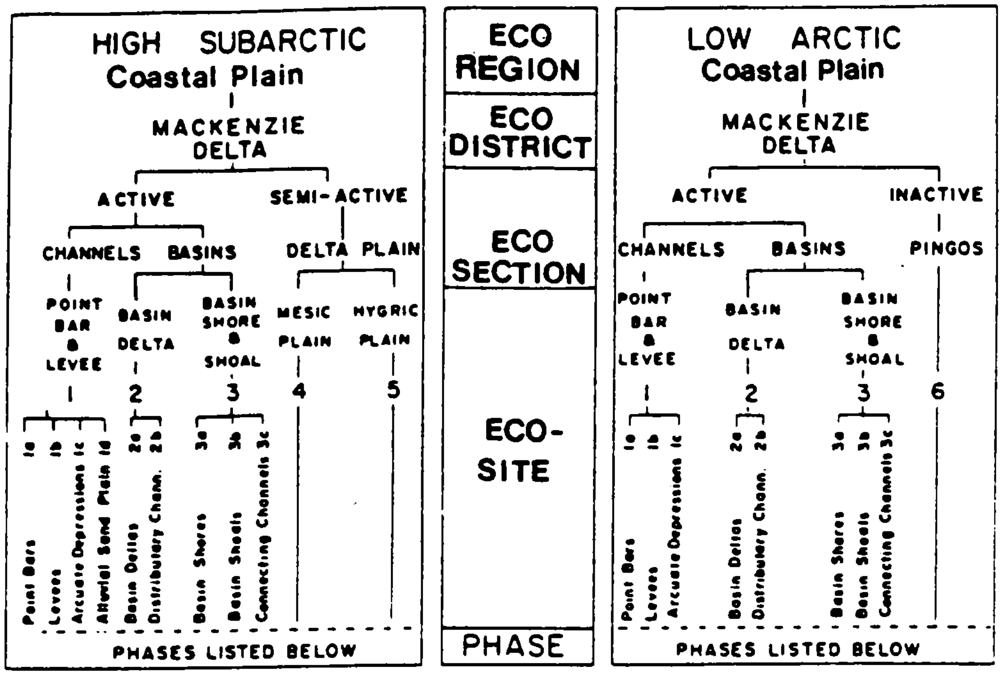
LEGEND

cb cutbank complex
svm sparsely vegetated mudflat
Ar Arctophila
C-Er Carex-Eriophorum[1]
C-Ag Carex-Arctagrostis[1]
S-E Salix - Equisetum (arvense)
Sr-C Salix richardsonii - Carex[2]
Sr-E Salix richardsonii - Equisetum[2] (arvense)
Sr-As Salix richardsonii - Arctostaphylos[2]
A Alnus

1 Sub-associations of Carex phase
2 Sub-associations of Salix richardsonii phase

Source: Cordes et al. 1984

ECOLOGICAL LAND CLASSIFICATION SYSTEM FOR THE MACKENZIE DELTA



High Subarctic

POINT BARS 1a	LEVEES 1b	ARCUATE DEPRESSION 1c	ALLUVIAL SAND PLAIN 1d	BASIN DELTAS 2a	DISTRIBUTARY CHANNELS 2b
svm Eq/E S-E S A-S Po Pi	cb svm Eq/E C S-C S-E S A-S Po Pi	C S-C	svm svs S-E S A-S Po	svm Eq Ar C S-C	cb svm Eq/E C S-E S A-S Po Pi
	BASIN SHORES 3a	BASIN SHOALS 3b	CONNECTING CHANNELS 3c	MESIC PLAIN 4	HYGRIC PLAIN 5
	svm Eq C S-C S A-S	svm Eq Ar C S-C	svm Eq C S-C S A-S	A-S Pi	Pi

LEGEND

cb	cutbank complex	S-E	Salix - Equisetum (arvense)
svm	sparsely vegetated mudflat	S	Salix
svs	sparsely vegetated sandflat	A-S	Alnus - Salix
Eq/E	Equisetum	Po	Populus
Ar	Arctophila	Pi	Picea
C	Carex		
S-C	Salix - Carex		

Low Arctic

POINT BARS 1a	LEVEES 1b	ARCUATE DEPRESSION 1c	BASIN DELTAS 2a	DISTRIBUTARY CHANNELS 2b
svm Ar S-E Sr-E Sr-As	cb S-E Sr-E Sr-C Sr-As	C-Er C-Ag Sr-C	Not found in study area	C-Er S-E Sr-E Sr-C Sr-As
BASIN SHORES 3a	BASIN SHOALS 3b	CONNECTING CHANNELS 3c	PINGOS 6	
svm Ar C-Er C-Ag Sr-C Sr-E Sr-As A	not found in study area	not found in study area	Sr-As A	

LEGEND

cb	cutbank complex	Sr-C	Salix richardsonii - Carex[2]
svm	sparsely vegetated mudflat	Sr-E	Salix richardsonii - Equisetum[2] (arvense)
Ar	Arctophila		
C-Er	Carex - Eriophorum[1]	Sr-As	Salix richardsonii - Arctostaphylos[2]
C-Ag	Carex - Arctagrostis[1]		
S-E	Salix - Equisetum (arvense)	A	Alnus

1 Sub-associations of Carex phase
2 Sub-associations of Salix richardsonii phase

- ▲ Benchmarks
- A—— Surveyed Transect
- Channels
- Numbered Lakes
- ★ camera

Source: Cordes et al. 1984

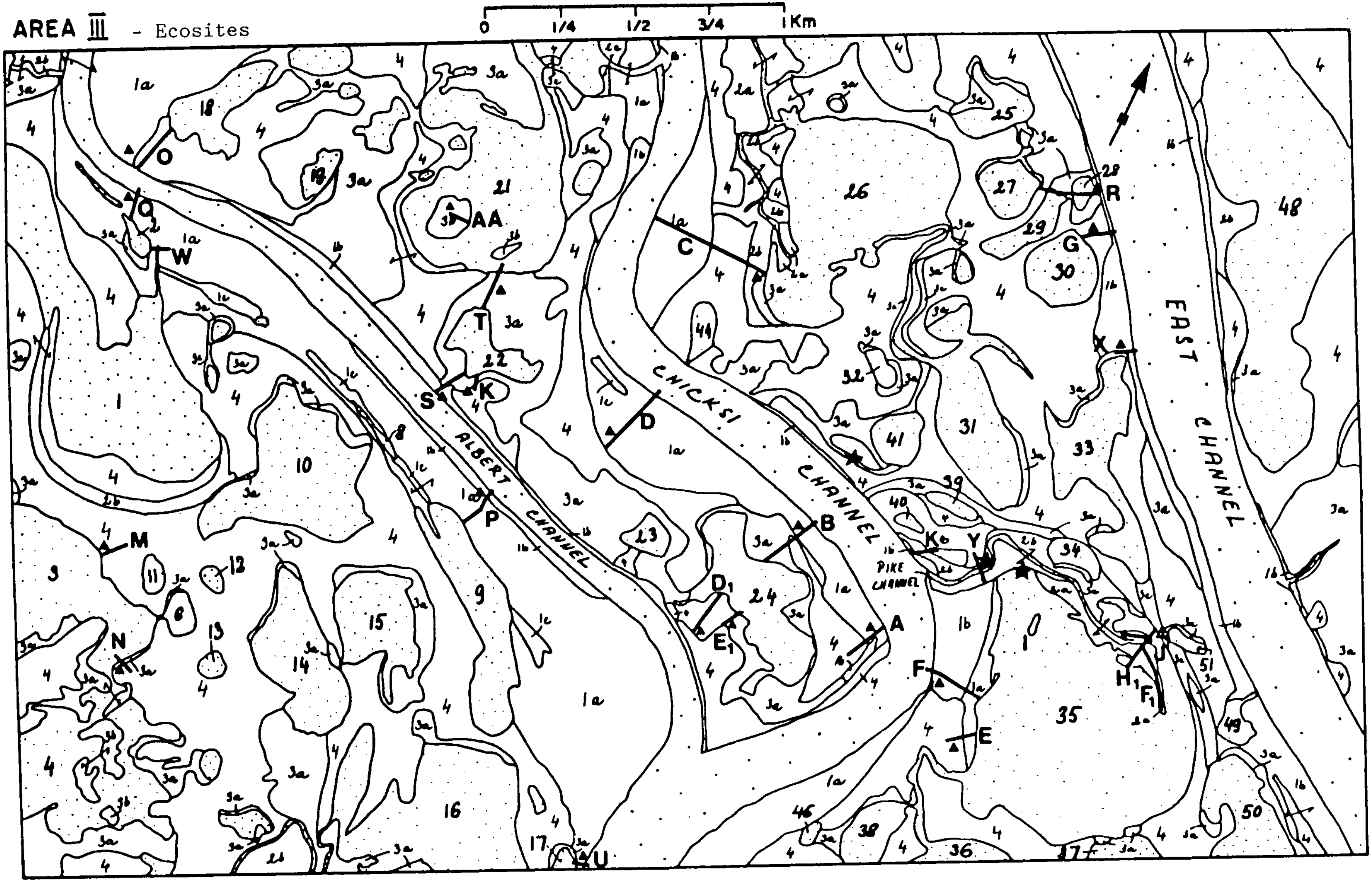


Figure 4(a): Ecosite map for Area 3 (legend on facing page). Transects used by Cordes et al. (1984) and Pearce (1986) are shown. (from: Cordes et al. (1984) and Pearce (1986)).

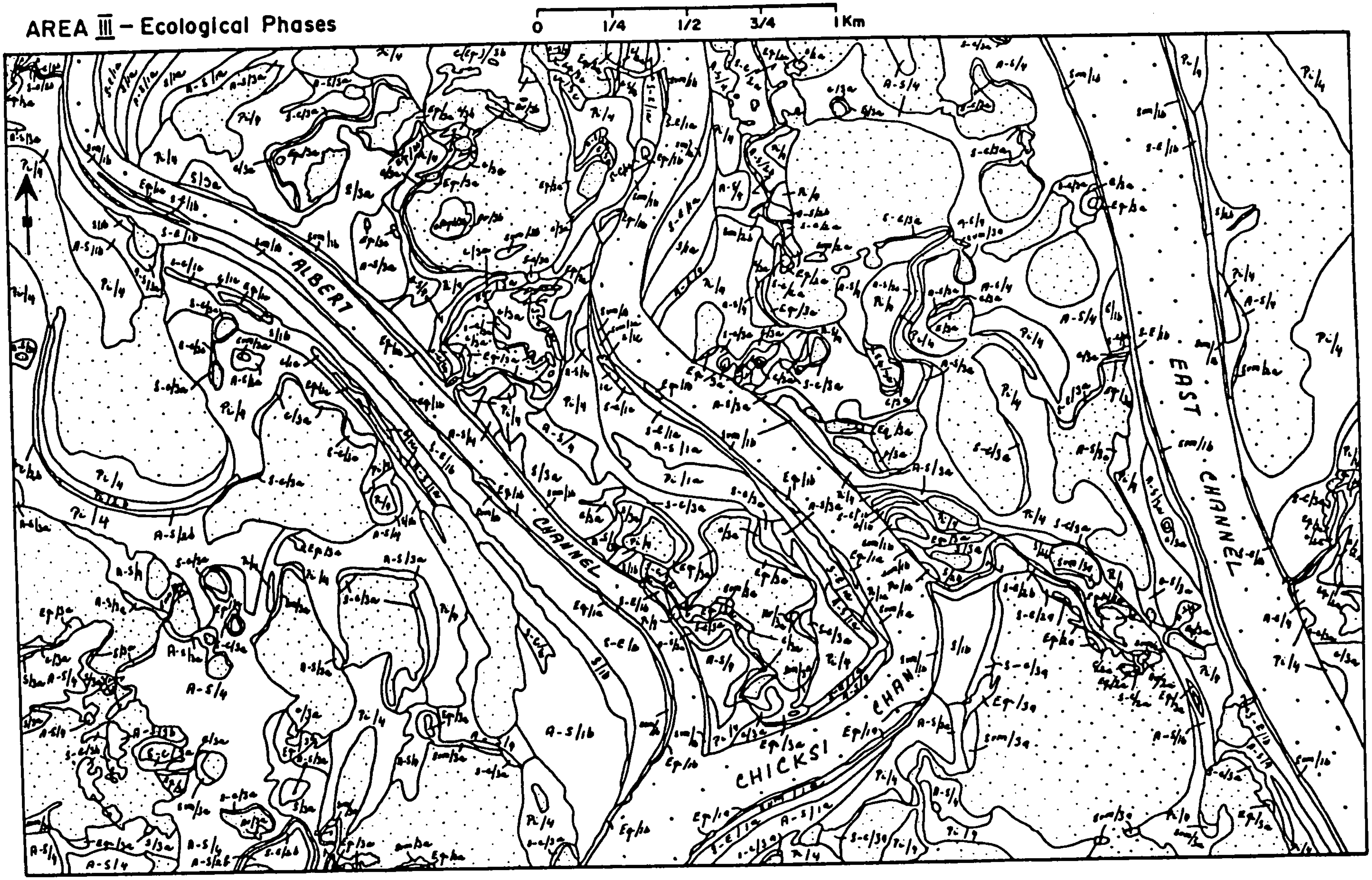
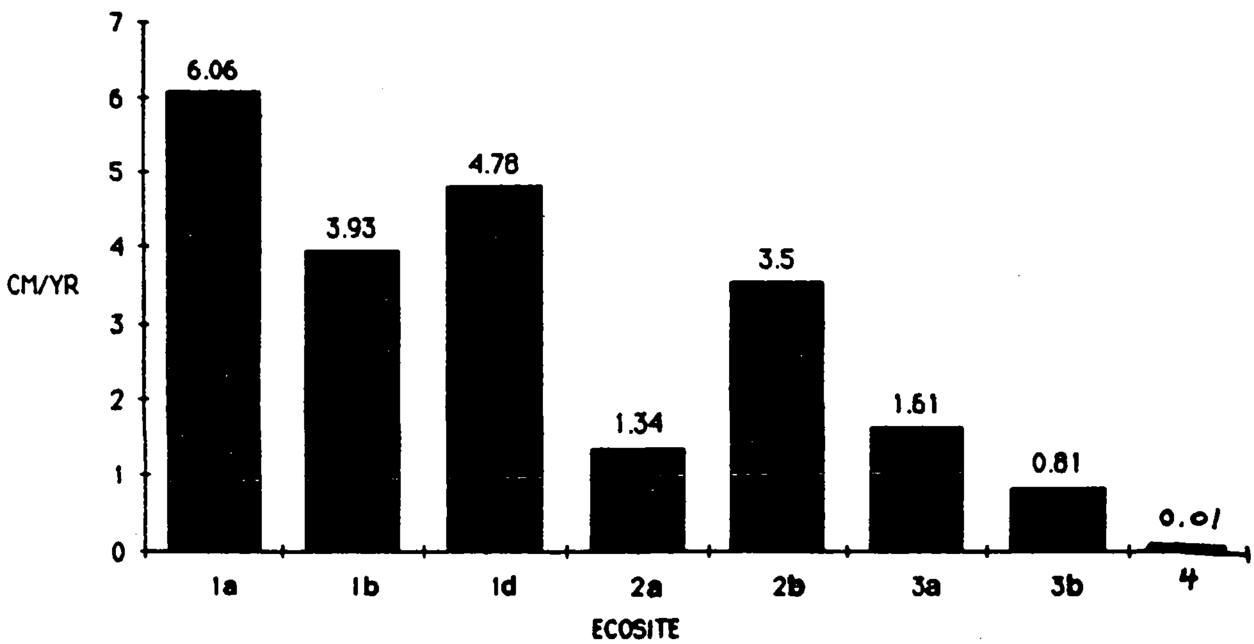


Figure 4(b): Ecological phase map of Area III.

Figure 5: Mean annual aggradation rates for Mackenzie Delta ecosites. (Source: Pearce [1986])



(1a point bars, 1b channel levees, 1d alluvial sand plain, 2a lake deltas, 2b distributary channels, 3a lakeshores, 3b lake shoals, 4 delta plain)

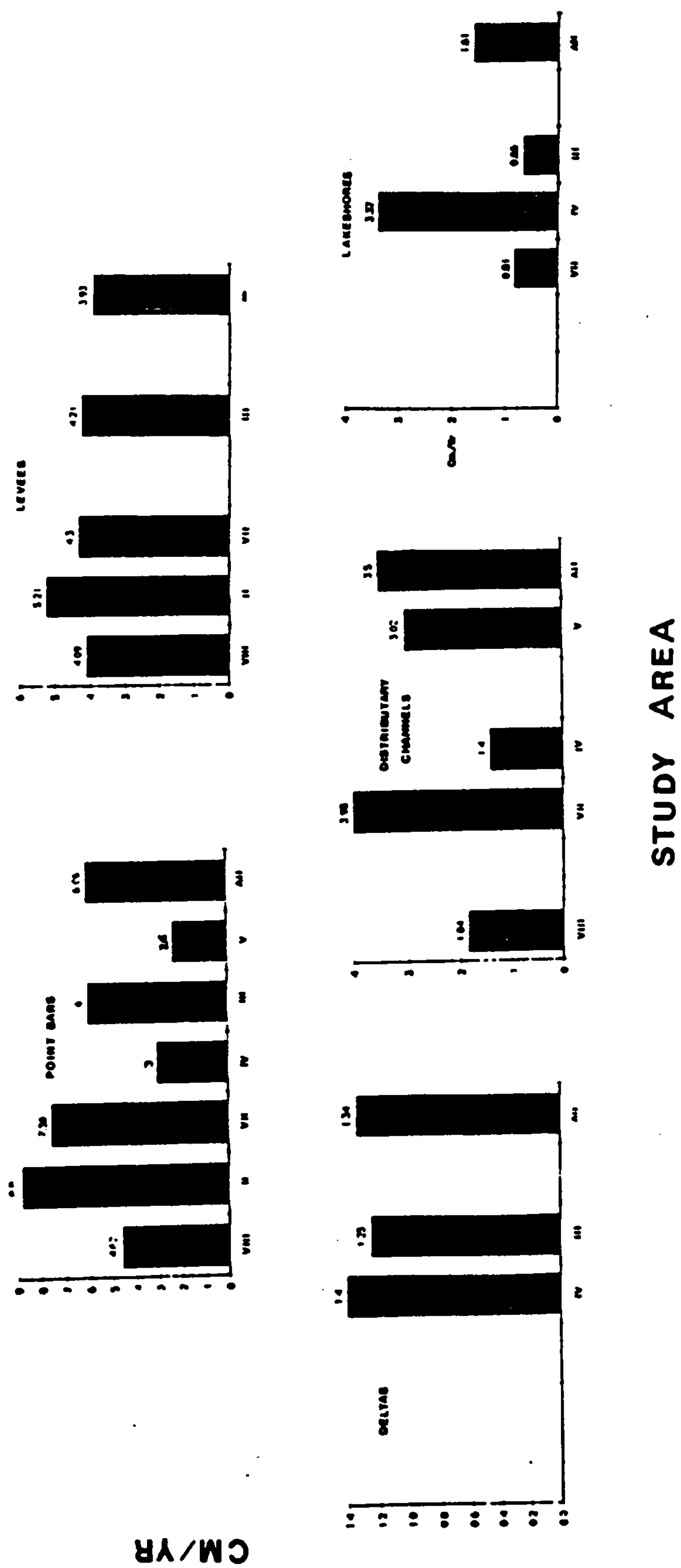


Figure 5 continued

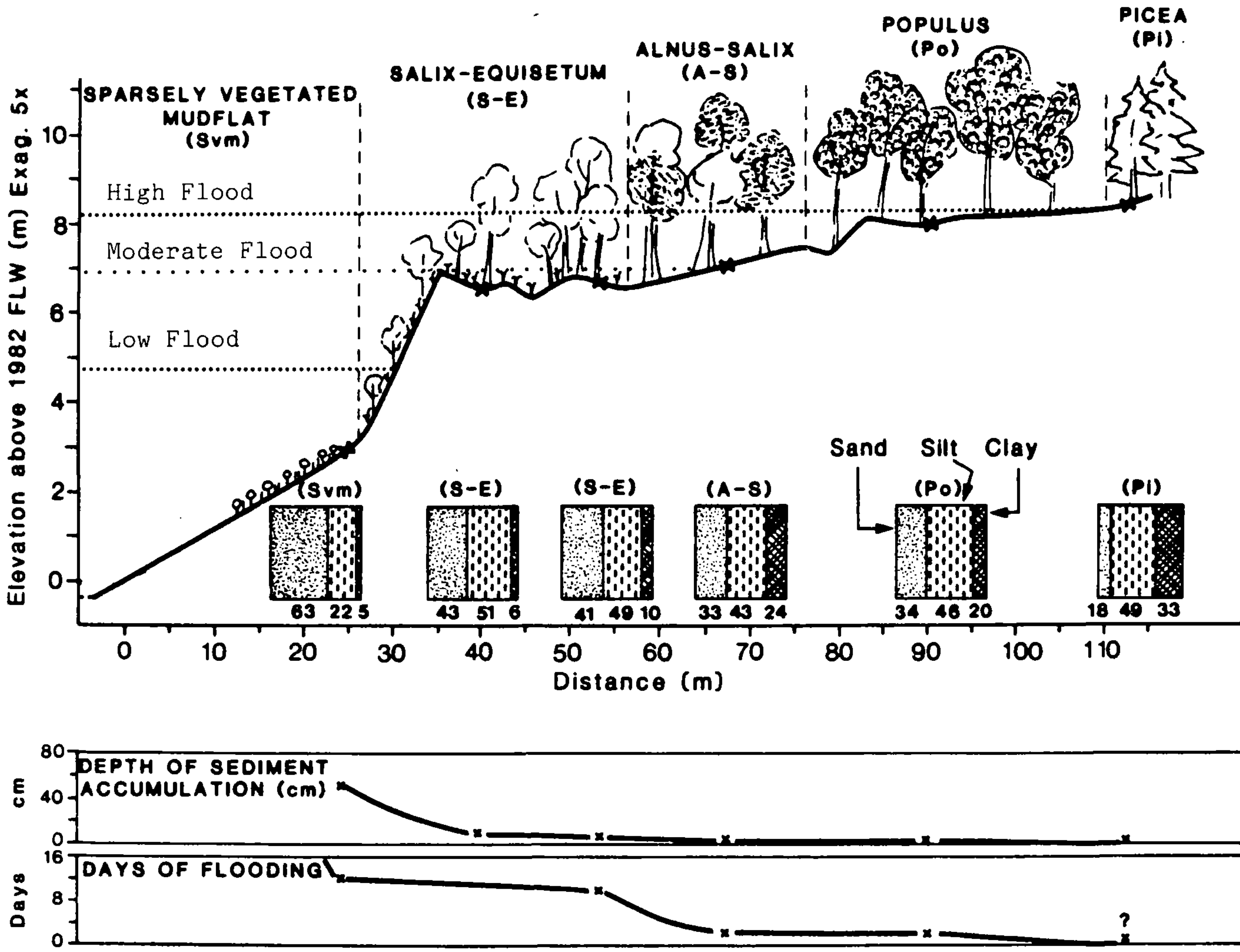


Figure 6: Example of a transect across a point bar in the inner delta showing low, moderate, and high flood peaks, ecophases, days of flooding, sediment deposits, and sediment texture.

(source: L.D. Cordes)

Pioneer willow-horsetail

1981 - ?
1982 - 60 cm
1983 - 0.6-3.5 cm

Alder-Willow

1981 - 0
1982 - 0.5-1.5 cm
1983 - 0

Decadent Alder-Willow-Poplar

1981 - 0
1982 - 0
1983 - 0

Mature willow

1981 - 0
1982 - 2.5-14 cm
1983 - 0-0.5 cm

Poplar

1981 - 0
1982 - 0.5-1.5 cm
1983 - 0

Spruce

1981 - 0
1982 - 0
1983 - 0

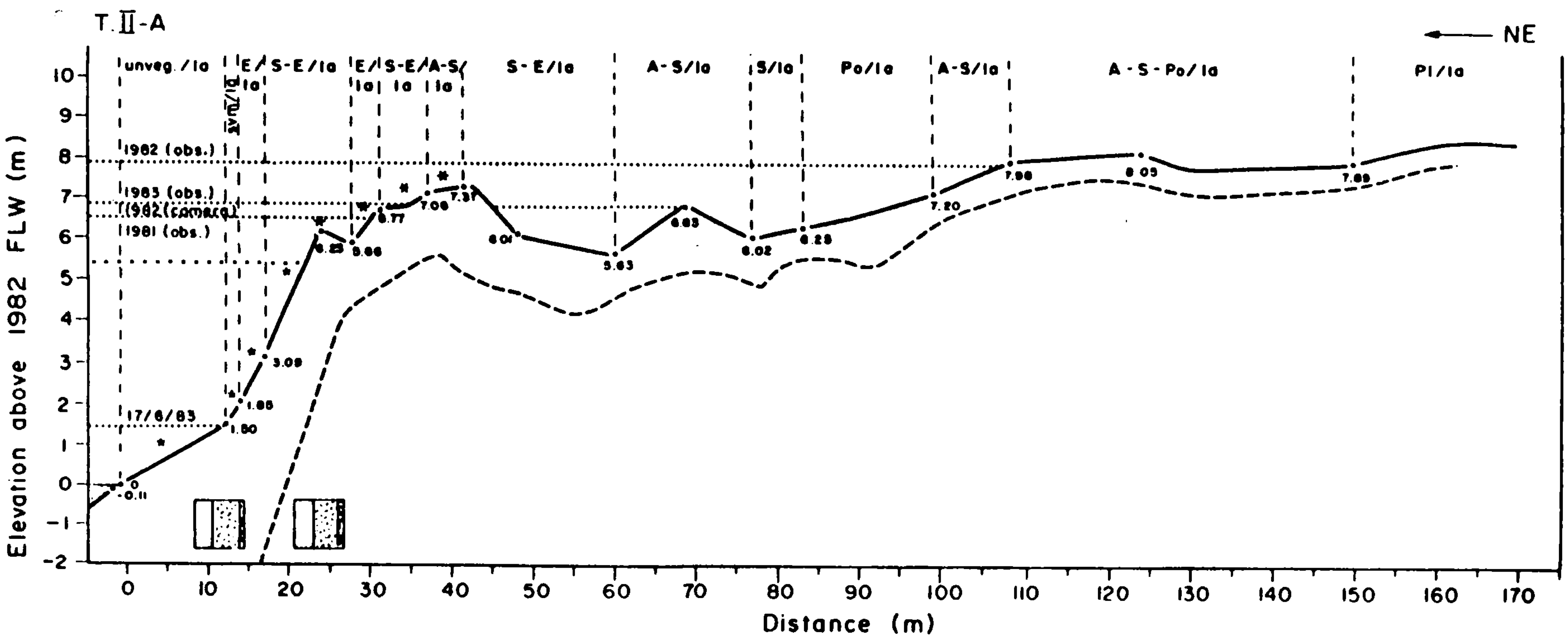


Figure 7: Transect II-A across a point bar in Area 2 on Peel Channel in the inner delta.

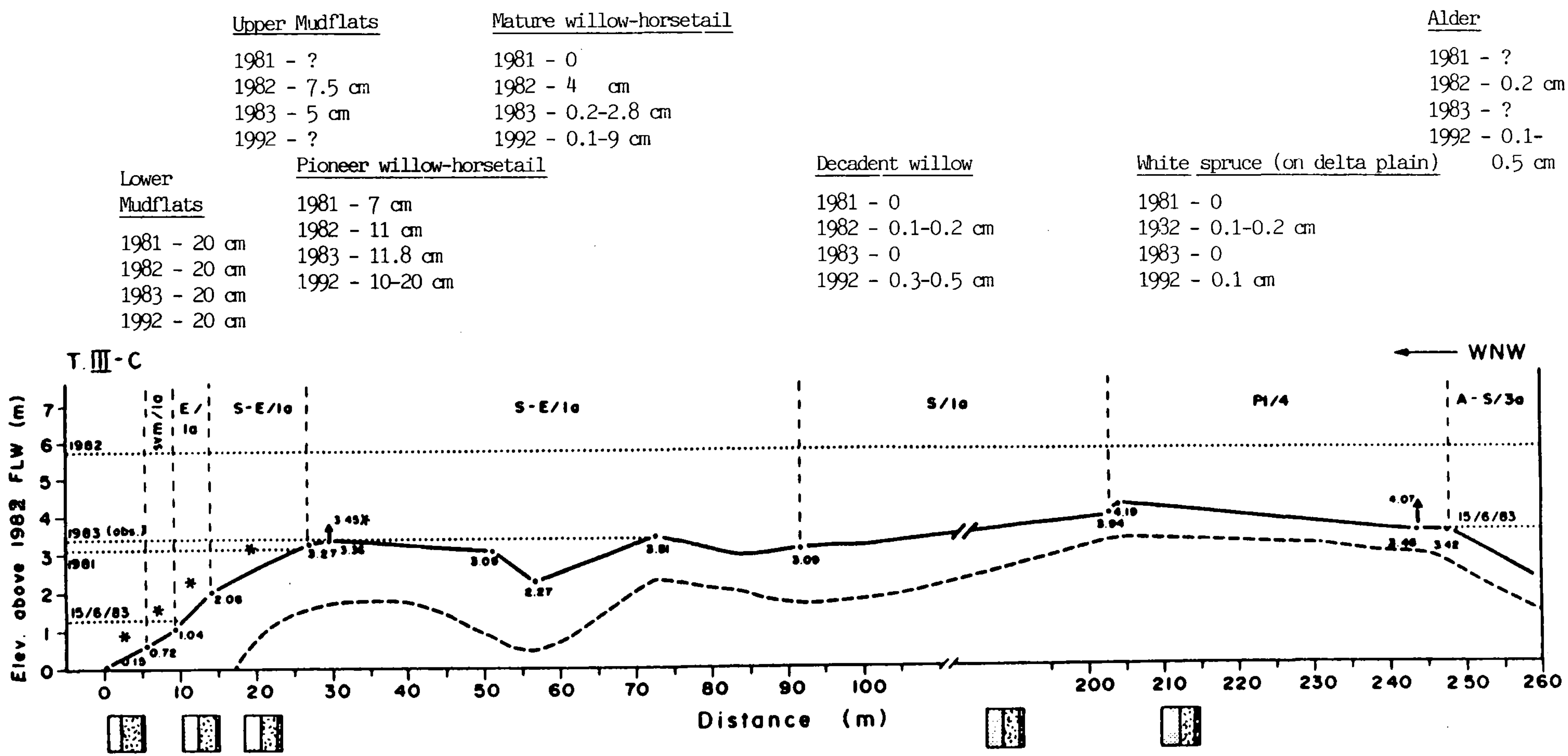


Figure 8(a): Transect III-C across a point bar in Area 3 on Chicksi Channel in the middle delta.

Figure 8(b): Lower elevations of III-C
in August 1992

Figure 10(b): Lower elevations of V-F
in July 1992

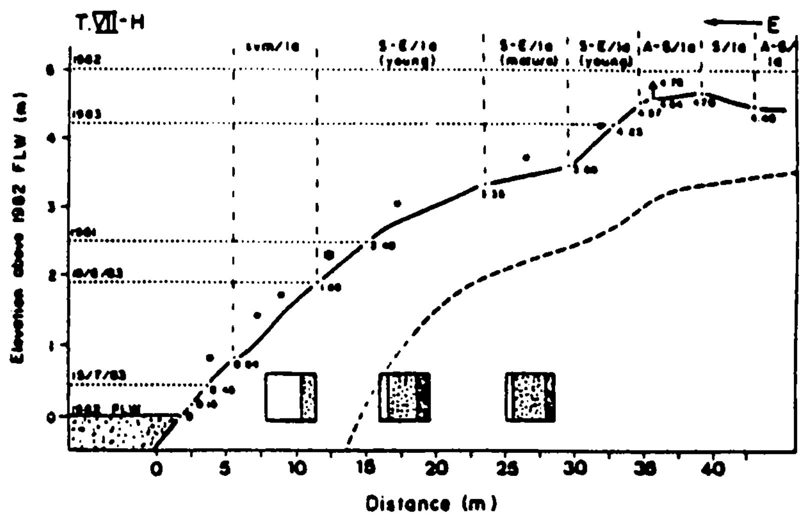


Figure 9: Transect VII-H across a point bar in Area 7 on Taylor channel

Mudflats

1981 - 5 cm
1982 - 11 cm
1983 - erosion
1992 - ?

Horsetail

1981 - 3 cm
1982 - 15 cm
1983 - 6 cm
1992 - ?

Pioneer willow

1981 - 1 cm
1982 - ?
1983 - erosion
1992 - 8 cm

Mature willow

1981 - 0
1982 - 2.4-6 cm
1983 - 3 cm
1992 - 4 cm

Richardson's willow
(not shown)
1981 - 0
1982 - 0.2 cm
1983 - ?
1992 - 0.3-0.5 cm

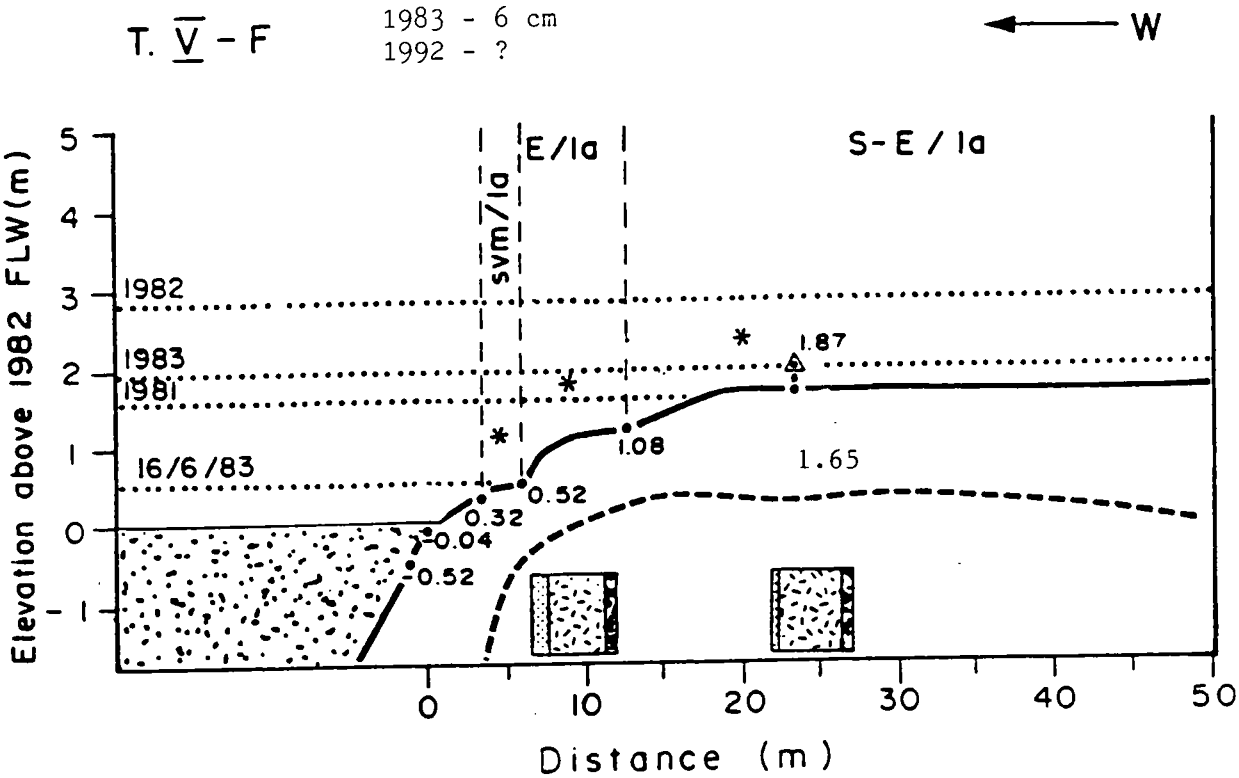


Figure 10(a): Transect V-F across a point bar in Area 5 in the outer delta

(Figure 10(b) is with Figure 8(b))

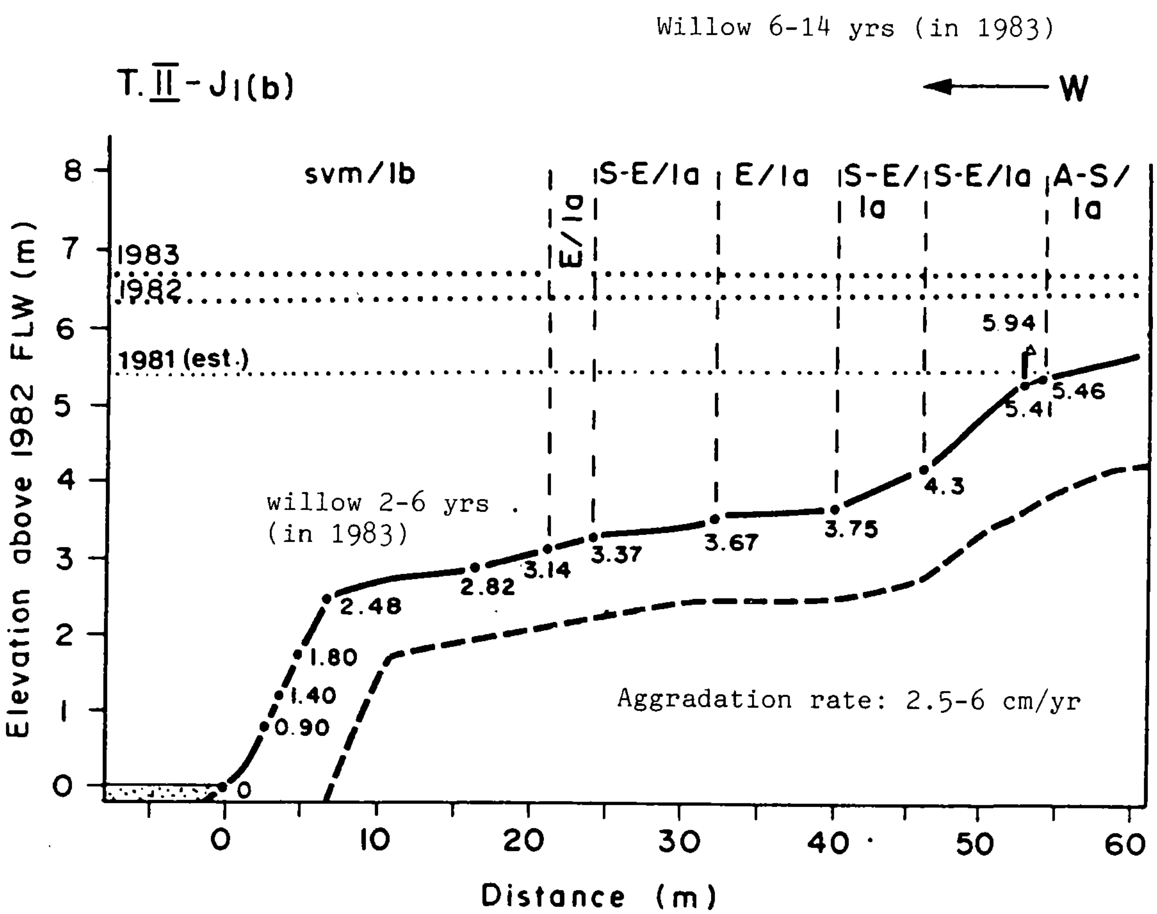


Figure 11(a): Transect II-J1(b) across a low closure levee on Peel Channel in Area 2 in the inner delta

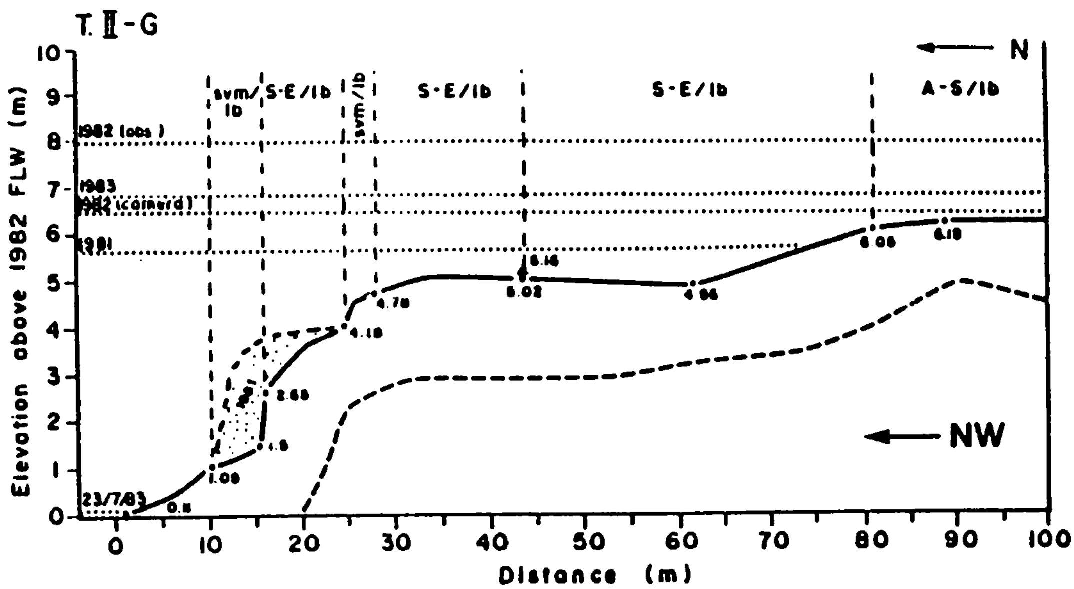
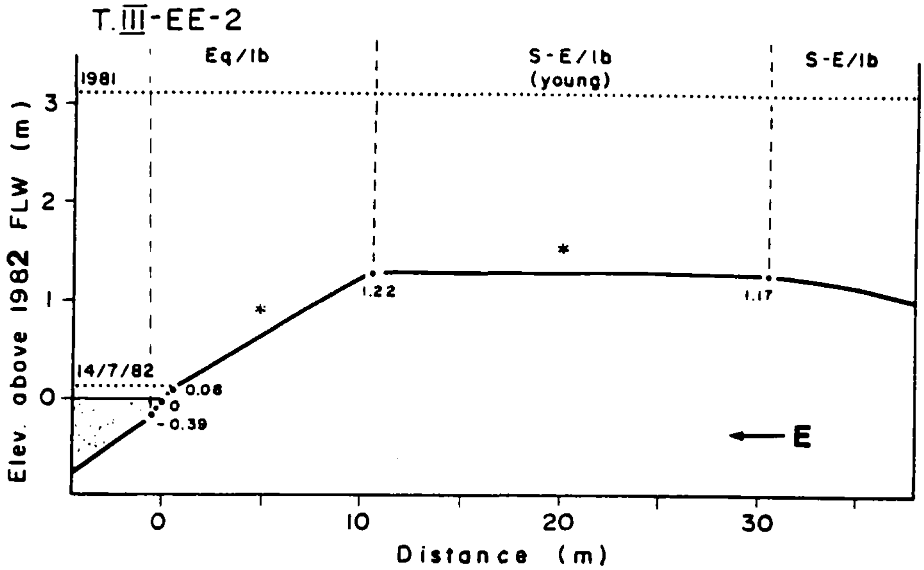


Figure 11(b): Transect II-G across a low closure levee on Peel Channel in the inner delta



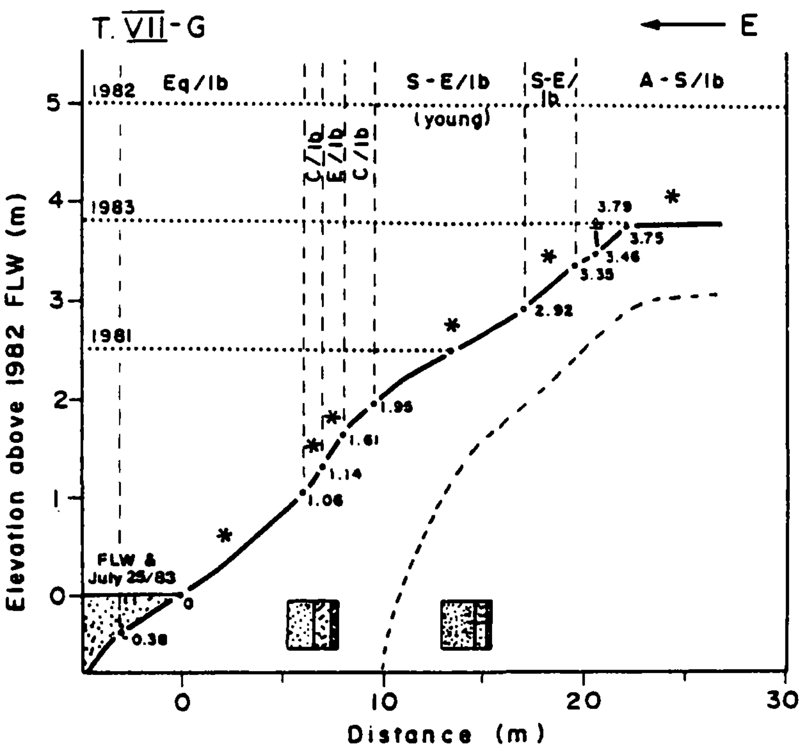


Figure 11(c) and (d): Transects across stable channel levees in the middle delta

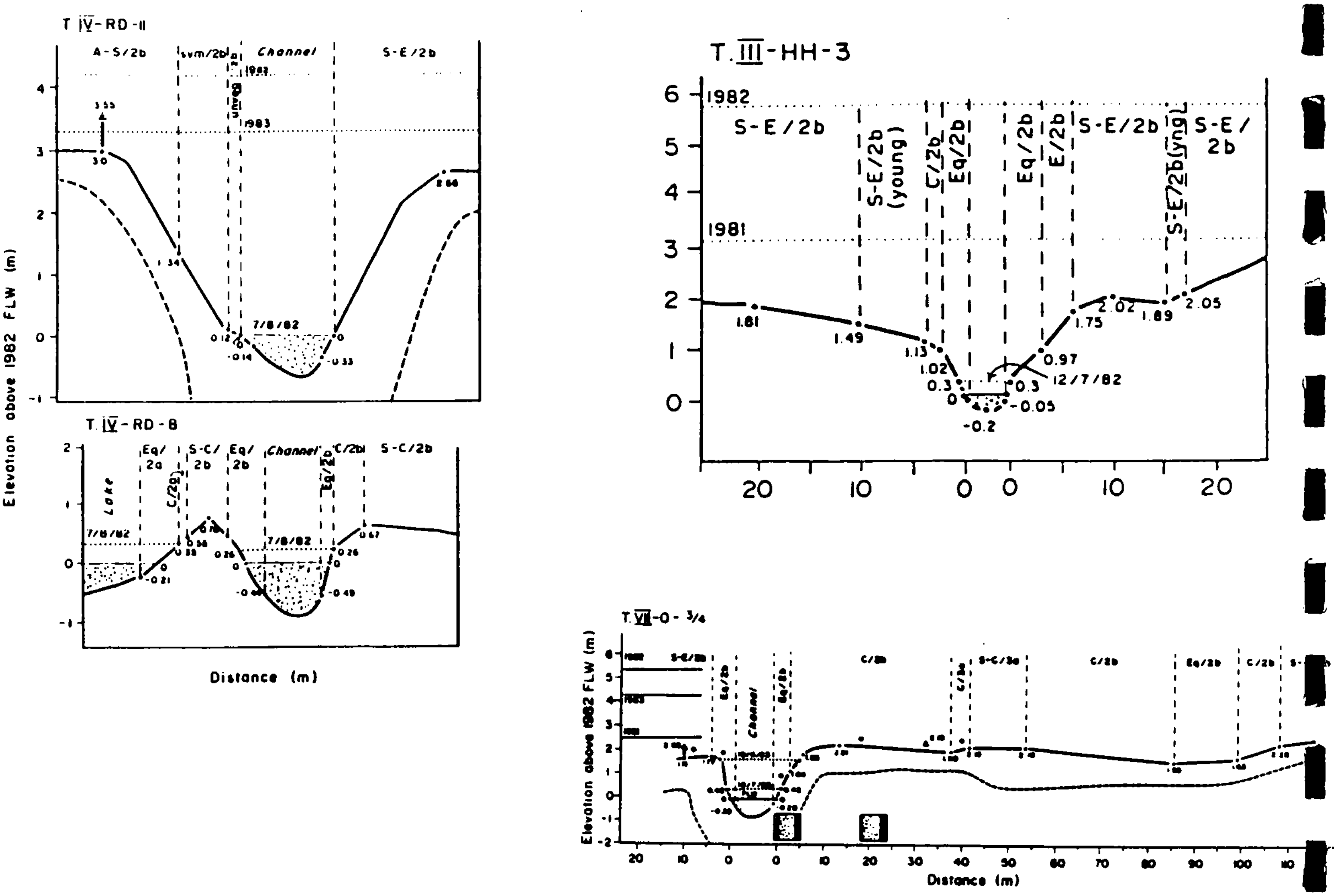
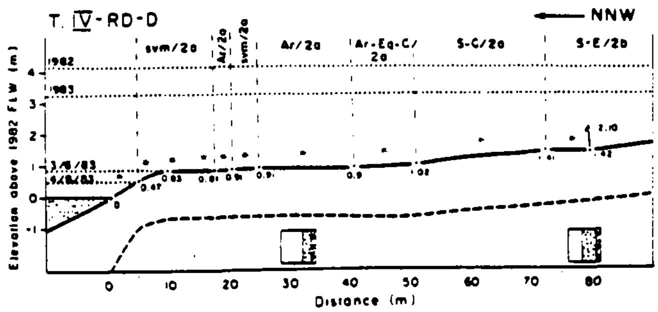


Figure 11(e)-(h): Transects across distributary channel levees in the middle delta



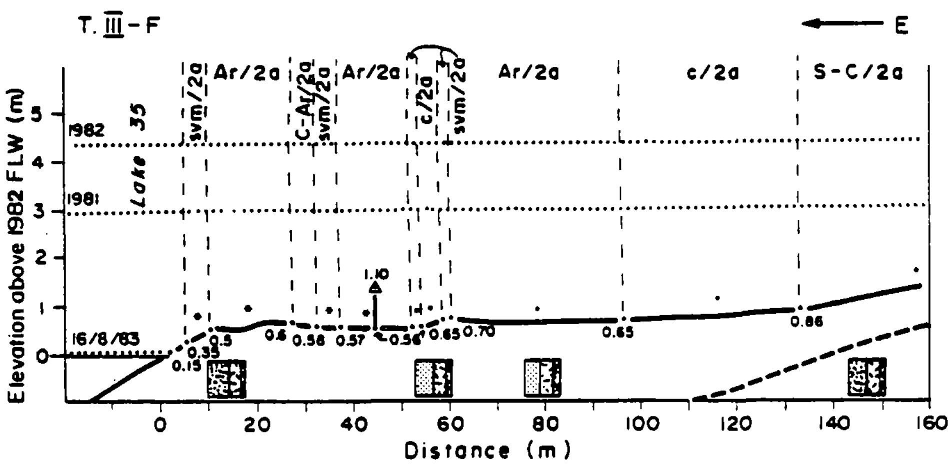


Figure 12(a) and (b): Transects across lake deltas in Areas 3 and 4

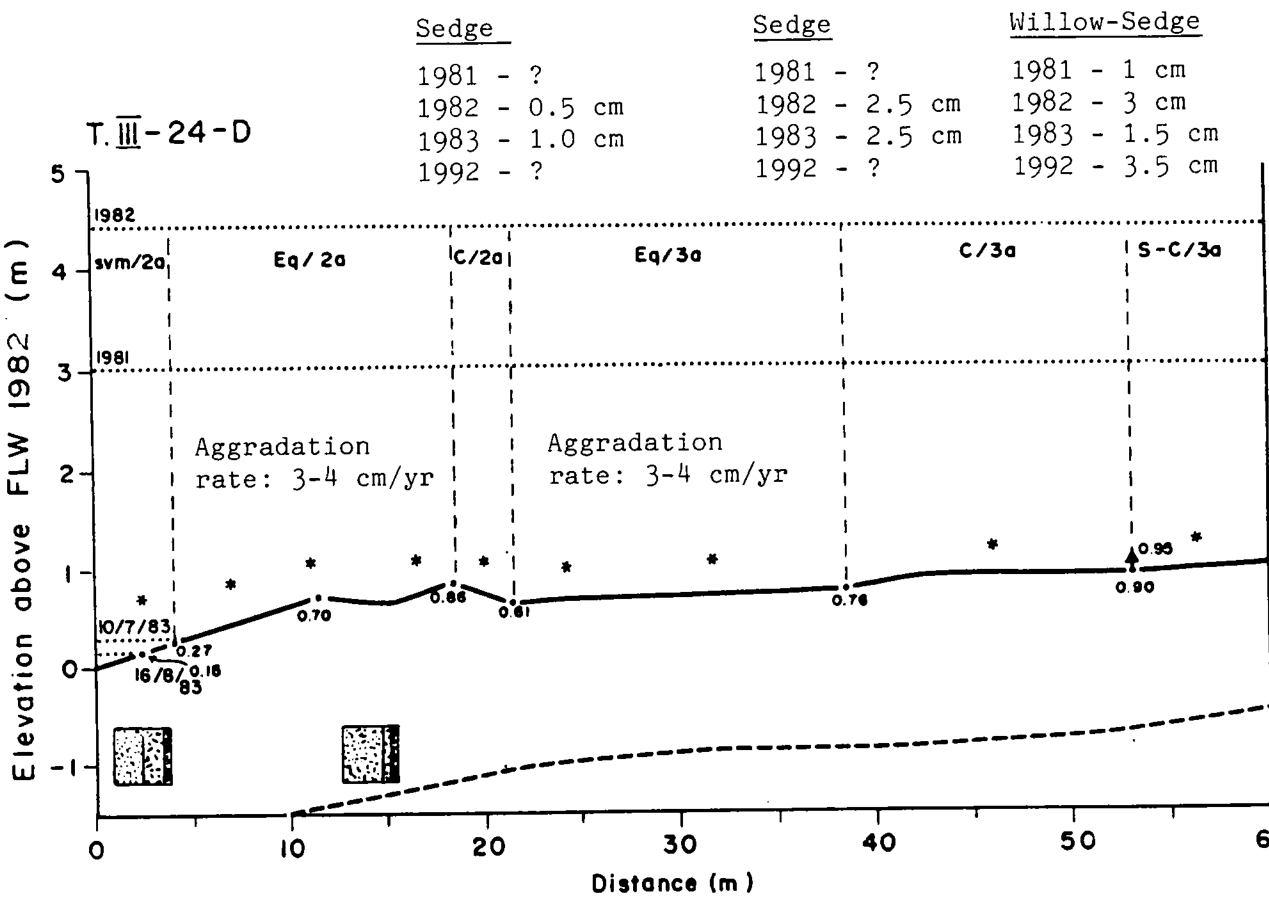


Figure 13: Transect III-24-D across a connected lake shoreline between Albert and Chicksi Channels in Area 3 in the Middle Delta. Lake 24 is at 0 m distance. The first horsetail (Eq) and sedge (C) ecophases are on a newly-forming lake delta (2a).

Sedge-Cottongrass

1981 - ?
1982 - 2.5 cm
1983 - ?
1992 - ?

Willow-Sedge

1981 - ?
1982 - 0.2 cm
1983 - ?
1992 - ?

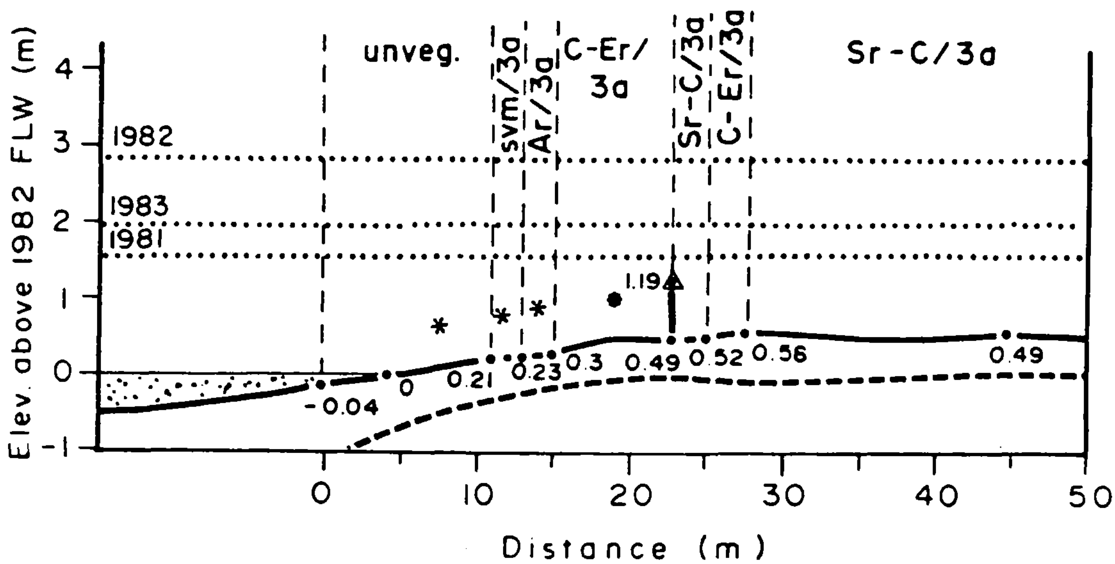


Figure 14: Transect V-B across a connected lake (7) shoreline in Area 5 in the outer delta.

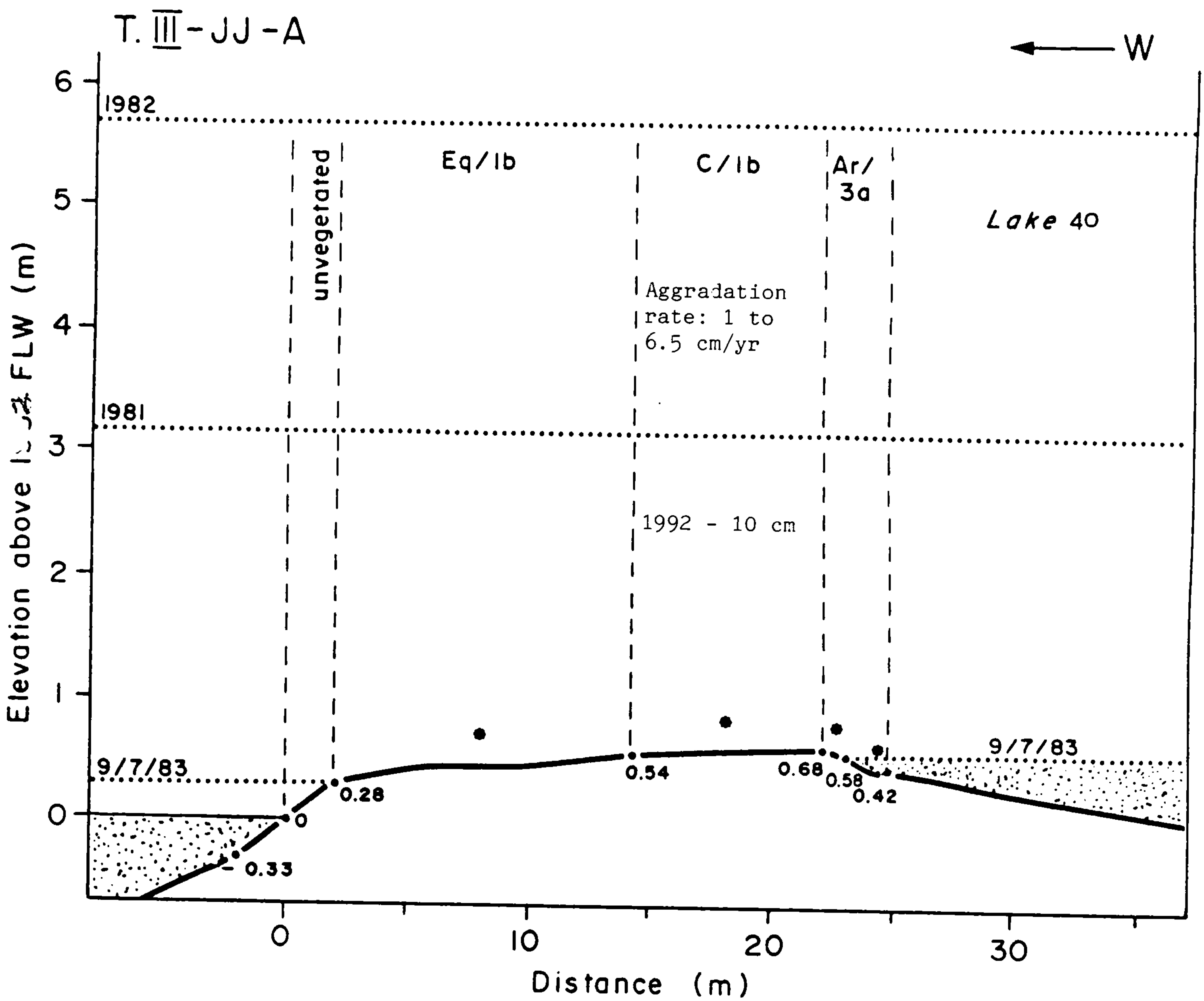


Figure 15: Transect III-JJ-A across a low closure levee on Chicksi Channel in Area 3 in the middle delta. Note that unvegetated between 0 and 0.28 m elevation and Ar/3a (pendant grass) on the shore of Lake 40 had changed to horsetail by 1992.

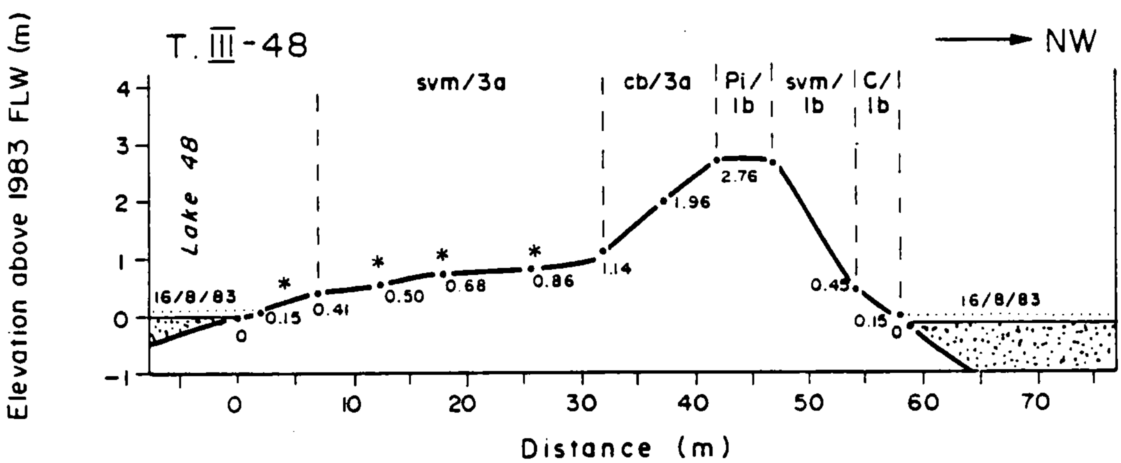


Figure 16: Transect III-48 across a low closure shoreline on East Channel in area 3

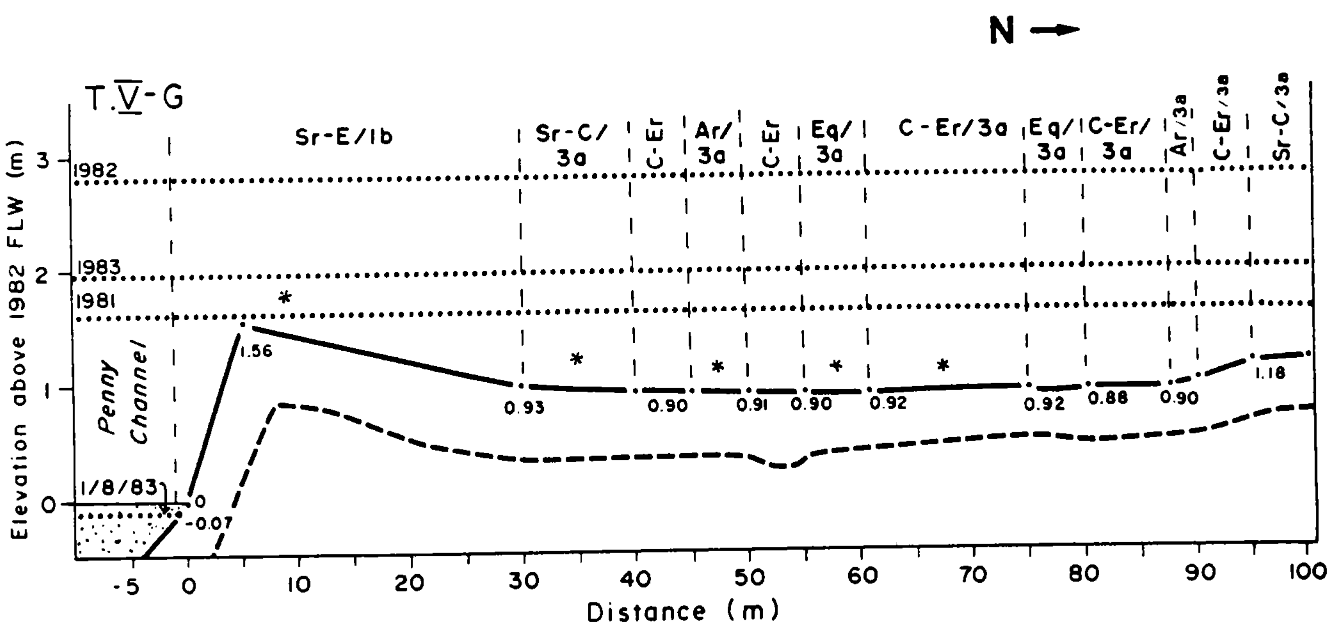


Figure 17: Transect V-G across a closed lake shoreline in Area 5 in the outer delta.

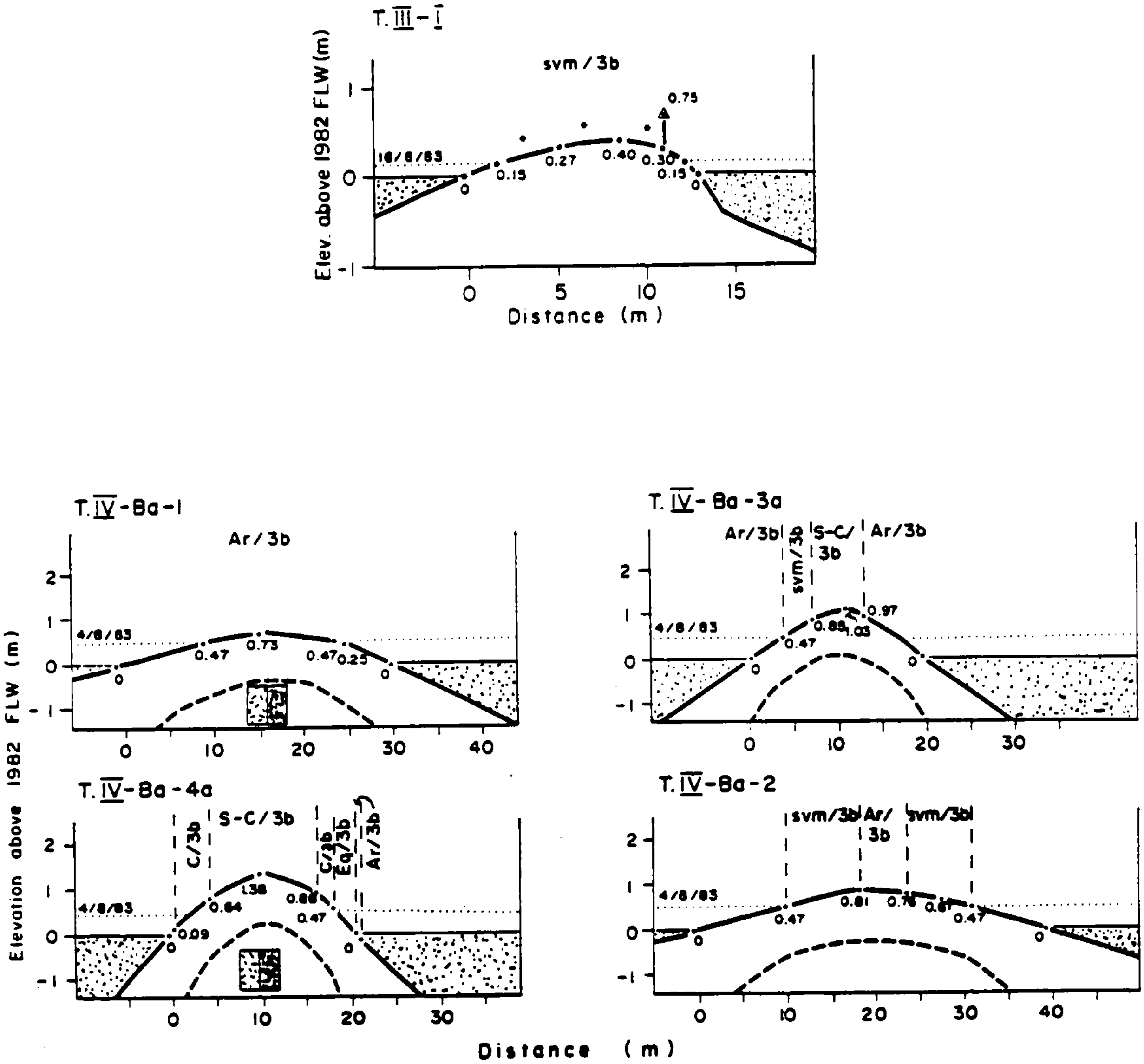


Figure 18: Transects across typical shoals in the middle delta

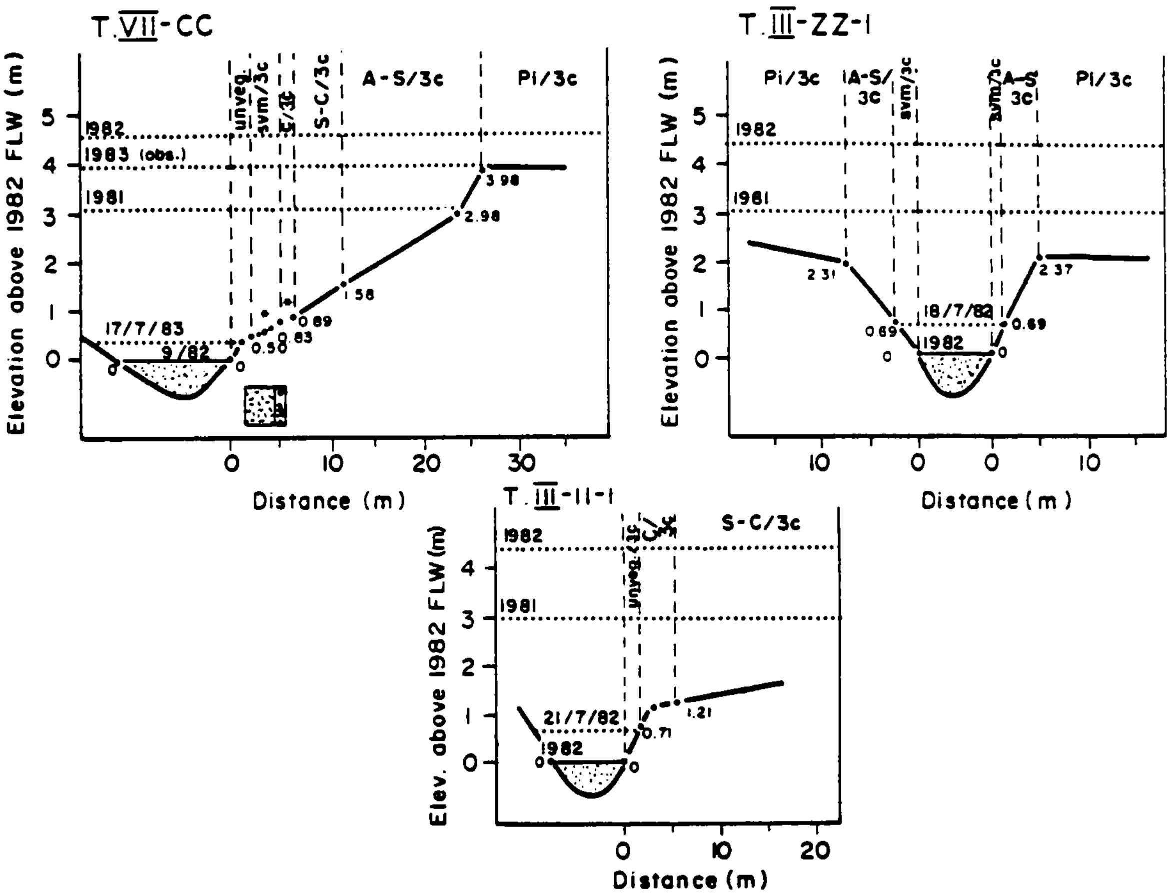


Figure 19: Transects across typical connecting channel levees in the
middle delta

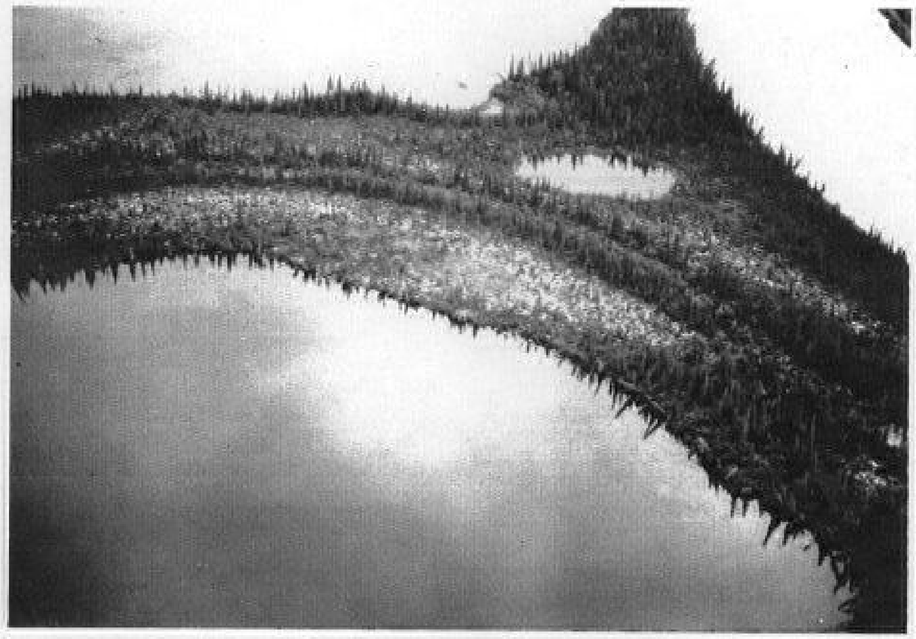


Figure 20a: Aerial view of high elevation spruce-lichen woodland (light-coloured area) on the delta plain in the west middle delta near Aklavik.

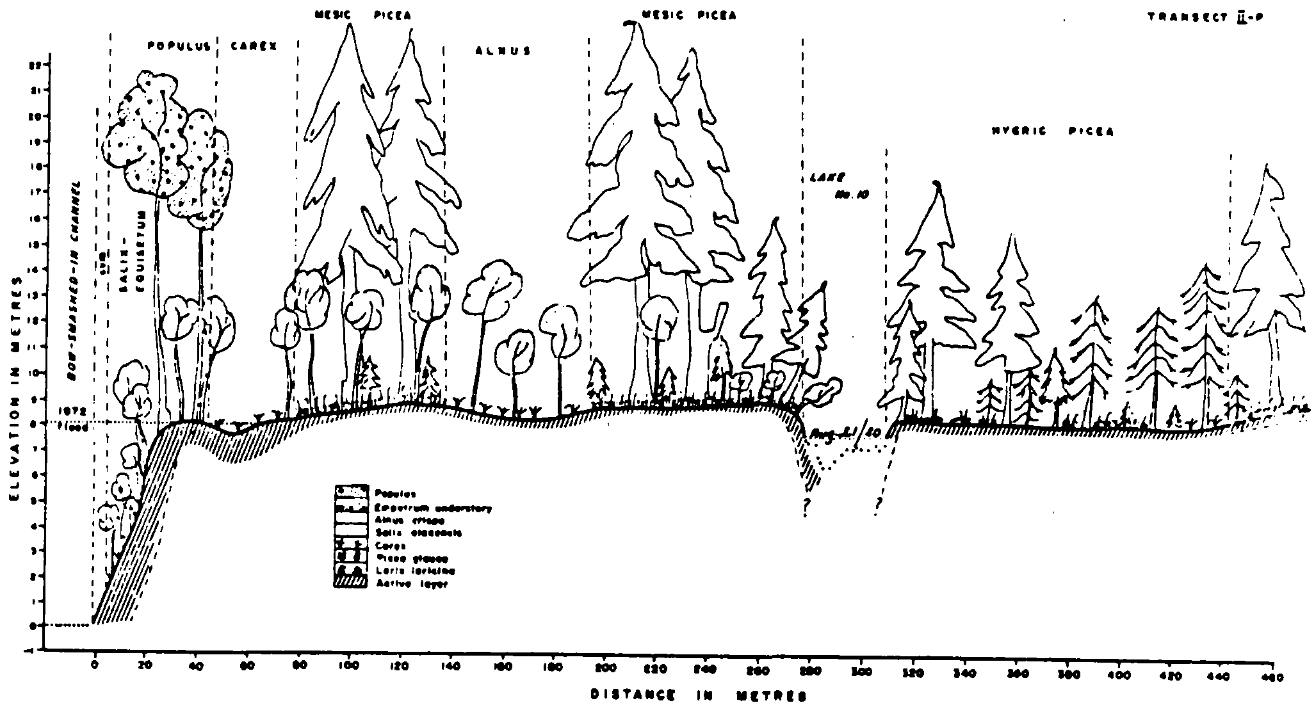


Figure 20b: Transect II-P across the delta plain in the inner delta (source: Cordes et al. [1984].

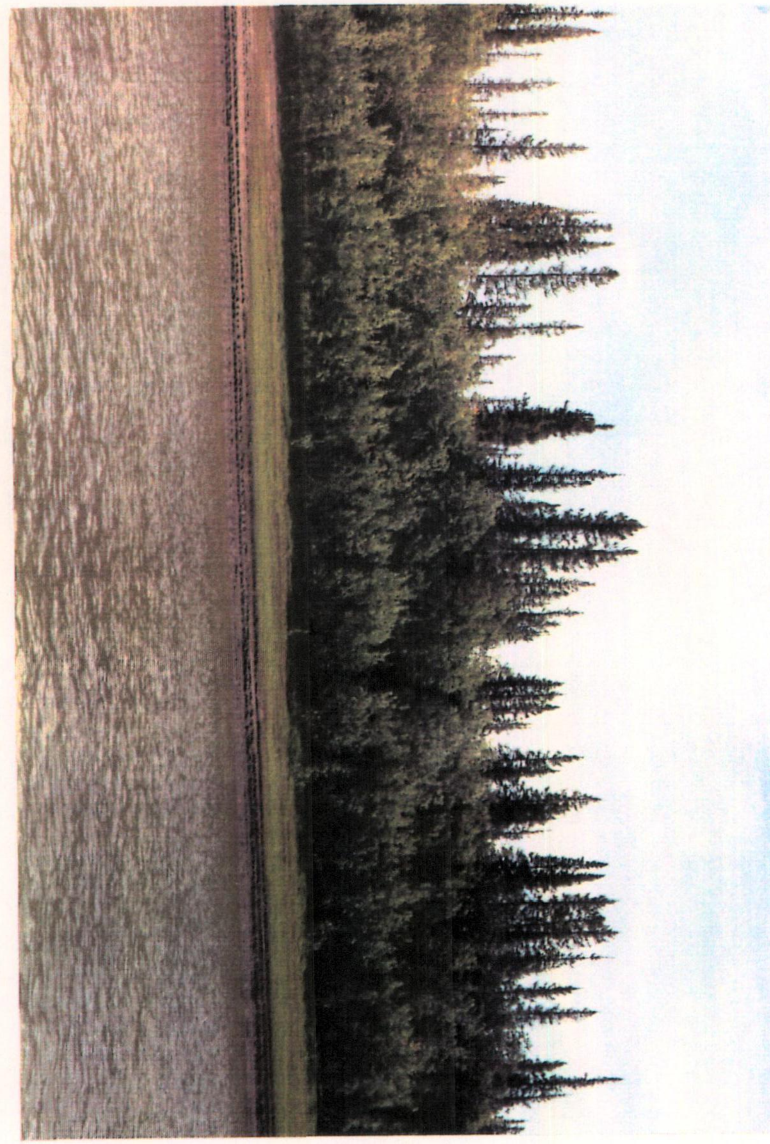


Figure 21: Point bar and delta plain on Big Lake Channel near Inuvik

Figure 22: Leaf litter layer used to measure sediment deposition within the pioneer willow-horsetail ecophase on the point bar shown on Figure 21

Figure 23: Lakeshore of connected lake off Big Lake Channel near Inuvik

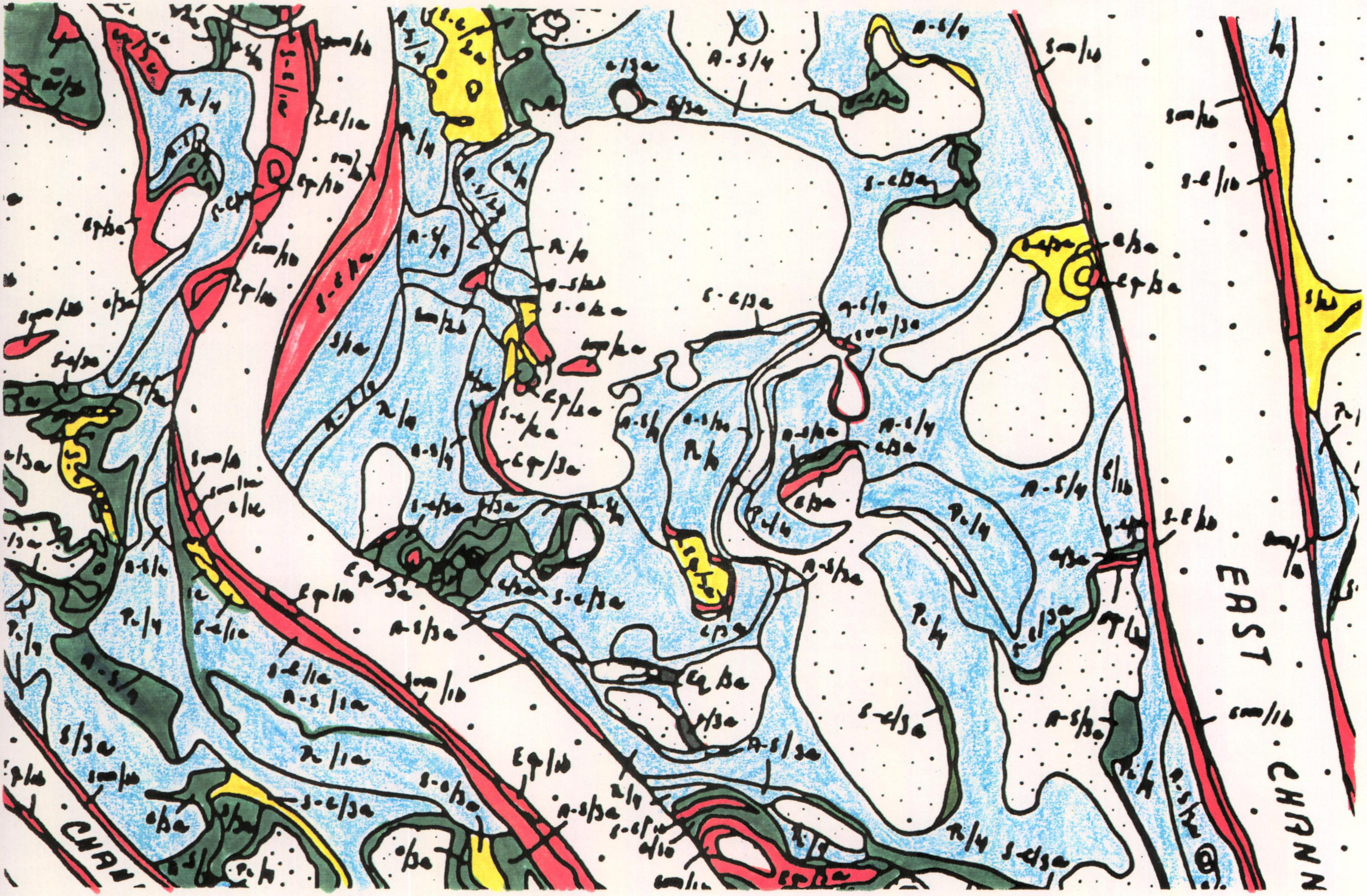


Figure 24: 200% enlargement of ecophase map for Area 3 used to estimate proportions of ecophases on ecosites.

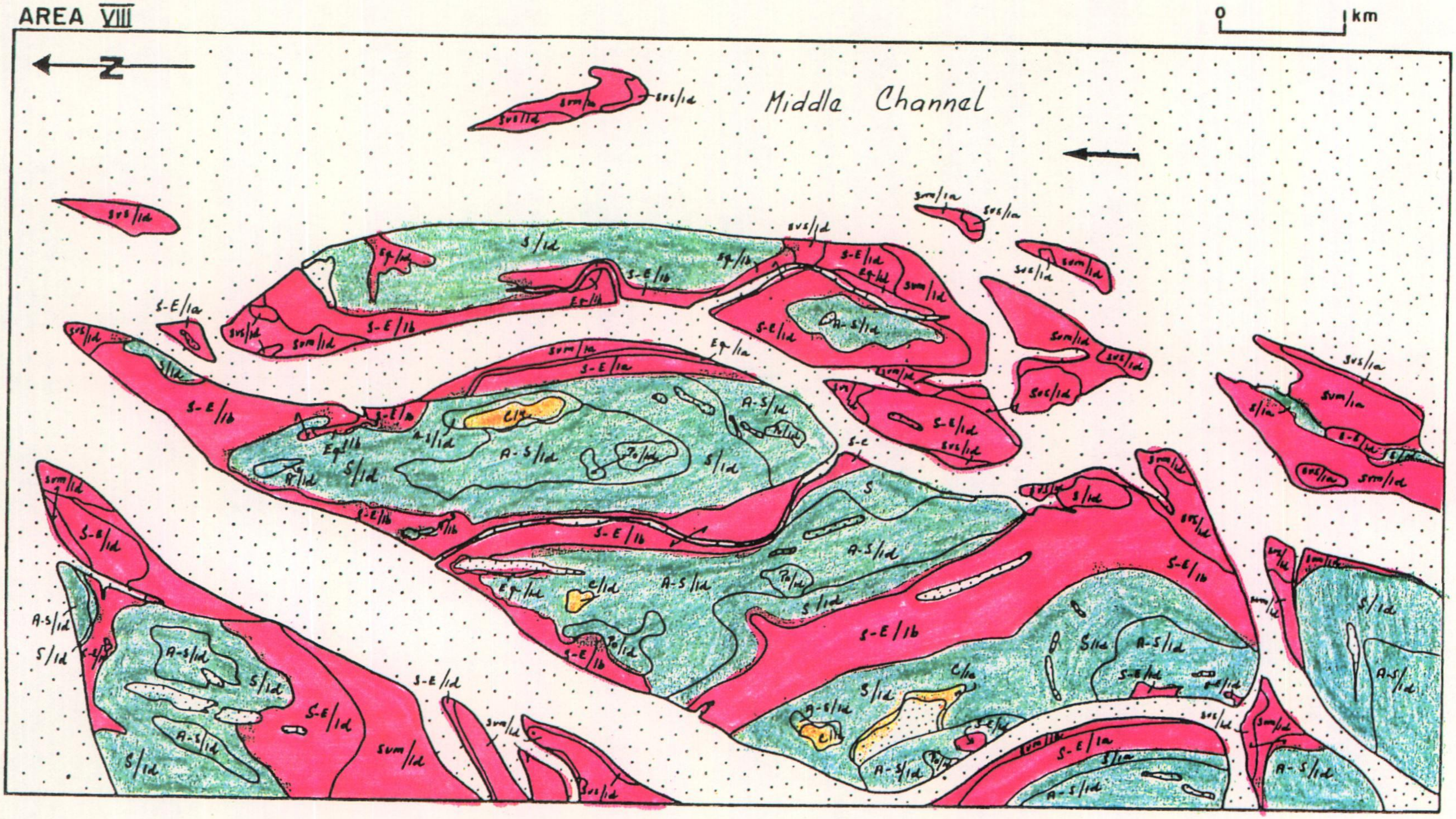


Figure 25: Sedimentation patterns in Area 8 using ecophases

High

Low

Moderate

Water

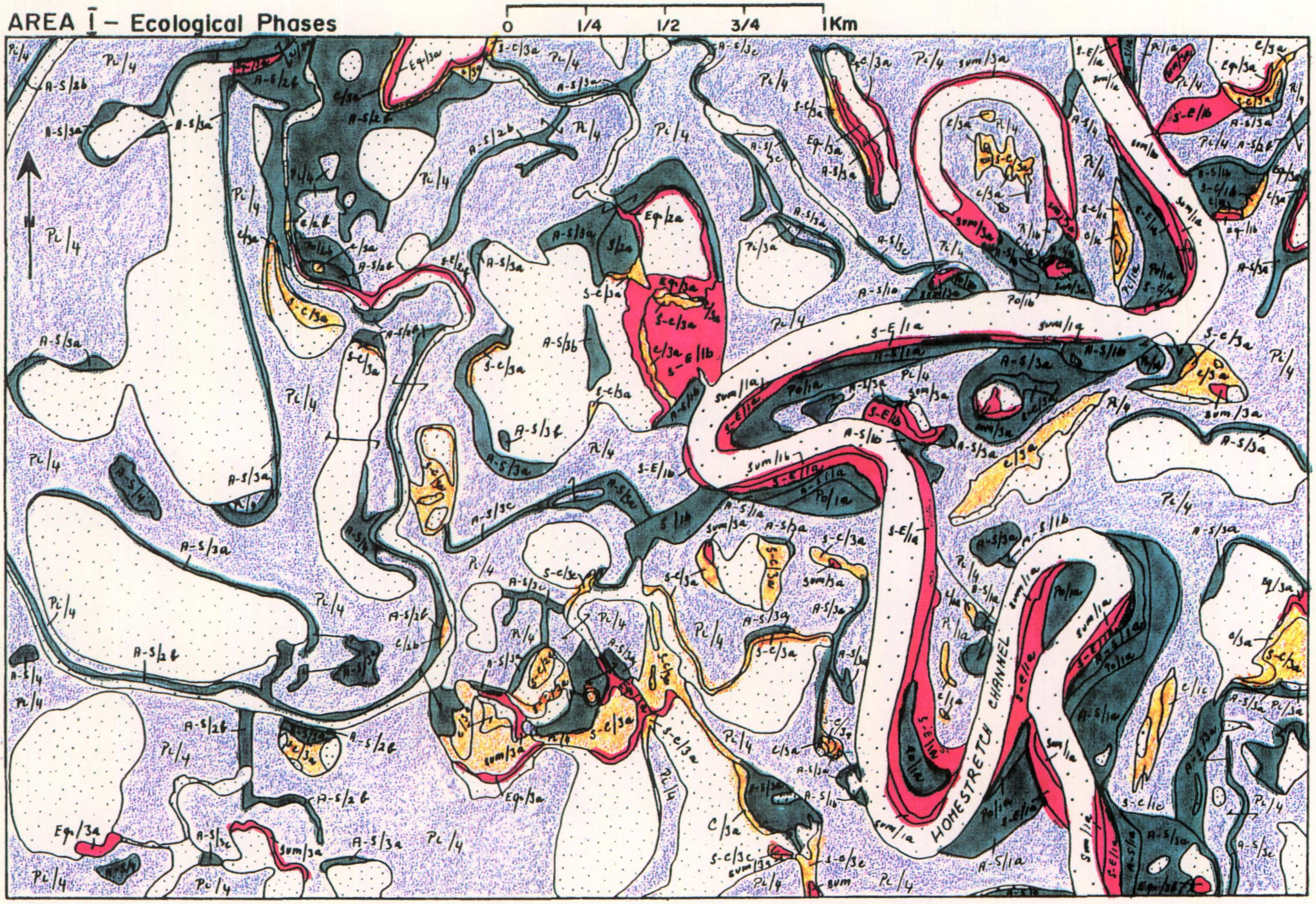
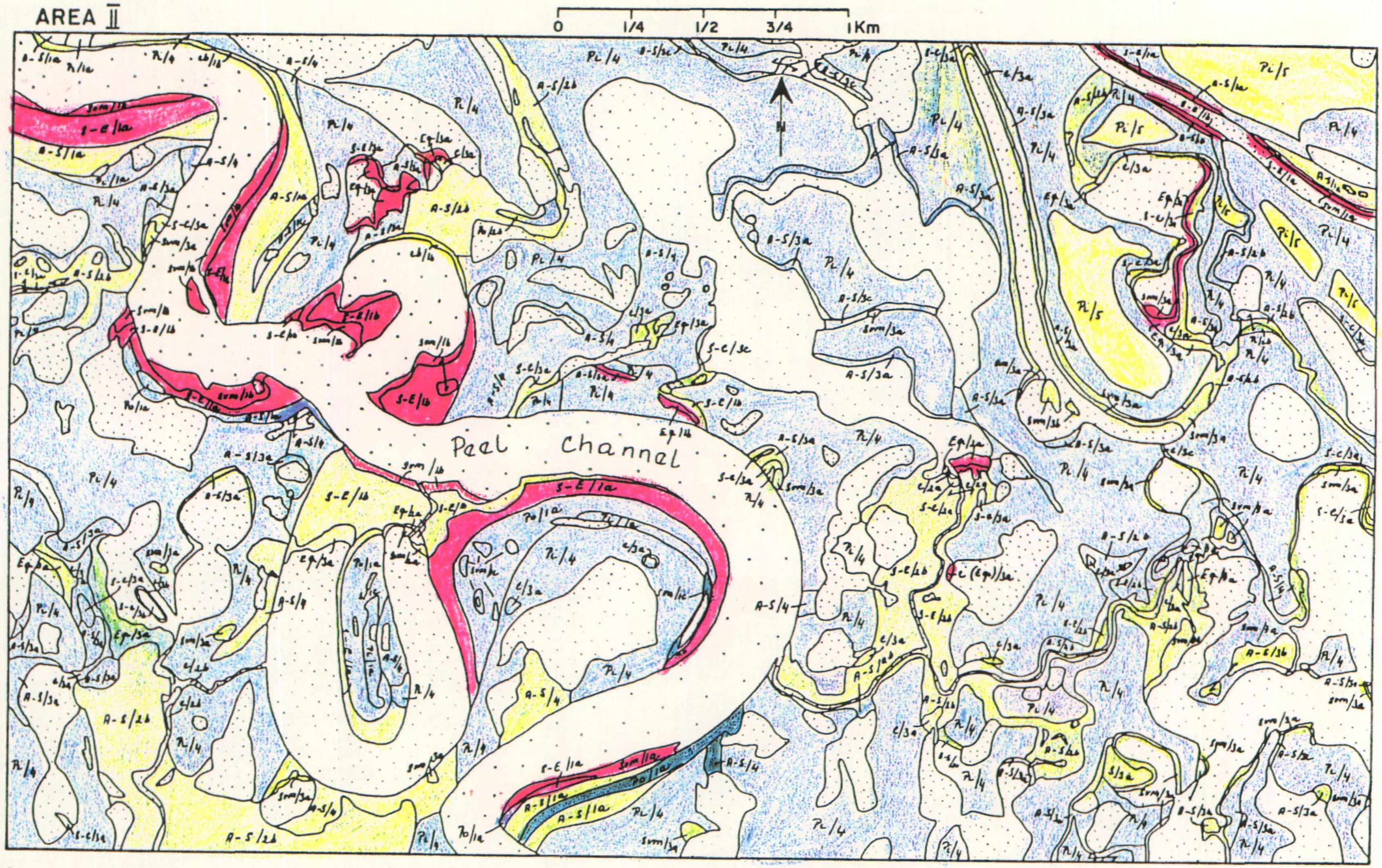


Figure 26: Sedimentation patterns using ecophases in Area 1

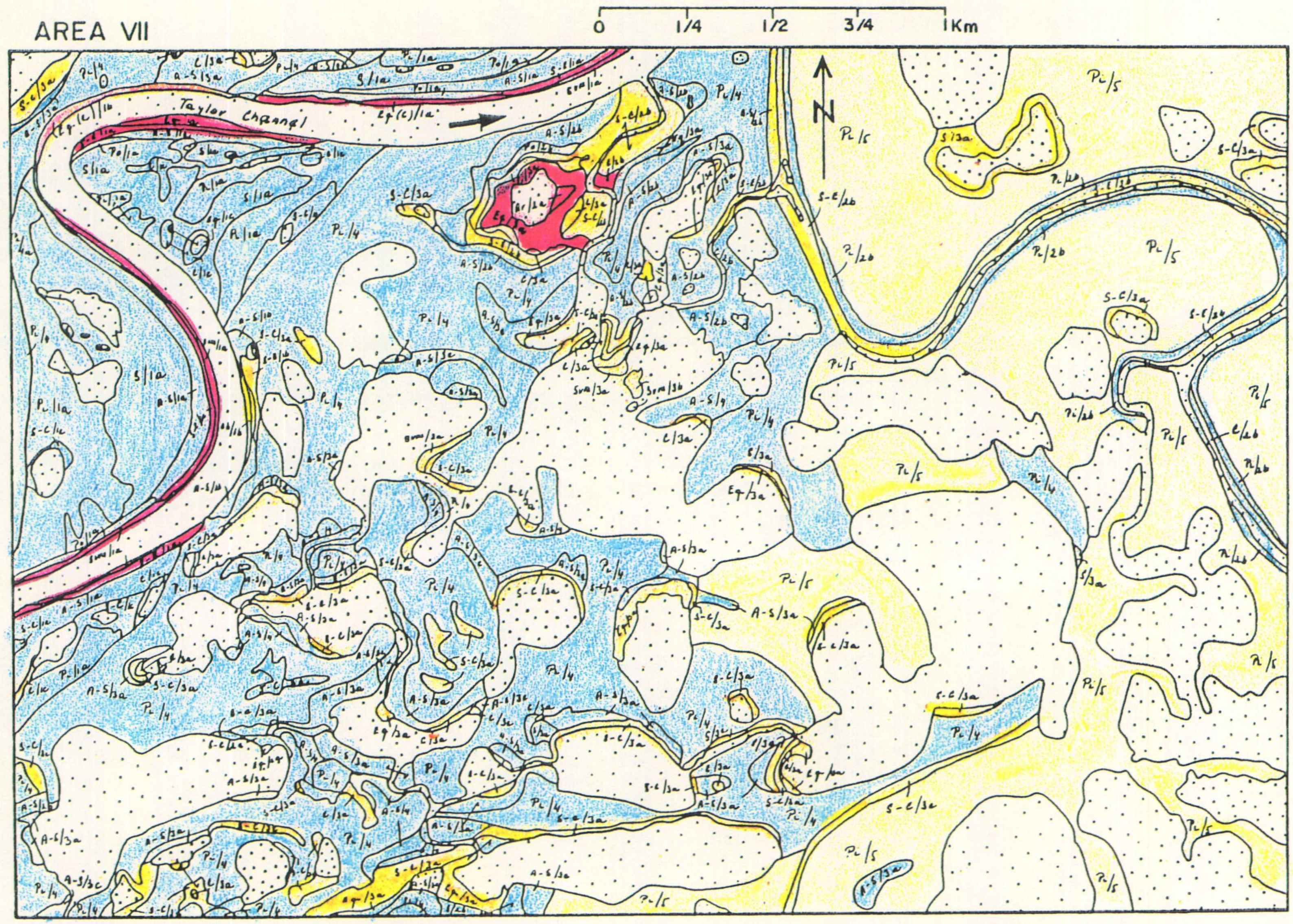
High
Mod.
Low
Very low
Water



High
Low
Very low
None
Water

Figure 27: sedimentation patterns in Area 2 using ecophases

AREA VII



High

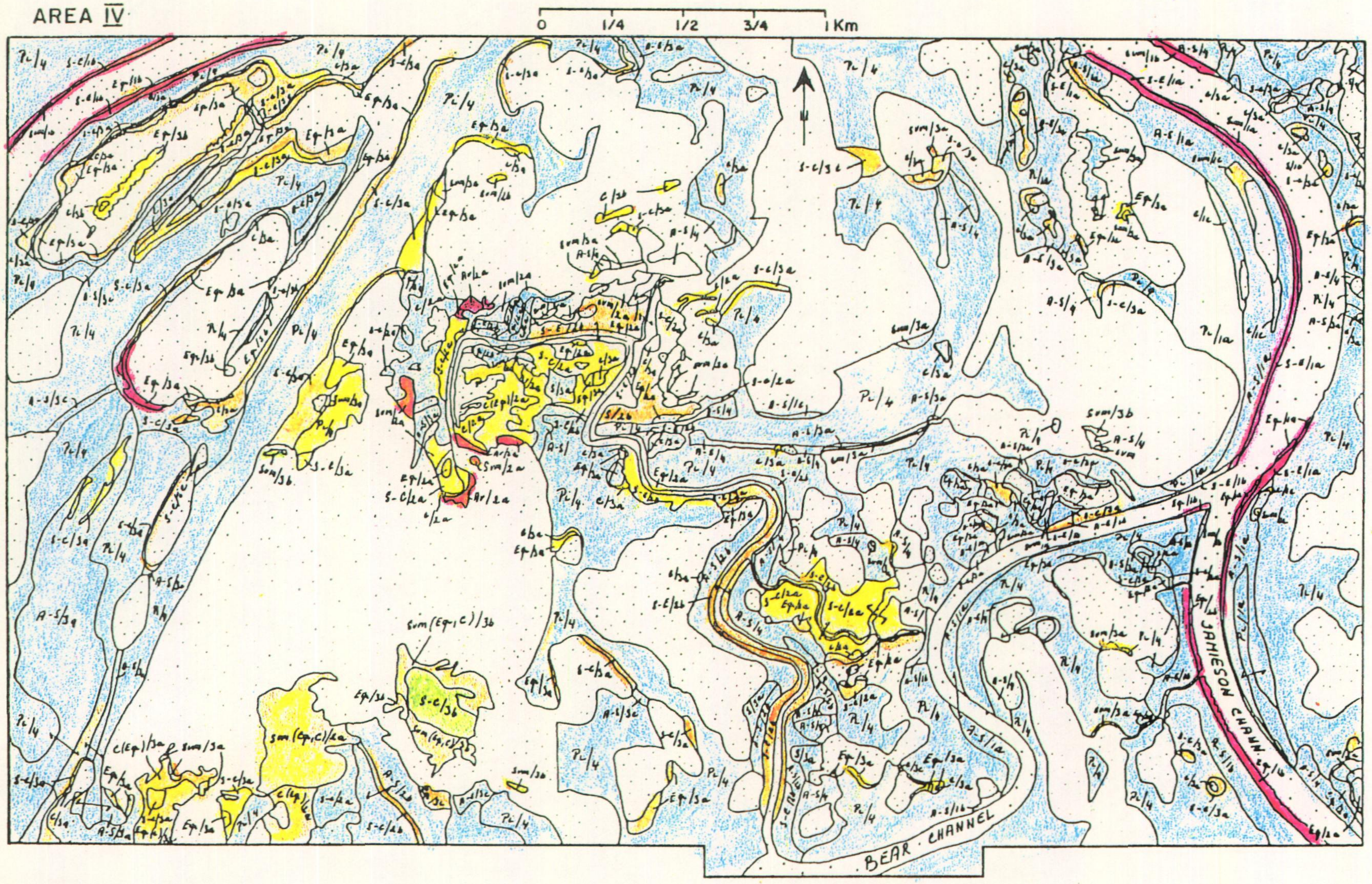
Moderate

Very low

None

Water

Figure 28: Sedimentation patterns in Area 7 using ecophases



High

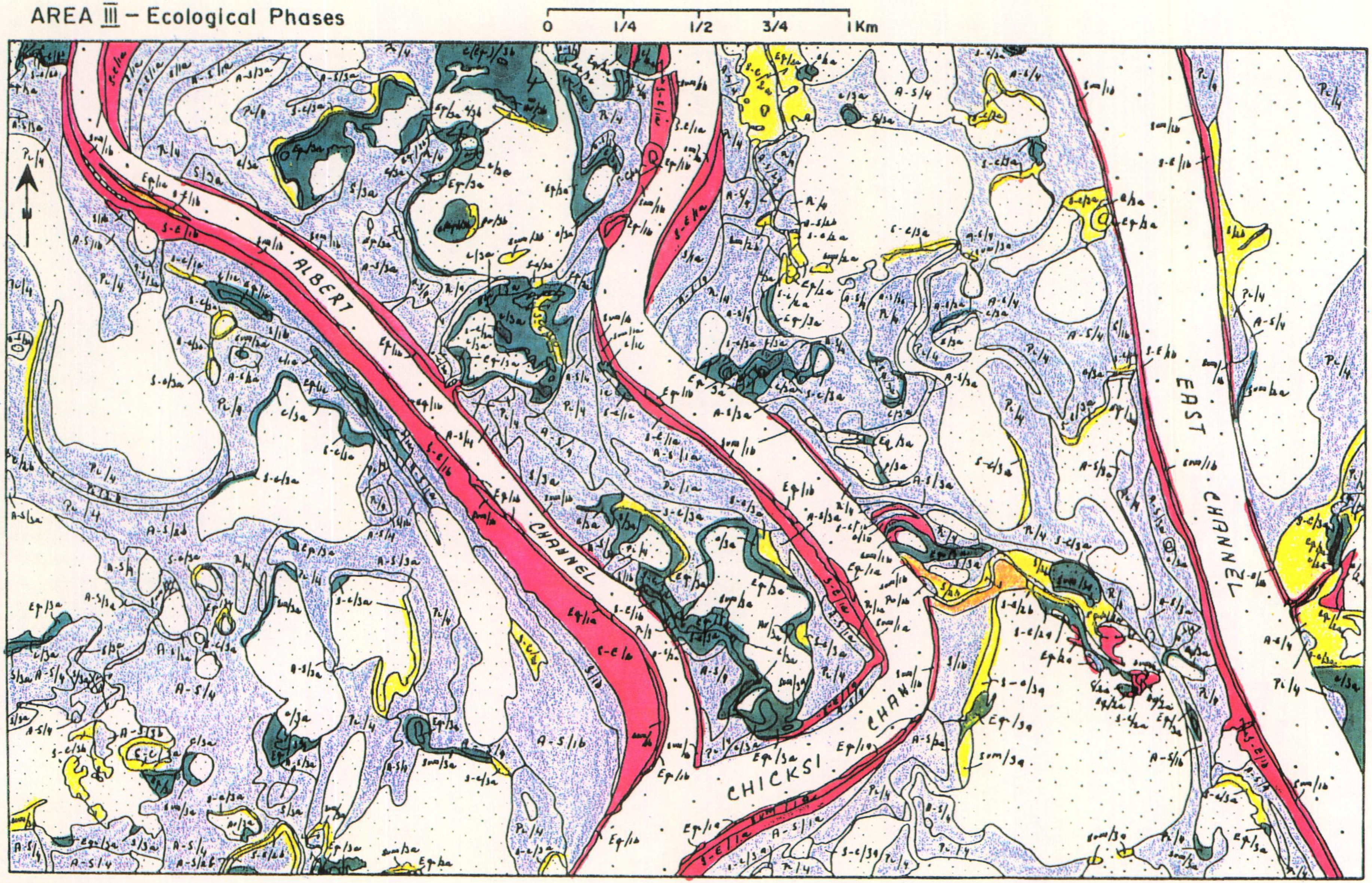
Moderate

Low

Very low

Water

Figure 29: Sedimentation patterns in Area 4 using ecophases



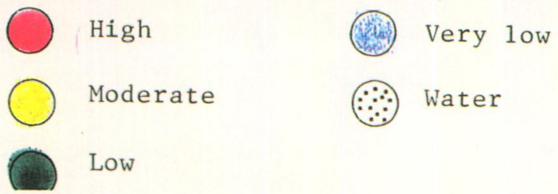


Figure 30: Sedimentation patterns in Area 3 using ecophases

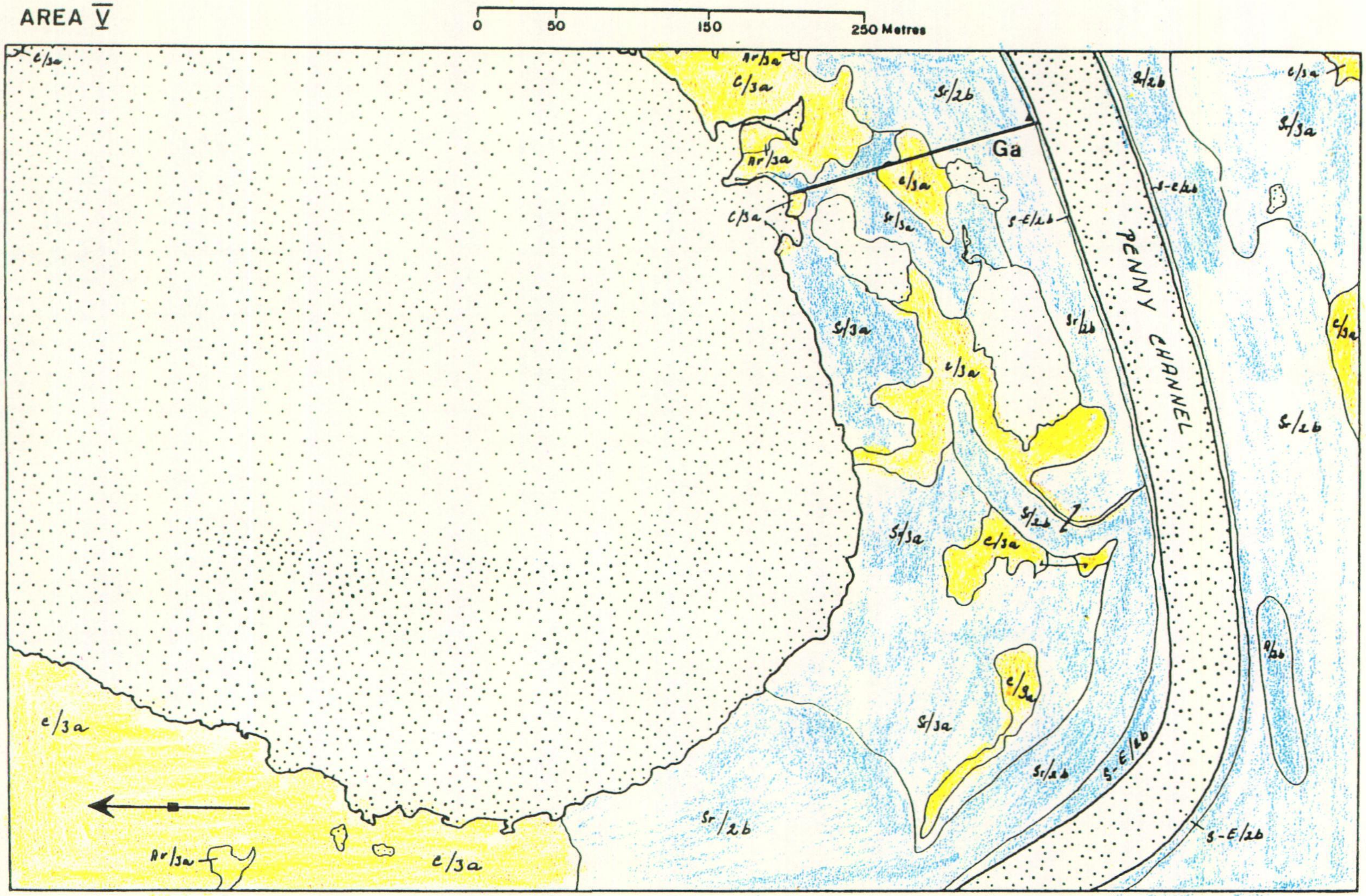
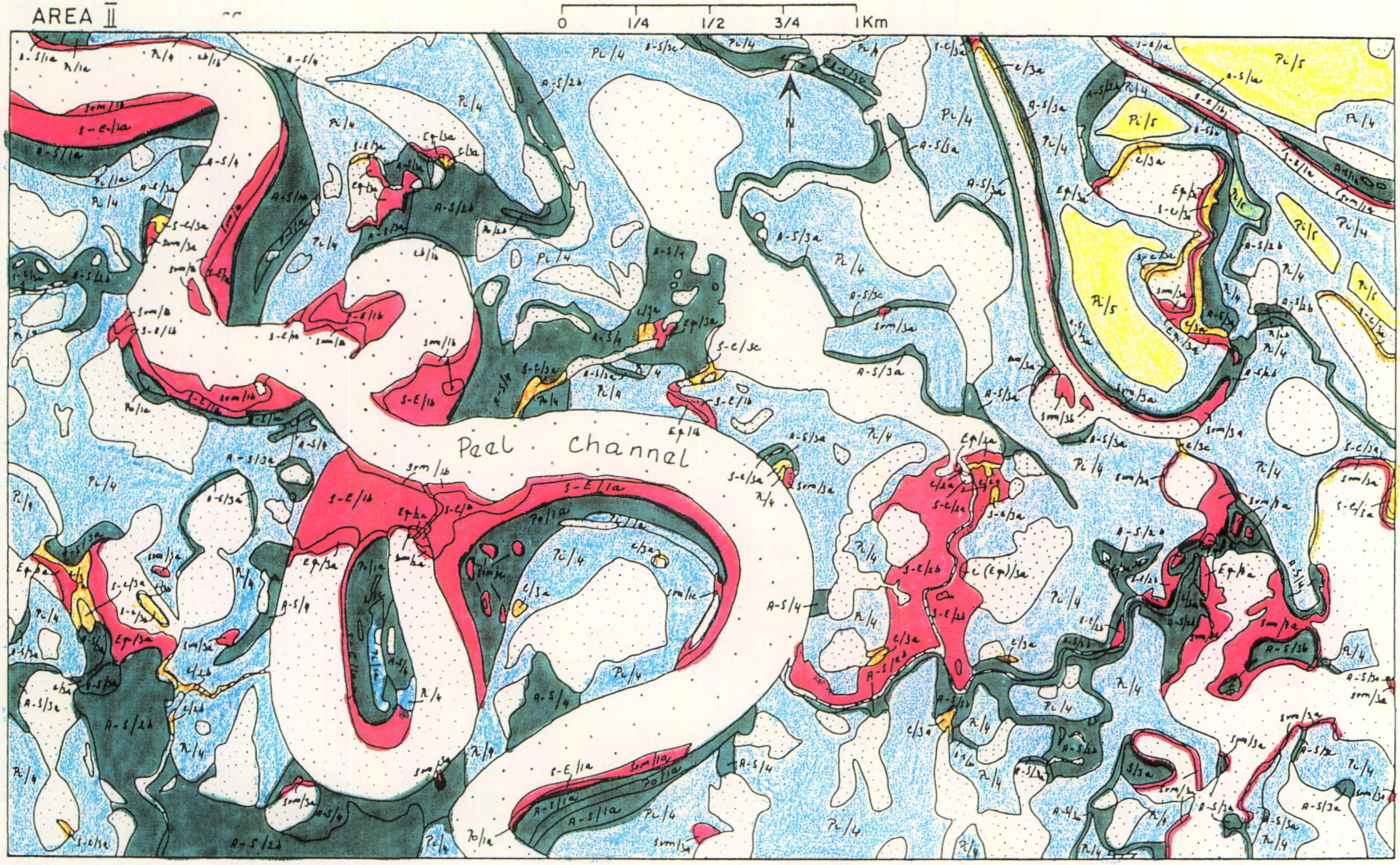


Figure 31: Sedimentation patterns in Area 5 using ecophases

Moderate

Very low

Water



High | Very low
Moderate | None
Low | Water

Figure 32: Sedimentation patterns in Area 2 using plant communities

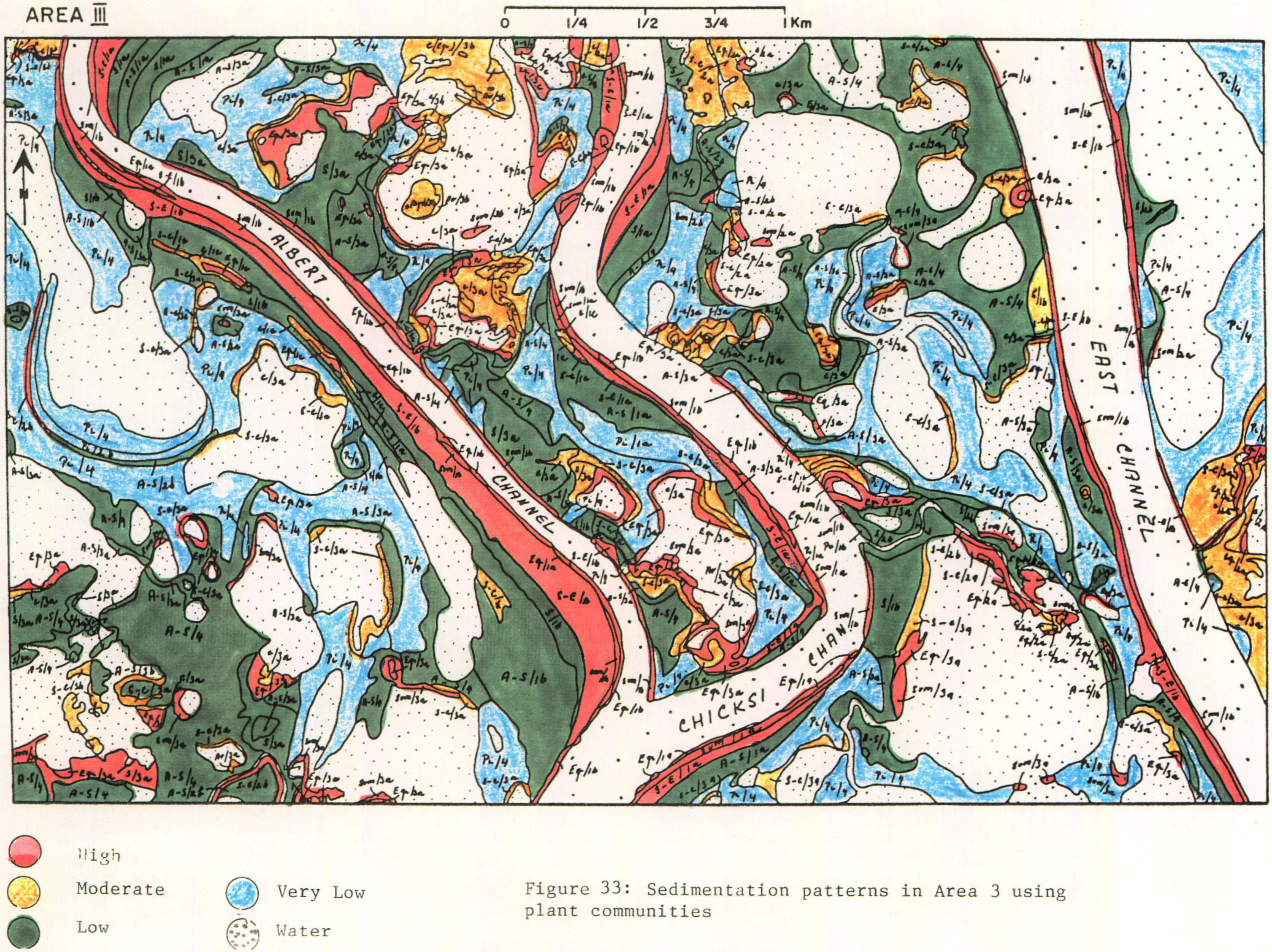


Figure 33: Sedimentation patterns in Area 3 using plant communities

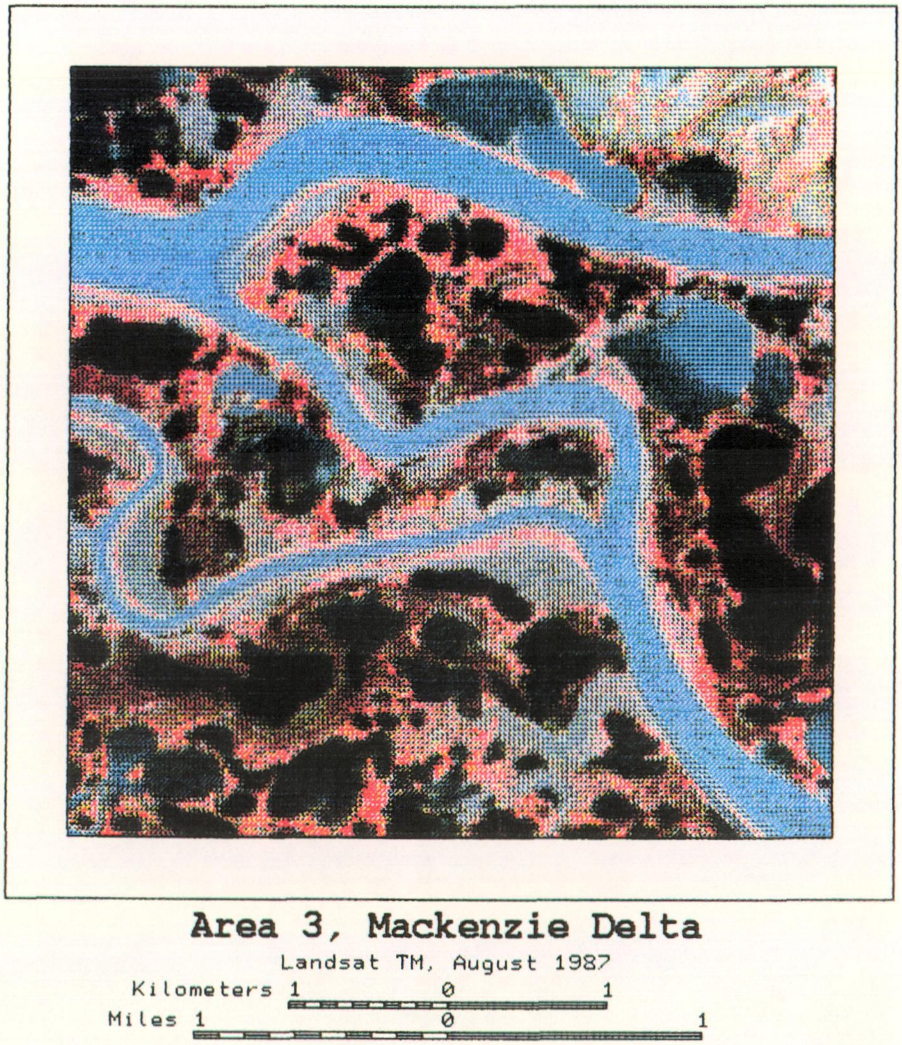


Figure 34(a): Satellite data map of Area 3 - Landsat TM
(Bands 2,3,4), August 1987

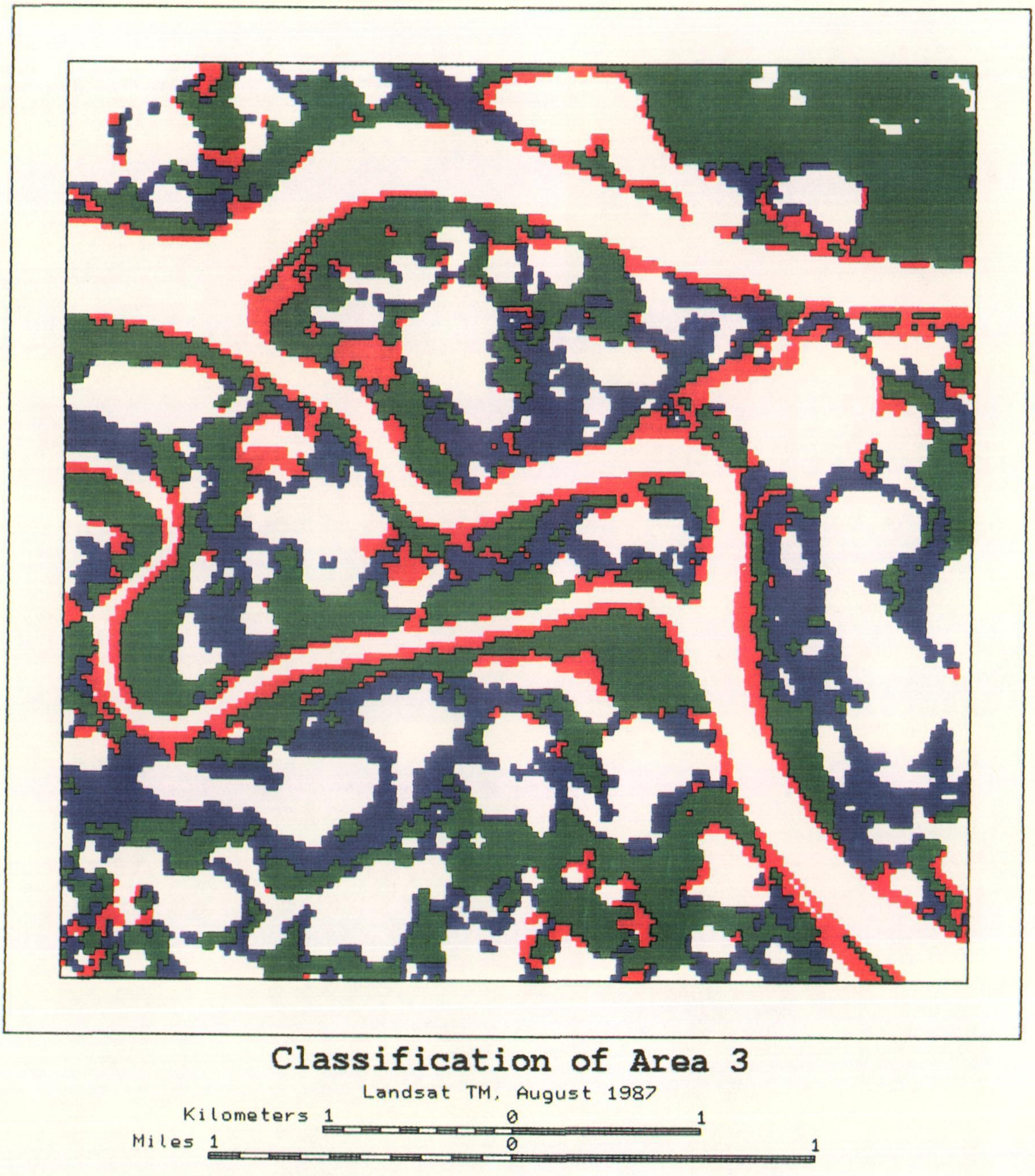
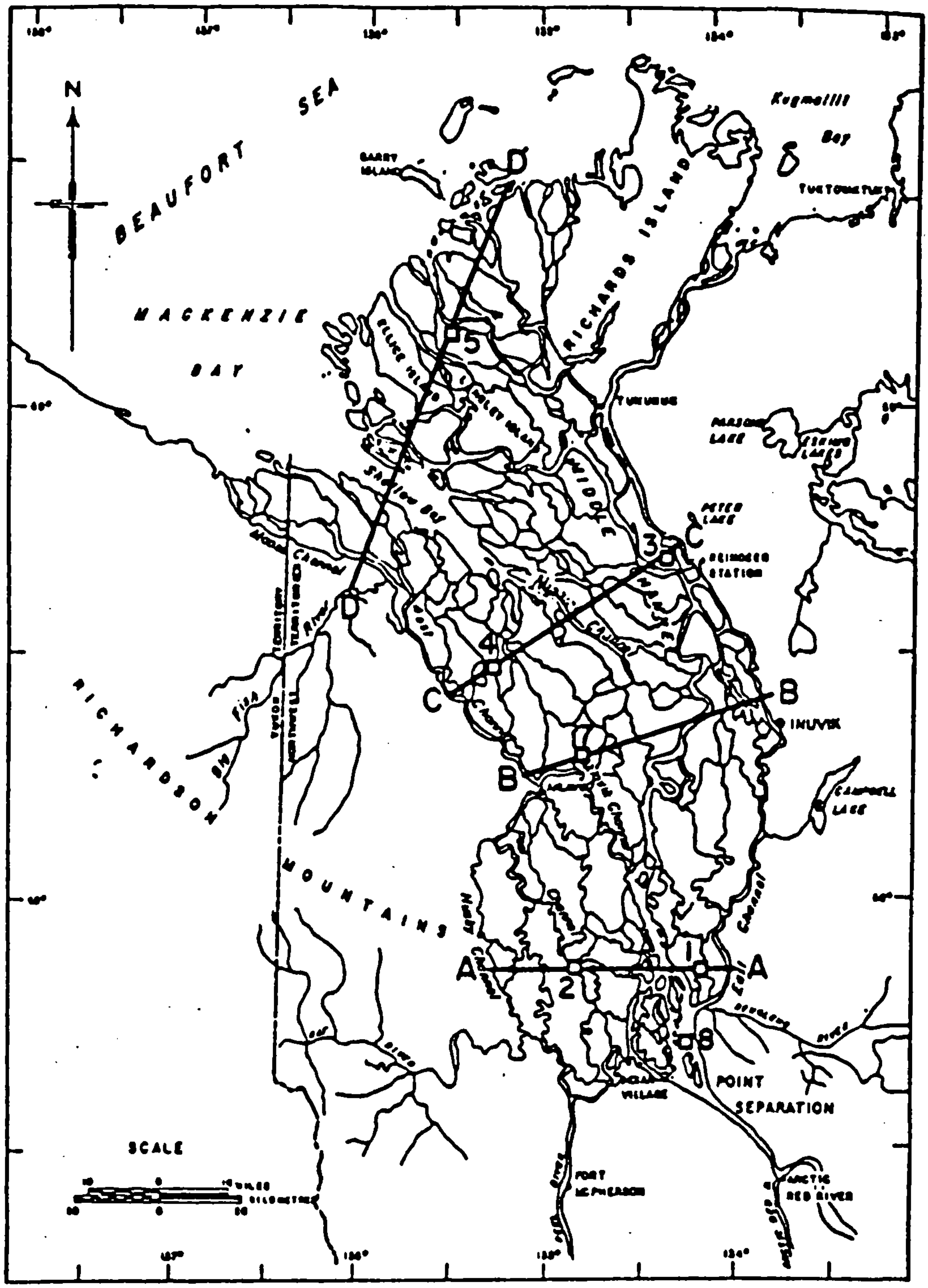


Figure 34(b): Classified satellite data, Area 3, showing sediment patterns inferred from identification of plant communities (red = high, green = low, blue = very low, white = water)



B.C. HYDRO STUDY AREAS IN THE MACKENZIE DELTA

Letters Indicate Position of Air Photo Transects

Figure 35: Photo-transects used by B C Hydro (in Carson 1991, from Blachut et al. 1985)

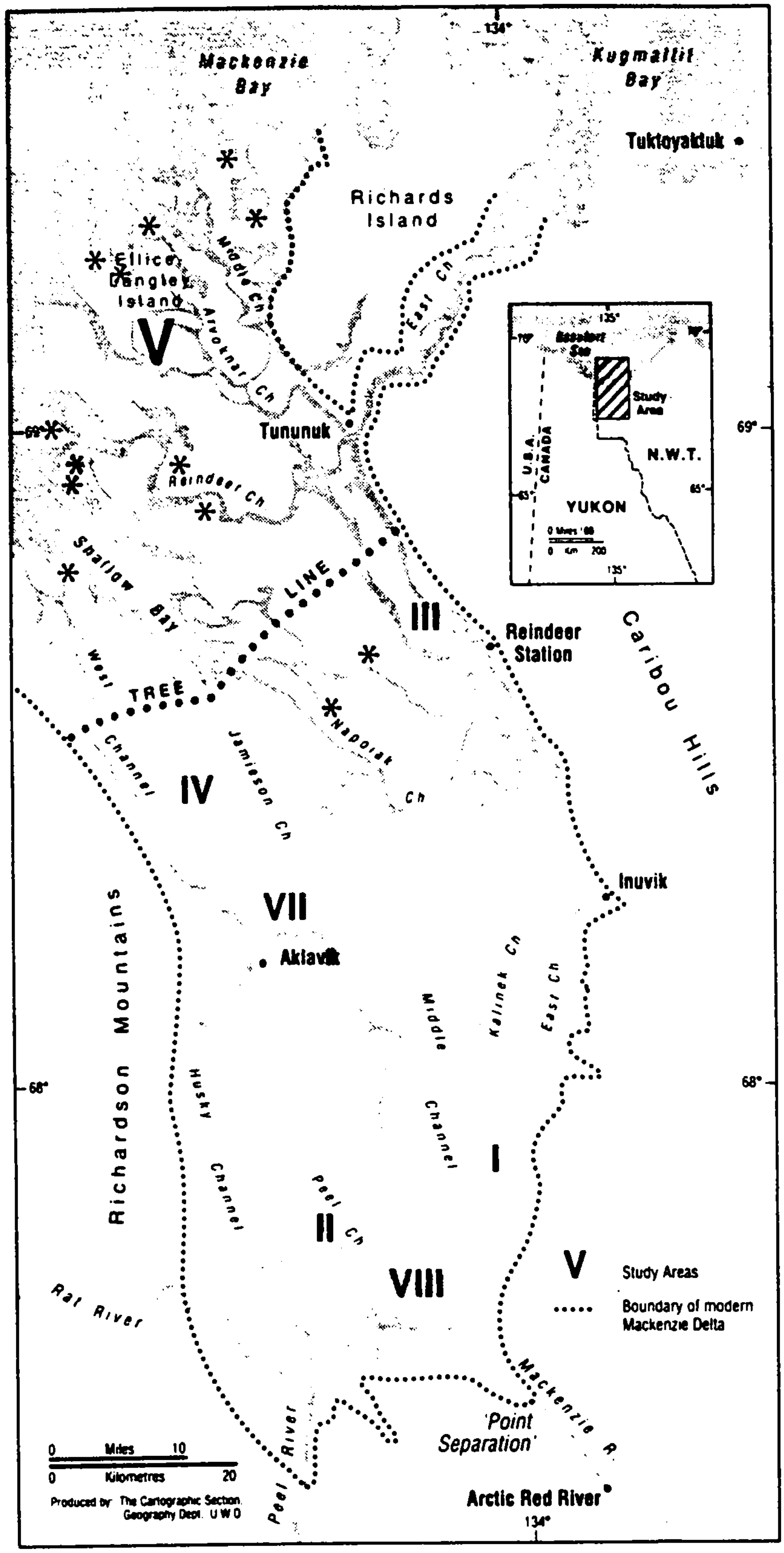
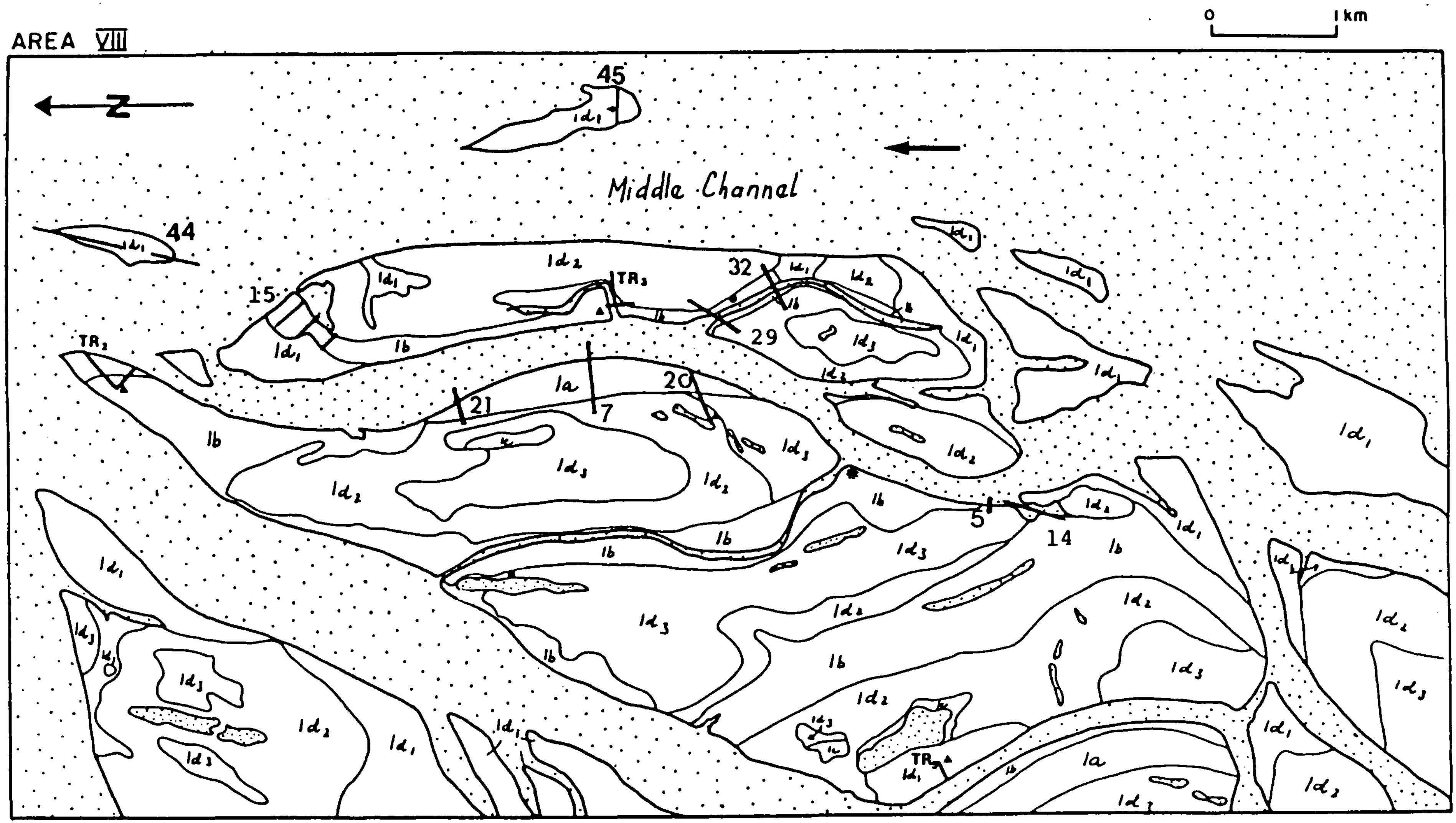


Figure 36: Suggested new areas for sediment sampling 1993-94. Also shown are some of the new study sites used by the author in 1987-1991.

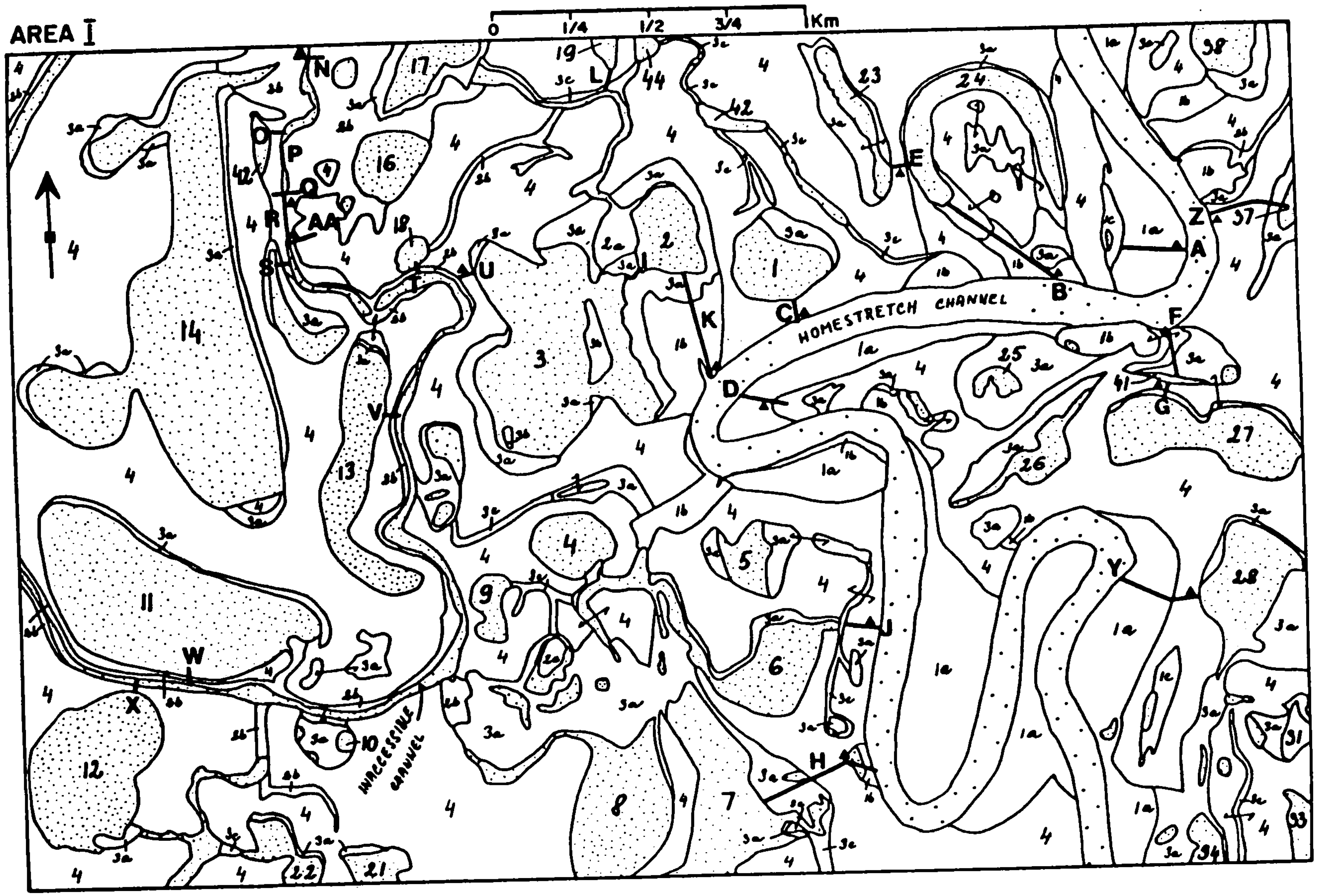
APPENDIX B

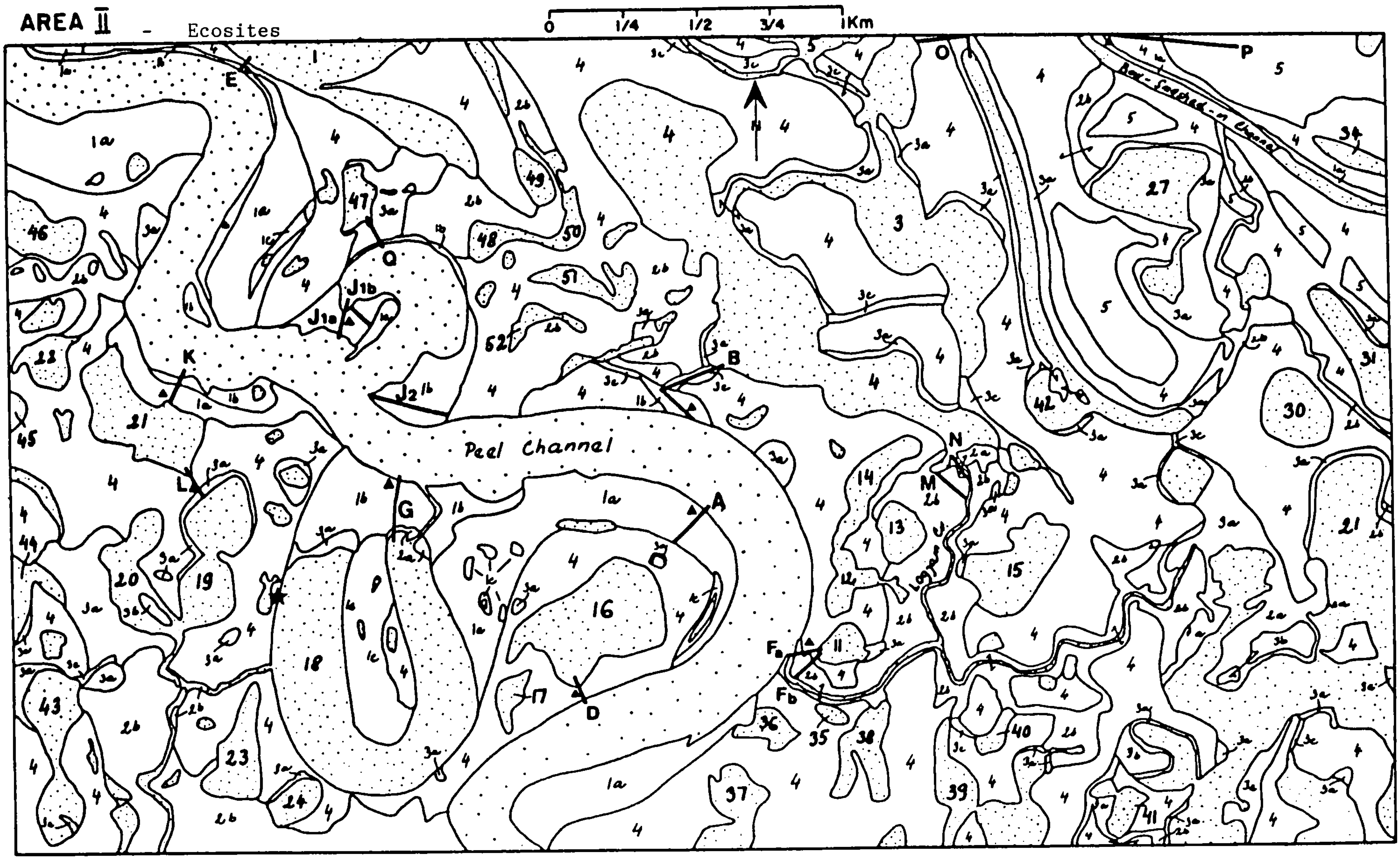
TRANSECT MAPS FOR MACKENZIE DELTA STUDY AREAS

AREA VIII


0
1 km
N
45
Middle Channel
44
15
TR3
32
29
TR2
21
7
20
5
14
TR
1a
1b
1d1
1d2
1d3

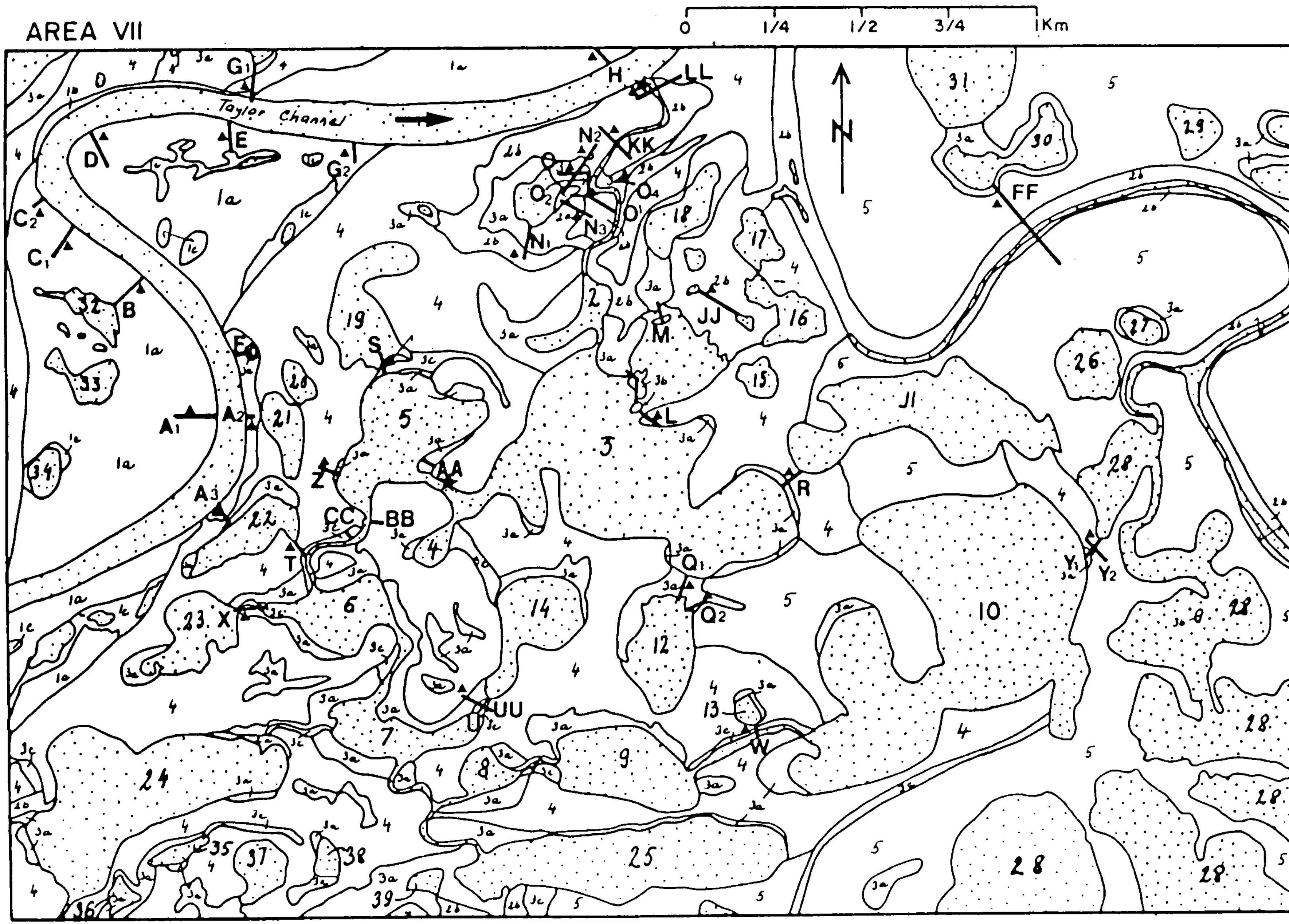
AREA I

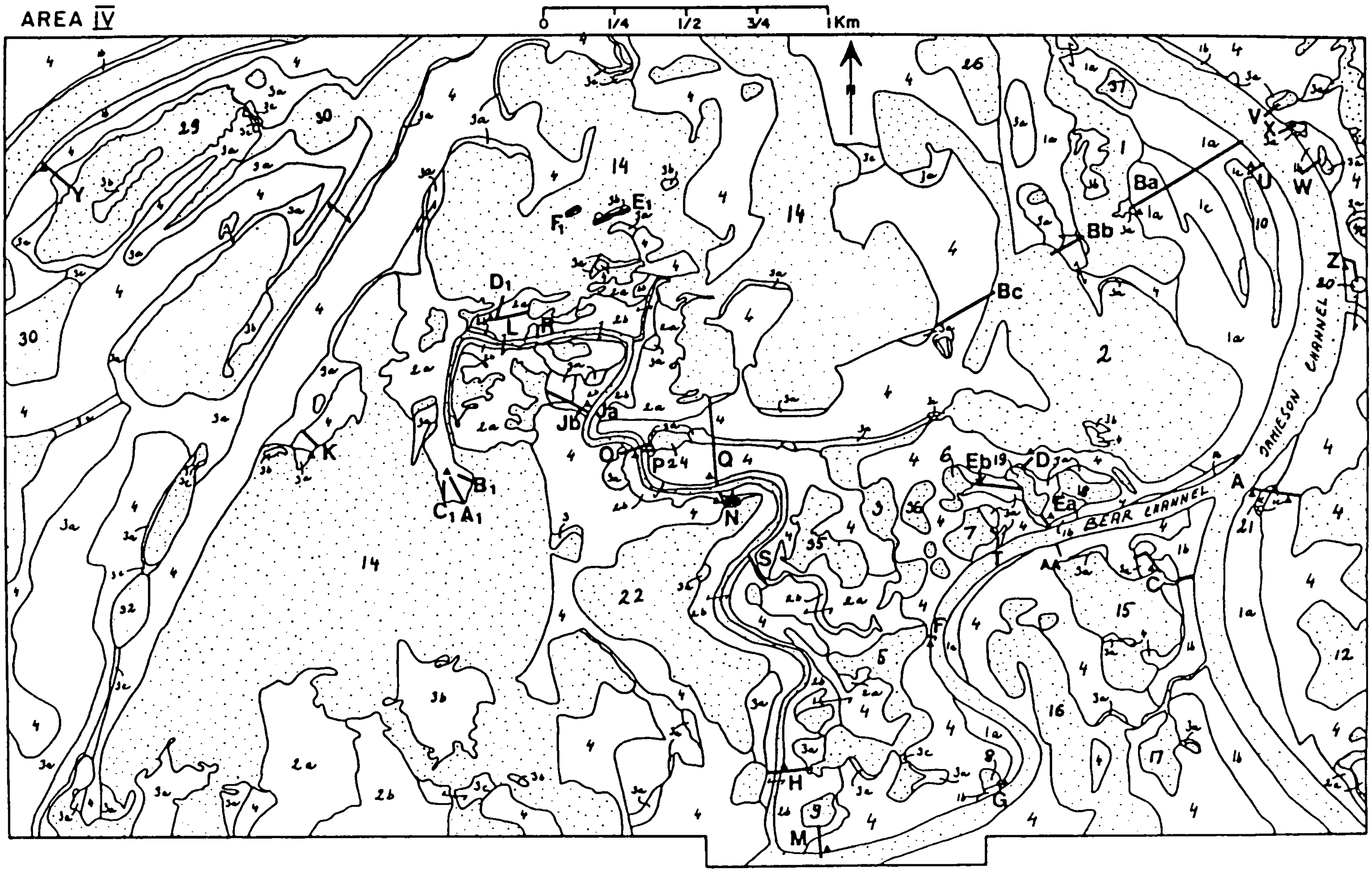




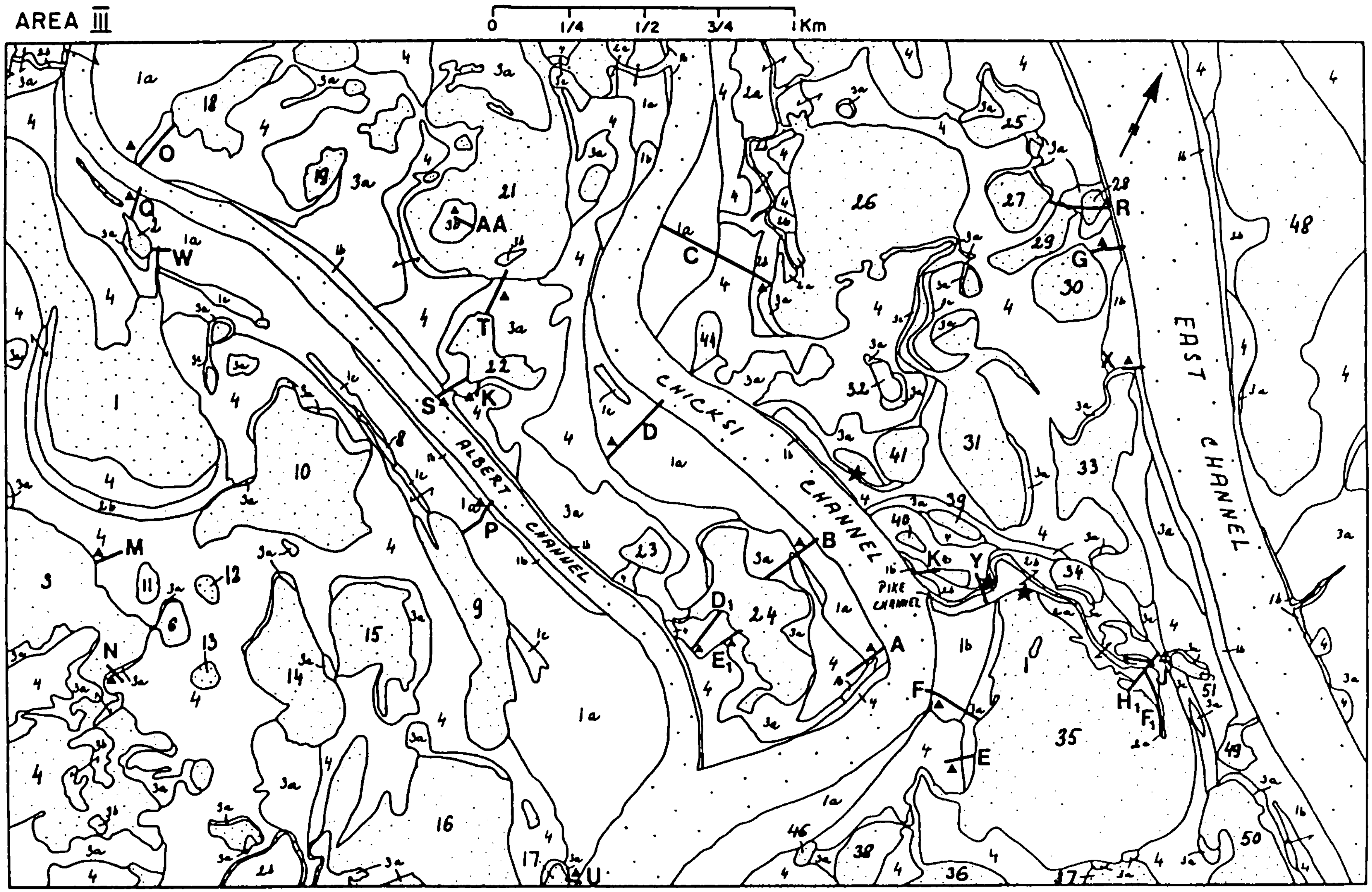
AREA II - Ecosites
0
1/4
1/2
3/4
1Km
Peel Channel

AREA VII

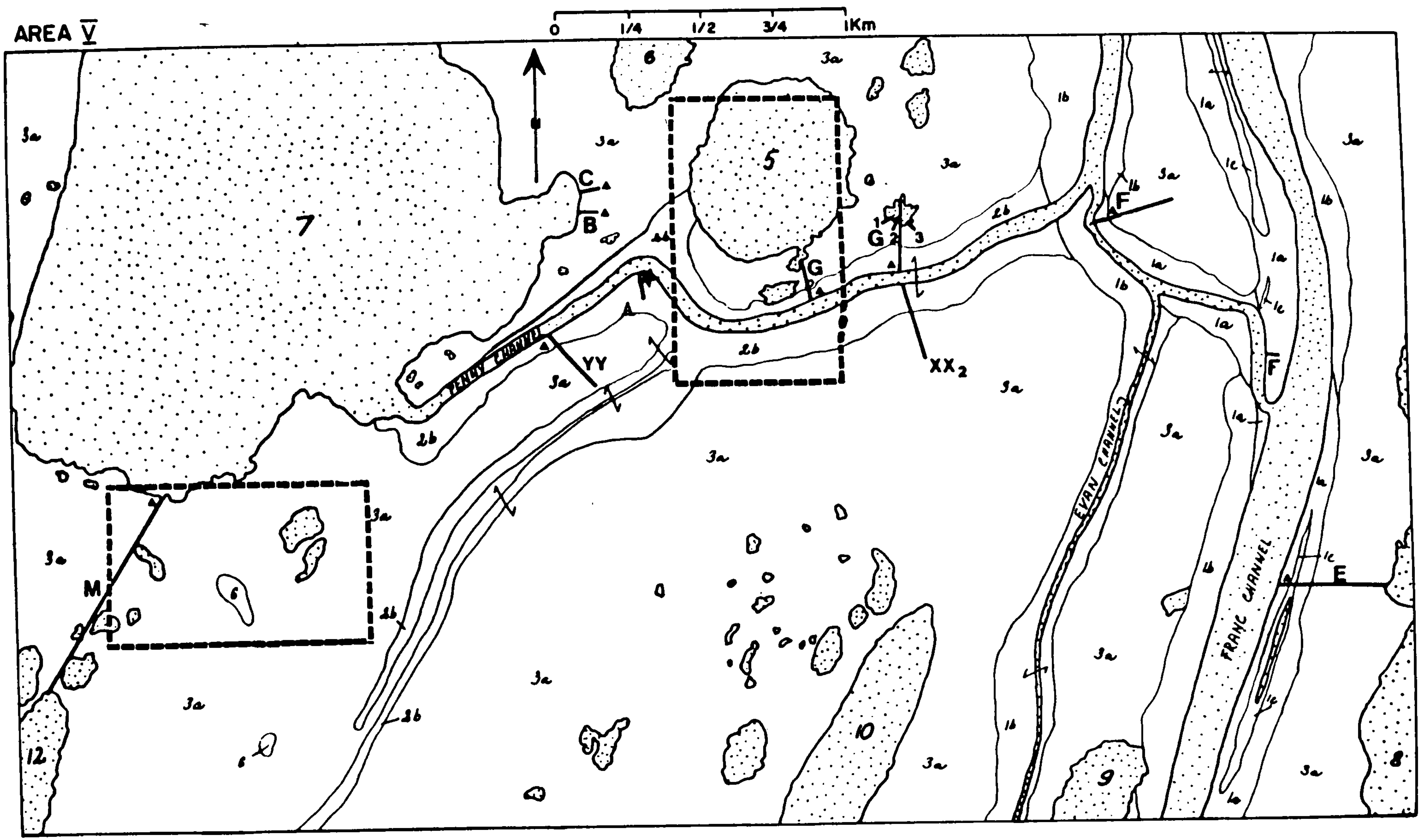

0 1/4 1/2 3/4 1Km
N
Taylor Channel
A1 A2 A3 B C1 C2 D E F G1 G2 H
JJ KK LL L M N1 N2 N3 O1 O2 O4 Q1 Q2 R S T U UU W X Y1 Y2 Z
AA BB CC FF
1a 1c 2b 3a 3b 3c 4 5 6
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 37 38 39


AREA IV
0
1/4
1/2
3/4
1Km
JAMIESON CHANNEL
BEAR CHANNEL

AREA III



0
1/4
1/2
3/4
1 Km
ALBERT CHANNEL
CHICKSI CHANNEL
EAST CHANNEL
PIKE CHANNEL



Ecosite/transect map for Area 5 in the outer delta.

APPENDIX C

VEGETATION AND SEDIMENTATION PATTERNS ON SELECTED TRANSECTS, 1980-1983

APPENDIX C

This appendix details the vegetation and sedimentation patterns on selected transects on point bars, channel levees, and lakeshores between 1981 and 1983, and for some transects, in 1992, as well.

POINT BARS

Transect II-A (Figure 7) represents the main depositional axis of point bars in the inner delta. Transect II-A was first surveyed in 1980 and used by Cordes et al. (1984), Hardy Associates (1982), and Pearce (1986) to analyze vegetation, flooding, and sedimentation patterns on inner delta point bars. Elevations were resurveyed in 1983 and have been adjusted to reflect elevation above 1982 fall low water, the datum used in Pearce (1986). Only elevations below 5.4 m (above 1982 FLW), within the sparsely vegetated mudflat (svm), horsetail (E), and lower elevations of the pioneer willow-horsetail (S-E) ecophases, were flooded in 1981, 1982, and 1983 (and presumably have been flooded every year since 1983, as well). These elevations were difficult to measure for new sediment as the vegetation was not dense or mature enough to provide an annual leaf litter layer and the survey stakes put in each year to estimate deposition were destroyed by ice during breakup. However, a rate of 15 cm/yr was estimated in 1981 and 1983 by measuring the height of erosional scarps (see Figure 8 for Transect III-3C) and the depth of sediment above nodes of horsetail plants. Overbank deposition depths of 60 cm were measured after the high 1982 spring breakup flood at 4.5 m within the pioneer willow-horsetail ecophase. This deposition eliminated the horsetails but most of the willow survived by producing new roots along buried stems, although they were bent and sometimes broken (presumably by ice rather than by the deposition of sediment).

The 1982 flood inundated most of the point bar to 110 m from Peel Channel and almost 8 m above it. Sediment deposition ranged from 60 cm within the middle elevations of the pioneer willow-horsetail ecophase as described above, 12-14 cm within the lower mature willow-horsetail (S-E) ecophase (6.77 to 7.06 m) but only 2.5 cm within the upper mature willow-horsetail ecophase on the first point bar crest, to 0.5-1.5 cm within the alder-willow (A-S) ecophase. The white spruce (Pi) ecophase on this transect was not flooded (however, spruce communities on some channel levees and lakeshores in the inner delta received 1 mm sediment).

The 1983 flood in this study area did not overtop the point bar crest and only the mudflats, horsetail, and pioneer willow-horsetail ecophases received new sediment (15 cm, 3.5 cm, and 0.5 cm respectively).

Sediment textures in 1982 ranged from 41% sand, 54% silt, 5% clay in the pioneer willow-horsetail ecophase to 30% sand, 43% silt, 27% clay in the decadent (very mature) alder-willow-poplar (A-S-Po) ecophase (Cordes et al. 1984).

This transect was last surveyed in September 1983 and was not resampled between 1983 and 1992.

Transect I-D (shown on Figure 6) was surveyed across a point bar in Area I on "Homestretch" Channel (between Middle and East Channels) in the inner delta. Sedimentation patterns between 1980 and 1983 on this point bar were similar to those on Transect II-A on Peel Channel except that the poplar (Po) community received small amounts (1-2 mm) of sediment in 1982. Some white spruce communities in Area 1 received a little sediment, as well, in 1982 because of ice-jams on East Channel that backed floodwater over this part of the inner delta. The mudflats at the lower elevations, occupied by a pioneer willow-horsetail ecophase (S-E), received up to 60-70 cm of new alluvium in 1982.

Transect III-C (Figure 8a) was surveyed across the main depositional axis of a point bar in Area 3 in the middle delta during the B C Hydro studies between 1980 and 1983, and is on B C Hydro's air photo transect C. This transect was also used by Gill for his Ph.D. studies on the Mackenzie Delta between 1966 and 1967 (Gill 1971). The low flood in 1981 (to 3.27 m above 1982 FLW) did not overtop the first bar crest. Nonetheless, 20 cm and 5 cm sediment deposition were measured in the upper mudflats and pioneer willow-horsetail ecophases respectively. In 1982, the high flood inundated the entire point bar and much of the surrounding delta plain, as well. Clay skins were measured up to 1.3 m above the delta plain ground surface on spruce trees at 4 m elevation. The mudflats and horsetail ecophases received 20 cm and 7.5 cm new sediment respectively, the pioneer willow-horsetail ecophase 11 cm, the mature willow-horsetail ecophase 4 cm, and the decadent willow (S) ecophase 1-2 cm (there is no alder-willow ecophase on this transect, but if it were present, it would occupy a similar elevation as the decadent willow ecophase). The white spruce ecophase on this transect is on the delta plain, and will be discussed later. In 1983, the breakup flood inundated the point bar to 72 m (3.5 m above 1982 FLW) depositing new sediment to the mudflat (20 cm), horsetail (5 cm), pioneer willow-horsetail (11.8 cm), and mature willow-horsetail (2.8 cm lower elevations, 2 mm to 1 cm upper elevations) ecophases.

In mid-summer in all years of the study, another 5 mm of new sediment was deposited onto the lower mudflats during increases in water levels resulting from storms.

This transect was resampled in August 1992 (Figure 8b) for sedimentation (the vegetation was resampled in 1987, 1990, and 1991). The flood in 1992 in this area must have been similar to, and perhaps even higher than, that in 1982 because clay skins were measured between 1.0 and 1.4 m on spruce trees on the delta plain. Unfortunately, the survey stakes used to measure overbank sedimentation were completely buried or destroyed except for the stake near the lower-elevation benchmark (another benchmark is located in the spruce ecophase 245 m from the channel on the delta plain). 1992 sedimentation was measured directly as the depth to the 1991 autumn leaf litter layer (if the vegetation was dense enough) or through examination of soil pits. Sedimentation patterns were very similar to those measured in 1982: 20 cm deposited onto the mudflats, 10-15 cm to the pioneer willow-horsetail ecophase, 6 cm to the lower elevations of the mature willow-horsetail ecophase but only 4 mm to the upper elevations, and 3-5 mm to the decadent willow ecophase (the spruce ecophase on the delta plain will be discussed later).

Transects VII-H (Figure 9) and IV-A were surveyed across point bars in Areas 7 (on Taylor Channel near Aklavik) and 4 (near Jamieson Channel between Aklavik and Shallow Bay and on B C Hydro's air photo transect C), both in the west middle delta. Present flood peaks in the west delta in areas dominated by flows from Peel Channel and its distributaries may be lower than in the past because extensive areas of spruce woodland occupy elevated levees on inactive point bars (see Pearce et al. 1988 for a discussion of the development of spruce woodlands on inactive delta sites). Flooding and sedimentation patterns on these transects were similar to those described for Transect III-C on the east side of the delta. On Transect VII-H, the 1981 low flood deposited sediment only to the lower elevations of the pioneer willow-horsetail ecophase and the 1983 moderate flood to the middle elevations of the mature willow-horsetail ecophase. The 1982 high breakup peak flooded all of the vegetation on this transect, depositing 3 to 12 cm into the pioneer and mature willow-horsetail, 1.5 to 2.5 cm into the lower alder but only 2 mm into the upper alder, and 6 mm to 1.0 cm into the decadent willow community. On Transect IV-A in 1982, white spruce forest on the most elevated parts of the point bar were flooded to a depth of 70 cm but only received 1 mm of new sediment, similar to the spruce on those sites on the delta plain in other middle delta areas that were flooded. Alder received only 1-2.5 mm of new sediment in 1982, the mature willow-horsetail ecophase 1.5-2.5 cm, and the pioneer willow-horsetail 20 cm.

Transect V-F (Figure 10a) was cut in 1981, was last surveyed in 1983, and was resampled in 1992. The low 1981 flood did not overtop the point bar levee and inundated only the lowest elevations of the pioneer willow-horsetail ecophase depositing 5 cm, 3 cm, and 1 cm into the mudflat, horsetail, and pioneer willow-horsetail ecophases respectively. In 1982, the breakup flood overtopped the point bar crest by about 1.2 m depositing new sediment to all ecophases: 11 cm and 15 cm onto the mudflat and horsetail ecophases, 6 cm onto the pioneer willow-horsetail ecophase, and 0.2

cm into the mature Richardson's willow-horsetail (Sr-E) and Richardson's willow-sedge (Sr-C) ecophases (not shown on Figure 10a). However, erosion dominated processes on this point bar between 1982 and 1983--44 cm were removed laterally on the mudflats and 18 cm at the lower elevations of the pioneer willow-horsetail ecophase, changing the shape of the point bar from that originally surveyed in 1981 (the 1983 surveys are shown on Figure 9). Flood levels in 1983 were high enough to completely inundate this point bar. Where erosion did not occur, 6 cm of new alluvium were deposited within the horsetail ecophase, 3-4 cm within the pioneer willow-horsetail ecophase, and <1 mm within the mature willow phases at the highest elevations.

The texture of the newly-deposited alluvium in 1982 varied from 22% sand, 51% silt, 27% clay onto the mudflats to 18% sand, 54% silt, and 28% clay into the mature Richardson's willow-horsetail ecophase (Pearce 1986).

Transect V-F was resampled in late July 1992. Although the transect was not resurveyed at this time, this point bar appears to have "flattened out" from erosion within the horsetail ecophase and the lower elevations of the pioneer willow-horsetail ecophase or substantial deposition onto the mudflats (see Figure 10b). The cutbank and part of the point bar upstream of the transect were eroding badly. None of the survey stakes used to measure sedimentation were visible. 1992 sedimentation was estimated by excavating to the fall leaf litter layer within the willow ecophases--8 cm at the lowest elevation of the pioneer willow-horsetail ecophases, 4 cm at the benchmark, 5 mm in the middle of the Richardson's willow-horsetail ecophase, and 3 mm within the Richardson's willow-sedge ecophase--but the sediments were much too wet to measure new deposition onto the mudflats.

MAIN CHANNEL LEVEES

Transect II-J1b (Figure 11a) was surveyed in 1981 across a rapidly-aggrading levee between Peel Channel and a cut-off meander loop in Area 2 in the inner delta. The low-elevation levee had built almost across the loop by September 1983. Aggradation rates could not be measured on the mudflats because these substrate were very saturated during all field seasons and impossible to traverse. However, mean aggradation rates of 2.5 to 6 cm/yr were estimated from excavation of willow within the pioneer willow-horsetail ecophases between 3.37 m and 4.3 m elevation (willow 6 to 14 years old). Most of these sediments appeared to have been deposited during the high flood in 1982. Aggradation rates of 11 to 15 cm/yr for the mudflats were estimated by Cordes et al. (1984).

Erosion and not sedimentation played a major role in the flooding regime and plant succession on an older levee (sampled by Transect II-G, Figure 11b) which had formed almost completely across another cut-off meander levee opposite Transect II-J1b, also on Peel Channel. A small channel connected the deep oxbow lake behind this levee to Peel Channel throughout the open water season. Between July 1 and August 10, 1981 a series of local storms with very strong winds raised water levels 30 to 70 cm in Area 2, eroded sediments from the foreslope of the levee to 3 m above Peel Channel, and formed a steep cutbank beyond a wide, gently-sloping mudflat (see Figure 11b). This erosion removed a section of substrate 3 m x 5 to 10 m from the levee, along with willow and alder 3 to 20 years old. However, sedimentation during 1982 and 1983 (and presumably in following years unless there have been other big storms in the area) had started to build up the mudflat once again.

Transect III-JJA was cut in 1981 across a low closure shoreline of Lake 40 and Chicksi Channel in Area 3 in the middle delta (Figure 13). Elevations across this levee are very low (only to 0.68 m above 1982 FLW in 1983) and it must be flooded during every breakup (it may also be overtopped by waves during particularly severe storms). The water table was just below the surface on the levee, and seasonal freezing and thawing within these saturated sediments displaced the survey stakes that were put in to measure annual sediment rates (this did not appear to be a problem in the drier, coarser-textured channel substrate). The only way that sedimentation rates could be measured on this levee between 1981 and

1983 was by digging to the initiation noda of the few willows that had colonized the site, measuring the depth from these nodes to the present surface, and then aging the plants. Using willow 3 to 6 years old, mean aggradation rates of 1 cm/yr (near Lake 40) to 6.5 cm/yr (nearer Chicksi Channel) were estimated for the higher elevations on this site.

This levee was revisited in 1992. The bench mark for this transect had been located on an old willow on the highest elevations of the channel levee adjacent to the closure, but ice and erosion have destroyed the site. The mudflats on Chicksi Channel and the pendant grass (Ar) on the lower shoreline of Lake 40 have been colonized by horsetail. Ten cm of new alluvium had been deposited into the sedge (C) ecophase at about 0.6 m elevation during 1992 breakup.

LAKESHORES

Transect III-24-D was put in across the shoreline of a connected lake (#24) adjacent to both Albert and Chicksi Channels in Area 3 in the middle delta (Figure 15). A short distributary connects this lake to Albert Channel. Sedimentation rates of 3-4 cm/yr into the horsetail (Eq) ecophases between 5 and 20 m and 22 and 38 m from the lake were estimated from willow 3 to 6 years old. Sedimentation into the sedge (C) ecophases was measured directly after flooding and drawdown: 1.0 cm in 1981 and 1983 and 0.5 cm in 1982 at 0.86 m elevation 20 m from the lake, and 1.0 cm, 2.5 cm, and 2.5 cm in 1981, 1982, and 1983 respectively at 0.8 m elevation 45 m from the lake. Sedimentation into the pioneer willow-sedge (S-C) ecophase at the benchmark varied from 1 cm in 1981 to 3 cm in 1982. Overbank flooding in addition to lake flooding in 1982 and 1983 could account for the higher rates at the elevations further from the lake (but closer to the channel levees).

Water levels were very high in this lake during the 1992 sampling period and only the pioneer willow-sedge ecophase could be measured for sediment. New sediments 3 to 5 cm deep were measured (mean 3.5 cm), but much of the sediment appeared to have been deposited from over the channel levee rather than from the lake as they were loamy in texture. The benchmark had been destroyed by the 1992 or an earlier flood.

Figure 16 shows a transect put in, in 1981 across the shoreline of Lake 48 adjacent to East Channel, also in Area 3. Floodwater breached the levee of this once closed lake in 1981 and the lake has drained to the levels of East Channel. The cutbank (cb) at 1.14 m (above 1983 FLW) marks the former shoreline. A mudflat (the former lakebed), colonized by seedlings of sedge and willow, extended for 20 m into the lake by 1983 and 30 m by 1992 when this area was revisited. A small distributary channel, 5 m wide by 1992, now connects the lake to East Channel throughout the open water season. However, even with the very close proximity of the lakeshore to a main delta channel, only 10 cm (on average) of sediment has been deposited onto the mudflats between 1981 and 1992.

Most of the lakes in the outer delta study area are closed rather than connected to delta distributaries. However, Transect V-B (Figure 17) was cut across a shoreline on Lake 7 (see Appendix B for location) connected to Arvoknar Channel via "Penny" and "Franc" Channels. Lakeshores in the outer delta are densely vegetated with sedge and Richardson's willow, and mudflats such as on this transect are rare. On this lakeshore, the only sediment that could be measured each year was on lower leaves and branches of sedge and willow because of the thick buildup of leaf litter between the ground surface and the living plants that trapped the alluvium within the litter. Thus, these measurements may be low. No sediment was observed during sampling in 1981, but in both 1982 and 1983 at least 2.5 cm was deposited into the sedge-cottongrass (C-Er) ecophase and only 2 mm into the Richardson's willow-sedge (Sr-C) ecophase. No new sediment was observed within ecophases beyond 20 m from the lake.

This lakeshore could not be measured for sediments during sampling in 1992 because of very high water levels in Area 5 at the end of July that flooded the shoreline right into the Richardson's willow-sedge ecophases. No new sediment was observed in the highest elevation ecophases that were above water.