GUIDEBOOK 2

GUIDEBOOK TO PERMAFROST AND RELATED FEATURES OF THE COLVILLE RIVER DELTA, ALASKA

By

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Cover photo: *NASA U-2 photograph showing about 25 square miles of the northwestern Colville River Delta. Included are the Sakoonang Channel (largest), the Tamayayak Channel (entering the Sakoonang), and Tolaktovut Point (northernmost point).*

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GUIDEBOOK TO PERMAFROST AND RELATED FEATURES OF THE COLVILLE RIVER DELTA, ALASKA

By
H.J. Walker[1]

INTRODUCTION AND ACKNOWLEDGMENTS[2]

The Colville River Delta (fig. 1), located about halfway between Barrow and Kaktovik (Barter Island), is the terminus of the Colville River, which drains 29 percent (60,000 km^2) of the North Slope of Alaska. Most tributaries of this river head in the Brooks Range and flow northward across the Arctic Foothills and Arctic Coastal Plain before reaching the Arctic Ocean. From the standpoint of the development of permafrost and permafrost-related forms, the 600-km^2 delta is situated in one of the most ideal locations in North America (fig. 2).

Basically, the Colville River Delta differs little from most deltas around the world. It has a large drainage basin (about 100 times its own area) and a large receiving basin (the Arctic Ocean); is composed of both subaerial and subaqueous portions; and has migrating distributary channels, lakes of various types, natural levees, sand dunes, sand bars, and mud flats. However, unlike most deltas, it also includes ice wedges, ice-wedge polygons, frost mounds, and pingos, all of which are related to permafrost. In addition, permafrost is important in deltaic modification because it influences the volume, timing, and character of river discharge and the nature of delta erosion. Emphasis in this field guide is placed on those deltaic forms and processes that are associated with or determined by permafrost.

This field guide is dedicated to Nannie Woods, her late husband, George, and those of her children and grandchildren who, for over 20 yr, have given assistance and encouragement to me and my colleagues and students in our endeavors to understand the environment of their homeland, the Colville River and its delta in arctic Alaska. I thank R.D. Reger (DGGS) for his thoughtful review of the manuscript.

DELTA MORPHOLOGY AND PERMAFROST

Although open taliks exist below the deep channels and lakes within the Colville River Delta (about 15 percent of the surface area), permafrost is

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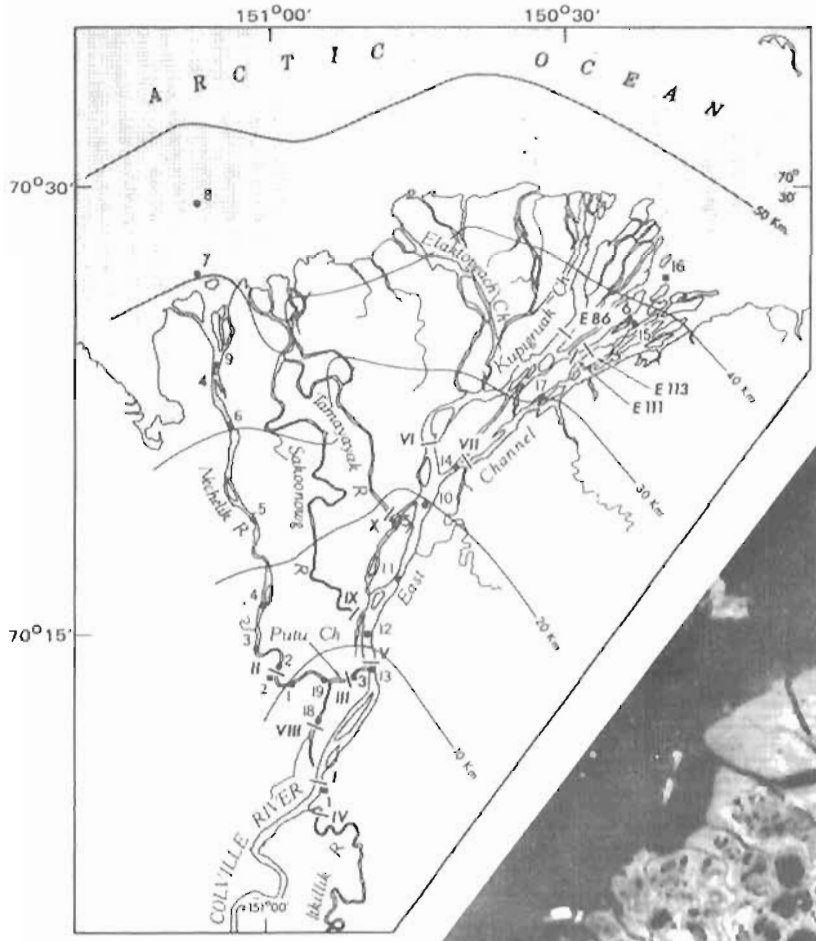
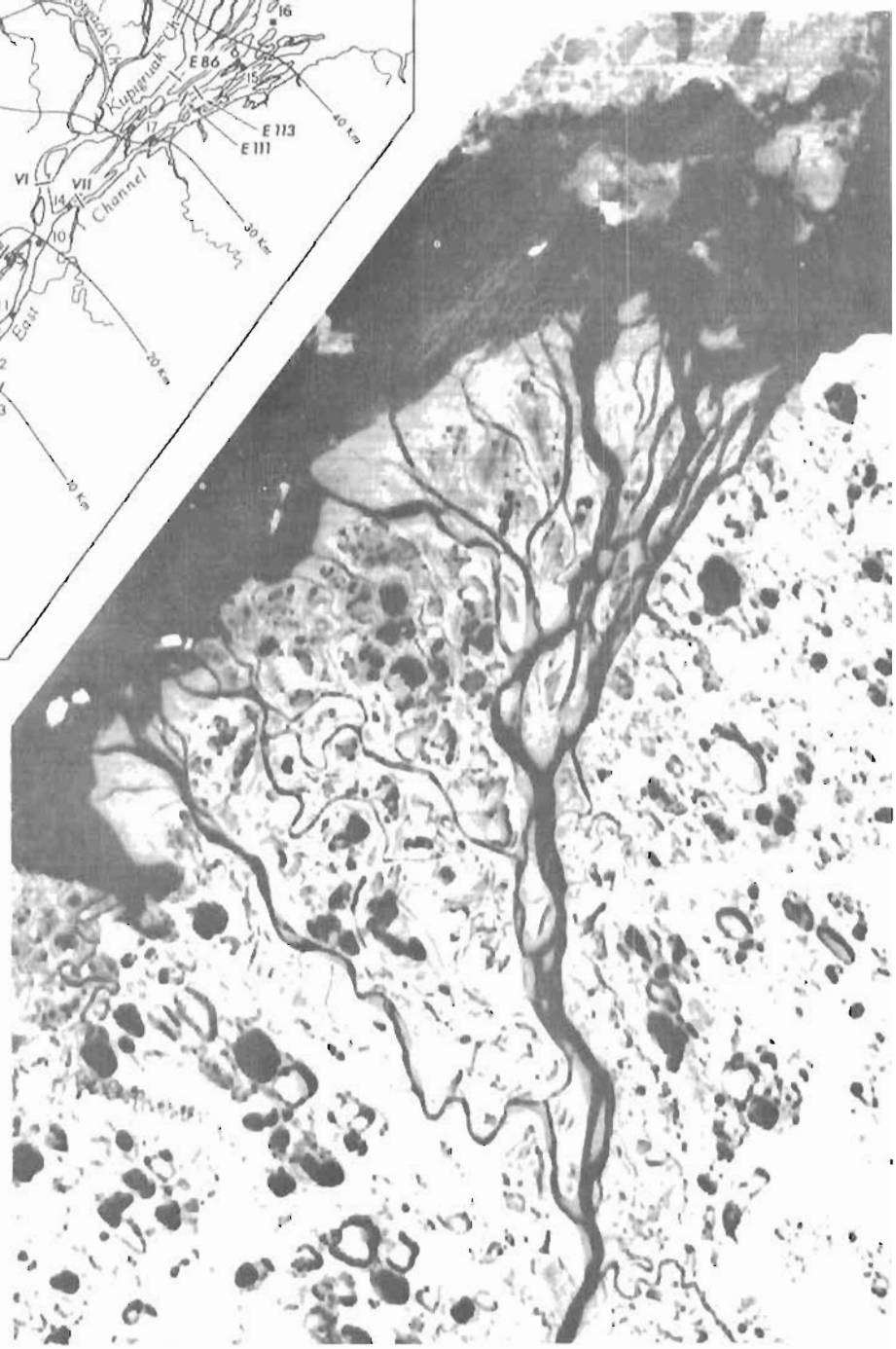
[1]Department of Geography, Louisiana State University, Baton Rouge, Louisiana 70803.

[2]A number of articles have been published by the author and his colleagues and students as a result of field and laboratory research on the Colville River drainage basin and delta during the last 20 yr. Nearly all topics in this field guide have been discussed in some detail in these papers, the most relevant of which are cited. To keep documentation within the text to a minimum, they are not cited in the text. However, points stemming from papers published by other individuals or teams are referenced. Most research for these articles and for this report was funded by the Office of Naval Research and the North Slope Borough and was supported in the field by the Naval Arctic Research Laboratory.



A. Location map with several sample-collection sites.



B. NASA ERTS E-1345-21342-702, Band 7, July 3, 1973.

Figure 1. The Colville River Delta and adjacent environments, Alaska.

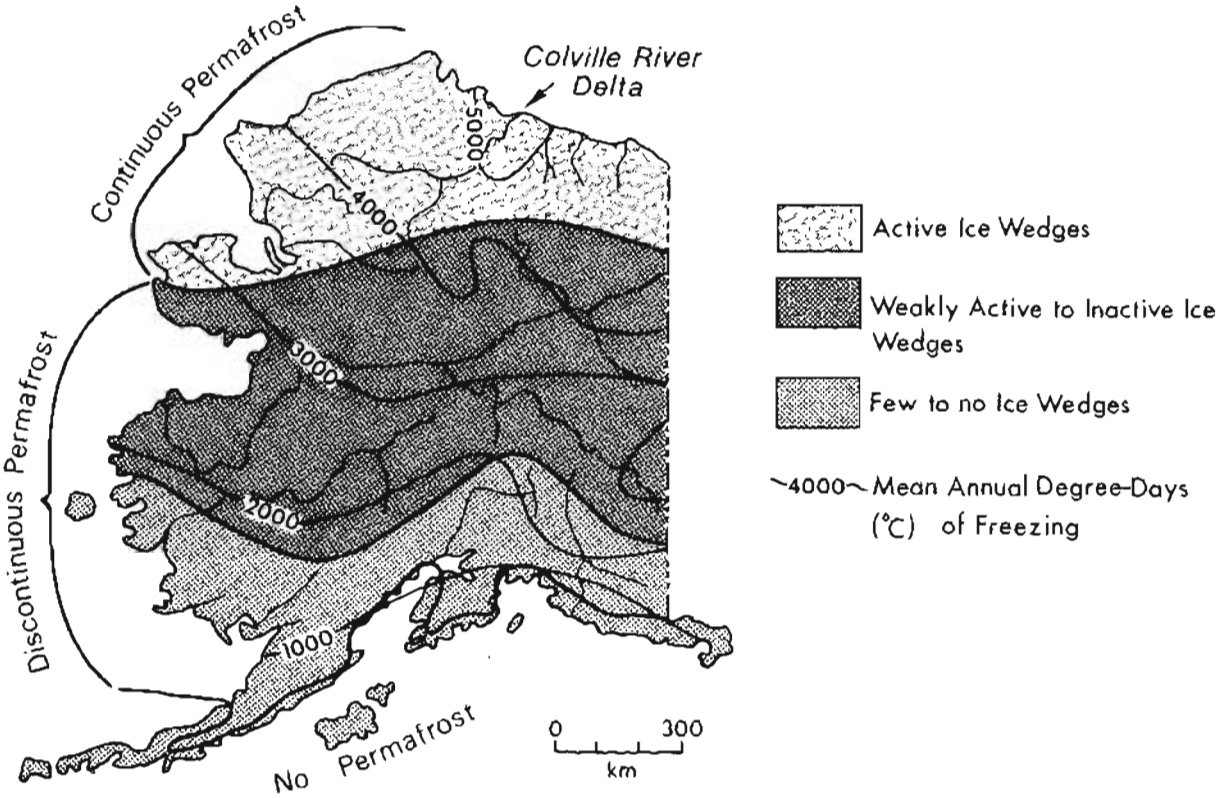


Figure 2. Degree-days of freezing, permafrost zones, and ice-wedge activity in Alaska (adapted from Péwé, 1966).

dominant, and few deltaic forms escape its influence. Exceptions include small surficial, ephemeral forms such as sastrugi, which are nearly ubiquitous on the snow surface in winter, and barchans, which frequently form on sandbars in summer. For convenience of description, deltaic forms are divided into the following groups: a) distributary channels and other streams, b) lakes and ponds, c) river banks and lake banks, including sandbars and mud flats, d) sand dunes, e) pingos and frost mounds, f) ice wedges and polygons, and g) microforms.

Distributary Channels and Other Streams

The Colville River Delta heads over 40 km upstream from its eastern mouth (fig. 1). Formerly, the head of the delta was 5 km farther upstream, but the initial diversion point has migrated oceanward. Most water reaching the head of the delta is carried to the ocean through two distributaries, the main channel of the Colville (East Channel) and the Nechelik (westernmost) Channel. Together, these two channels carry about 90 percent (about 70 percent in the East Channel alone) of the total flow during flood period and up to 99 percent during the rest of the hydrologic year. Several other distributaries branch from the East Channel, including the Sakoonowg, Tamayayak, and Elaktoveach Channels. Combined, they transport about 10 percent of the water flowing to the ocean during breakup (fig. 3), but very little during the rest of the year.

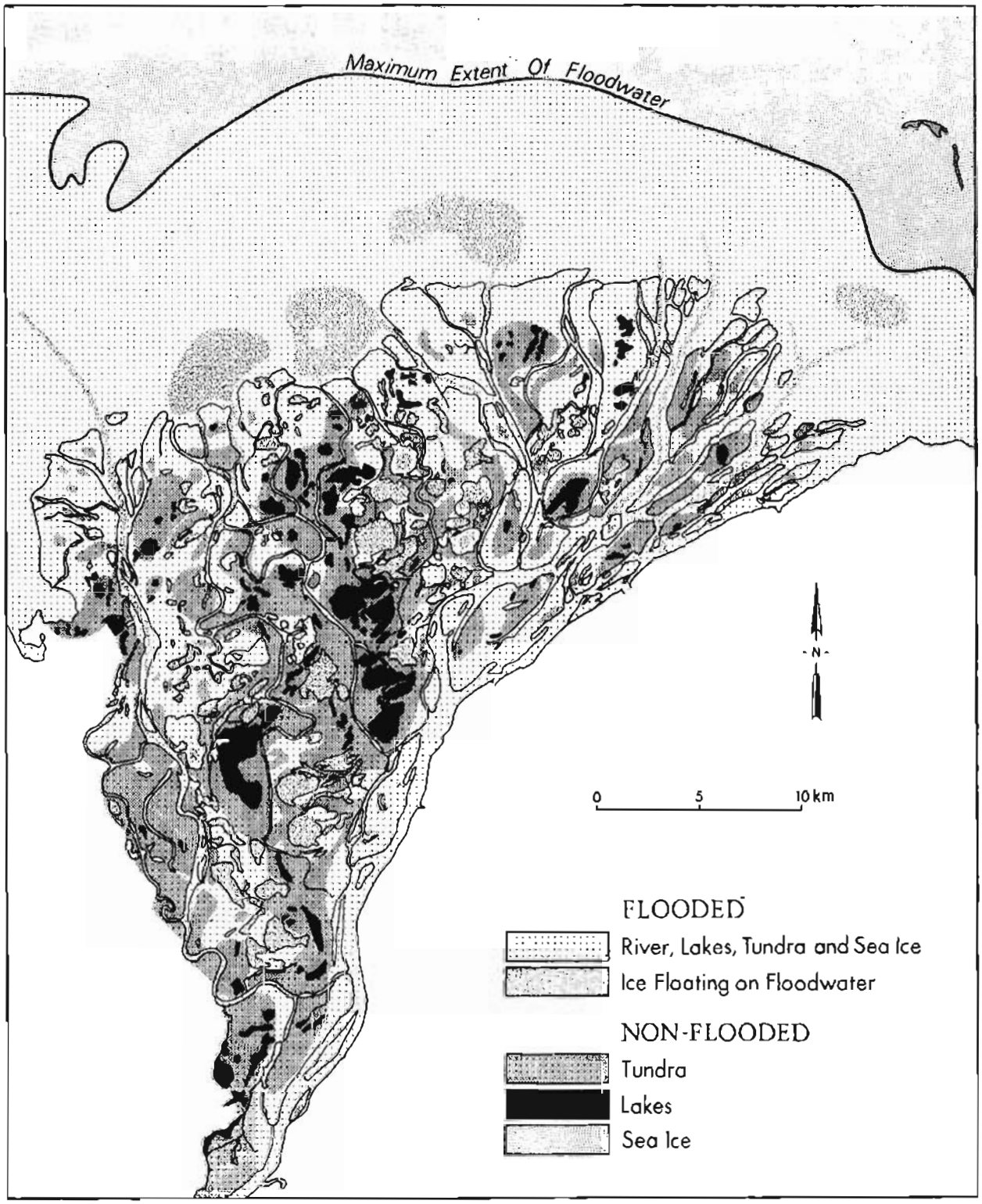


Figure 3. The Colville River Delta, Alaska, during typical flooding in late May.

The Colville and Nechelik Channels vary greatly in depth and width. The thalweg of the main channel is deep enough to remain open beneath the ice throughout winter, whereas the other channels, including Nechelik Channel, have reaches that freeze to the bottom during winter, thus blocking seawater intrusion for part of the year. Maximum depths (as much as 12 m) occur adjacent to cut banks, at entrances to tapped lakes, and at heads of inter-channel islands.

Flowing into the delta are a number of streams that drain the tundra. Some drain lakes of various types, including oriented lakes that are common both east and west of the delta (fig. 1B); few streams are beaded (fig. 4A). Within the delta, short streams have developed either as connecting channels in small deltas that are forming in tapped lakes (fig. 4B) or as drainage channels from interdistributary surfaces. These streams are especially functional during snowmelt.

Lakes and Ponds

The Colville River Delta is a maze of lakes and ponds that range in length up to 3 km, in area from small ponds covering a few square meters to over 2.5 km^2, in depth up to 8 m, and in shape from regular to very irregular and from circular to extremely elongate (fig. 4B). Most are shallow and freeze to the bottom during winter, and the majority are associated with ice-wedge polygons. Types of lakes within the delta include: a) oriented lakes, b) abandoned-channel lakes (fig. 4C), c) point-bar lakes, d) perched ponds (fig. 4D), e) ice-wedge-polygon ponds (fig. 4E), and f) miscellaneous thaw lakes.

The term 'oriented lake,' as applied to a type of lake on the Arctic Coastal Plain, refers to a relatively large lake with a long axis oriented generally north-northwest. Some oriented lakes near the delta have been drained because of encroachment by migrating river channels. Within the delta, only one section (near the mouth of Nechelik Channel) contains the remnants of oriented lakes. The Nechelik Channel has cut through a section of the oriented-lake system and in the process has isolated and fragmented some oriented lakes.

Two types of abandoned lakes are present in the Colville River Delta. One type has resulted from channel braiding, the other from meandering. The former is most common on midchannel islands in the lower reaches of the East Channel. Abandoned meanders, or oxbow lakes, are common throughout the rest of the delta and tend to be larger and more regular in outline than lakes occurring in braided channels.

Butted against the base of bluffs---especially bluffs along the western edge of the delta---are numerous lakes occupying channels that were active when the river flowed at its westernmost position. These lakes are similar in some respects to levee-flank-depression lakes common in other deltas.

Point-bar lakes (fig. 4C) might also be considered abandoned. They are common in swales within the ridge-and-swale topography that occurs in many parts of the delta. Some point-bar lakes are seasonal because a) the swales in which they occur serve as part of the river channel during flooding, and

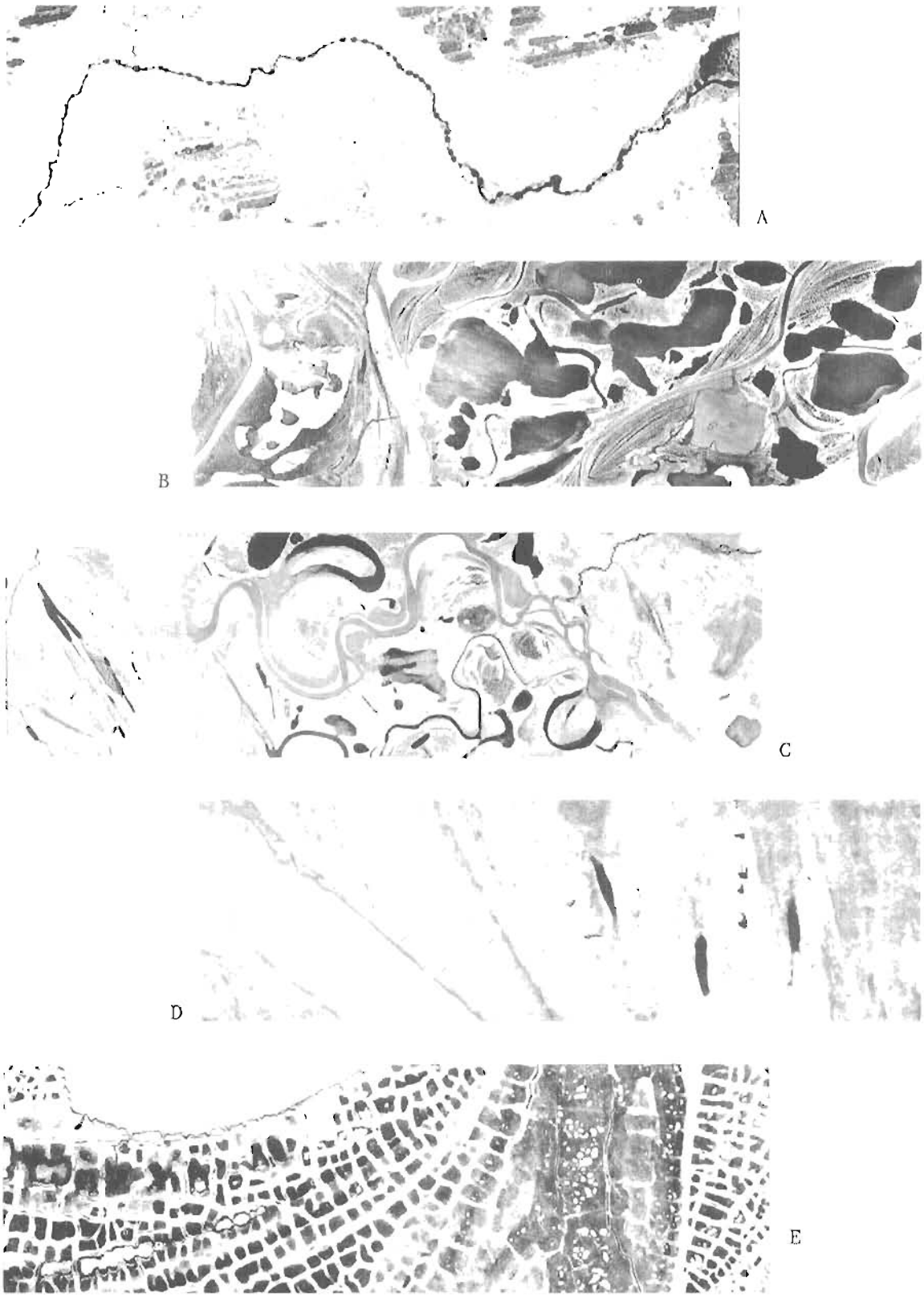


Figure 4. Lakes and ponds associated with the Colville River Delta, Alaska. A, beaded drainage; B, lakes of varied shapes and sizes; C, abandoned river channels; D, perched ponds, and E, ice-wedge-polygon ponds.

the lakes or ponds in them represent water left after the drop in stage level, and b) some are ephemeral. During the formation of the active layer in the ridges, these lakes drain and often become dry by the end of summer.

Among the most interesting lakes within the delta are those that are best described as perched (fig. 4D). Perched lakes occur in many parts of the world for a variety of reasons, but in the Colville River Delta they are chiefly perched on permafrost. In regions of continuous permafrost, ground-water flow occurs within the active layer only during the period of thaw. In areas of the Colville River Delta where surface relief is irregular, as in many of the sand-dune belts, ponds are established each summer.

By far the most common type of water body in the delta is the pond in low-center ice-wedge polygons (fig. 4E). Most ponds are very shallow, although a few are 1 to 2 m deep. Their shape is controlled by the polygonal basin in which they occur. Even smaller ponds, which are often quite elongate, are present in troughs between and at intersections of many ice-wedge polygons.

Several types of thaw lakes occur within the delta. In one sense, any growing lake in the zone of continuous permafrost expands, at least partly, because of thawing; frozen banks thaw before, during, and after recession of the lake edge, and depths increase as a result of subsidence that accompanies the thawing of the permafrost beneath lakes. Some dunal blowouts in the delta have become thaw lakes, numerous ice-wedge-polygon lakes have coalesced because of bank thaw, and thaw---including melting of ice wedges---has led to inverted relief in many lakes (fig. 5A). Associated with such changes is the tapping of lakes by migrating rivers, a process discussed below.

River Banks, Lake Banks, Sandbars, and Mud Flats

River banks and lake banks are composed of various materials, including silt, sand, gravel, peat and other organics, and ice (fig. 5) and range in height from near water level at the distal end of the delta to 9 m above normal stage. Average bank height ranges from 1.8 to 4.5 m, with higher levels predominating toward the proximal end of the delta. Of 170 banks studied in detail in 1971, 59 percent are classified as erosional, 35 percent as depositional, and 6 percent as neutral. Seventy-two percent of the eastern banks are erosional, whereas only 46 percent of the western banks are erosional.

Many river banks, especially those composed of peat and numerous ice wedges, are serrate in plan (figs. 5A and 5B). Banks where sediment predominates are usually straight. The vertical profile of river banks also varies. Banks composed mainly of peat tend to be vertical throughout the year (fig. 5B). In contrast, banks dominated by inorganic sediments are probably vertical only after breakup flooding (fig. 5C), because rapid thawing of newly exposed permafrost promotes sloughing, which promotes the development of a sloping bank as the summer progresses.

Sandbars and mud flats abound in the delta. Gravel bars (fig. 5D) are few and, except for a few patches of gravel and boulders that occur along Nechelik Channel where it has eroded into the Gubik Formation, are restricted

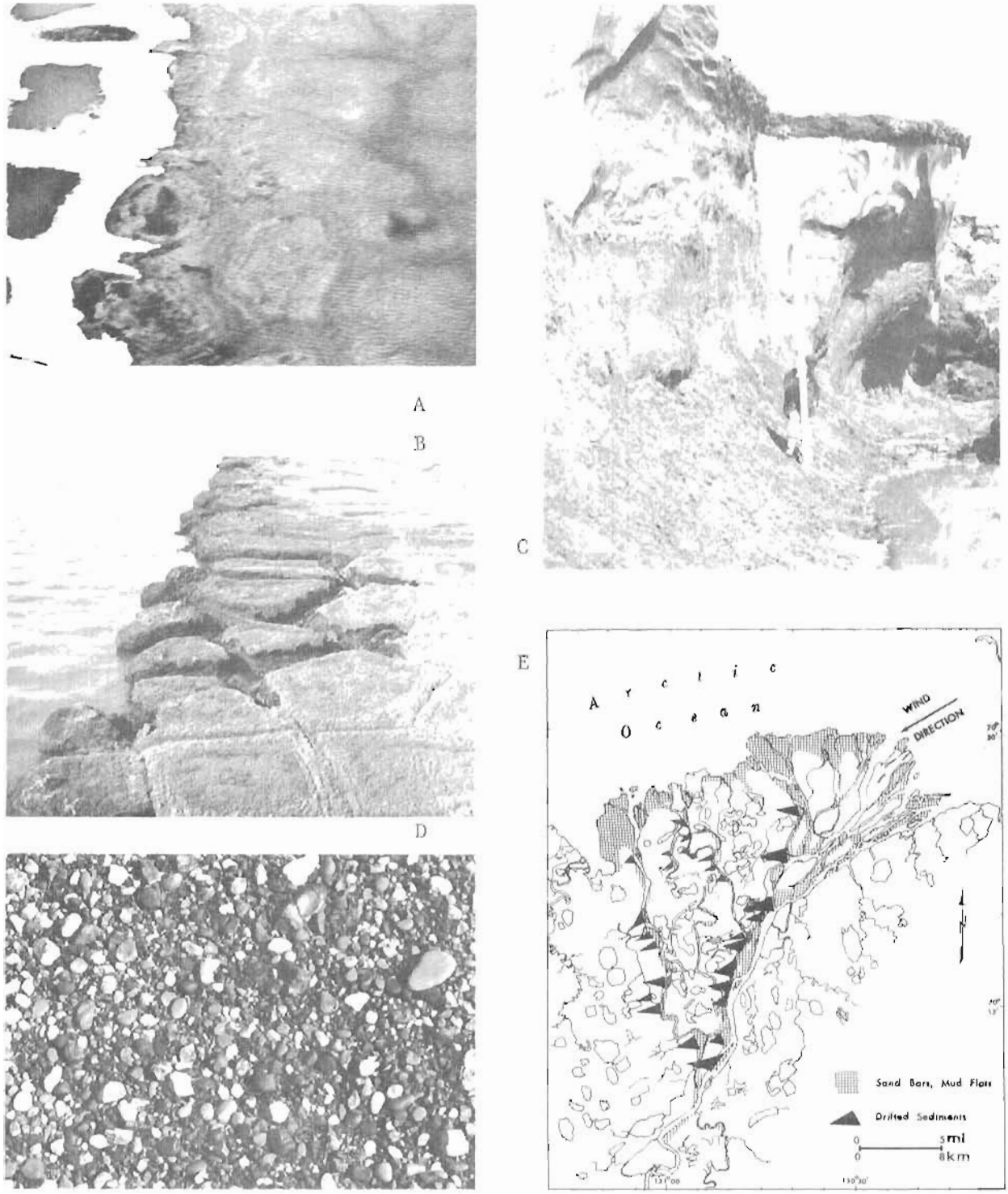


Figure 5. River banks and bars on the Colville River Delta, Alaska. A, relief inversion produced by melting of ice wedges; B, serrate river bank formed by ice-wedge thaw; C, ice wedge in a river bank a few days after breakup flooding; D, gravel on a bar near the head of the delta; E, sediment source regions and wind transport in the vicinity of the Colville River Delta.

to the head of the delta. Sandbars are common along the sides of distributaries and are numerous within channels, especially the East Channel. Many midchannel bars are large and support their own dune systems. Point bars are best developed along the Nechelik Channel where meandering predominates.

Sand and silt supplied to these bars by the river are adequate to maintain them as effective source regions for the extensive dune systems that occur throughout the delta (fig. 5E).

Sand Dunes

Within the Colville River Delta, both active and stabilized sand dunes are present. Stabilized dunes tend to have long, narrow, rounded crests. A few stabilized zones have blowouts, most of which were initiated by ground squirrels or brown bears. The general position and orientation of stabilized dunes show that they formed when river channels and bars were present in a windward direction.

Active dunes are found at the front of the delta and along the west banks of delta distributaries (fig. 5E). All active dunes lie immediately leeward of adequate sediment sources. Dune sizes correlate closely with the sizes of their source areas. At the front of the delta, sand dunes are usually low and irregular and occur in small fields. Along distributaries, dune ridges form, some as long as 4.5 km. Most are very active and are so furrowed that they have been broken into many parallel blowouts (fig. 4D), some of which have perched lakes. The windward face of these leeward dune ridges is generally straight. In some cases, where they form the river banks, they are being destroyed.

Pingos and Frost Mounds

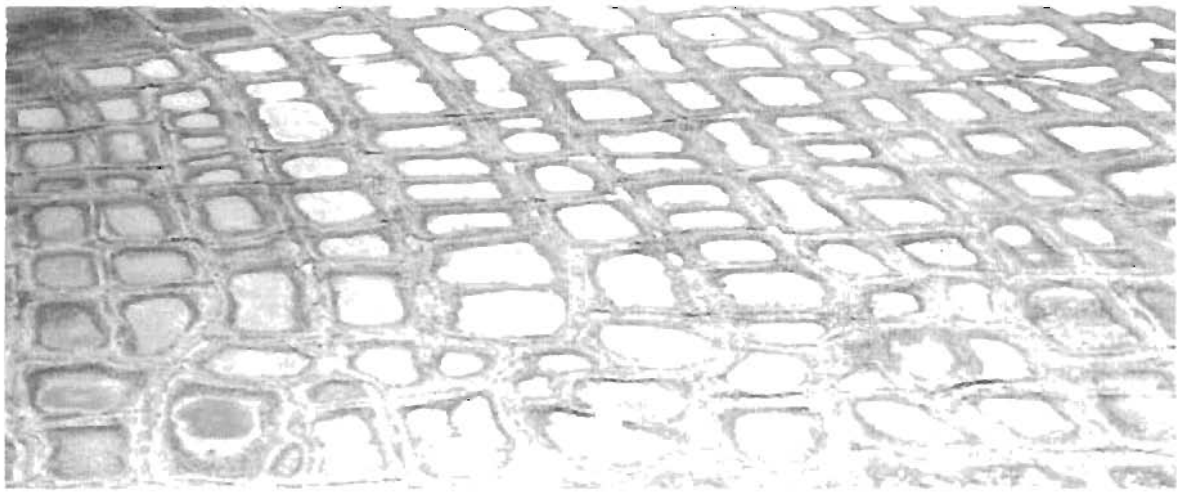
Pingos are relatively rare within the delta, although they are quite numerous on the tundra surface adjacent to it. The two best examples of delta-related pingos were formed as the result of lake drainage, one in a deltaic oxbow lake, the other in an oriented lake that was tapped by the migrating East Channel.

Frost mounds are more common within the delta. Although individual frost mounds are scattered throughout the delta in favorable locations, frost-mound fields are mainly restricted to the north-central part of the delta where marshy surfaces predominate. Maximum height of frost mounds is about 1.5 m; maximum diameter is about 5 m. Many are found within low-center polygons, and some are surrounded by a narrow moat.

Ice Wedges and Ice-wedge Polygons

Ice wedges (fig. 5C) and ice-wedge polygons (fig. 6) are very well developed in the Colville River Delta. Ice wedges vary from narrow veins of ice that form in some coarse-grained sediments such as dune sand to wide (up to 8 m) wedges that are common in peat banks, where they may occupy over 25 percent of the upper few meters of material.

A



B

C

Figure 6. Forms of ice-wedge polygons on the Colville River Delta, Alaska. A, square and rectangular; b, irregularly shaped; and C, ice-wedge polygons that developed in various environments.

Both low- and high-center ice-wedge polygons occur, but the low-center variety is dominant. Polygons are located from the head of the delta to the ocean (where some retreat is occurring). They are found within dune and point-bar systems, in recently drained lakes, and in newly formed bars.

Almost every possible shape of polygon is present in the delta. They range from very regular, four-sided forms (fig. 6A) to highly irregular, multisided and even extremely elongate forms (fig. 6B). Most low-center polygons support ponds and help account for the high proportion of the delta surface that is covered by water (fig. 6C).

High-center polygons are most common along the edges of river banks, where ice wedges have thawed (fig. 5C). They are also present beneath some lakes, where they represent an excellent example of topographic inversion when ice wedges thaw (fig. 5A).

Microforms

Most small features that develop in the delta are not related directly to permafrost, although many develop because of the same conditions that cause permafrost. Sastrugi, ice-carved grooves and ice-push ridges, alluvial fans, and strandline terracettes are associated with wind, snow, ice, and flowing water and occur naturally in both permafrost and nonpermafrost areas. Frost cracks, drainage pipes and channels (figs. 7A and B), and melt-drip deposits in thermoerosional niches (figs. 7C and D) are often related to permafrost and the active layer. Although some microforms such as grass tussocks (fig. 7E) and river-bank ice-shove features may last for years, most are quite ephemeral and range in age from minutes to a few seasons.

DELTA HYDROLOGY AND PERMAFROST

Like the Olnek, Kolyma, and Indigirka Rivers in Siberia, the Colville River lies within the zone of continuous permafrost (fig. 8). Only beneath water bodies with depths greater than about 2 m are permafrost-free zones or thaw bulbs (taliks) likely to occur. Although such unfrozen zones occur beneath deeper lakes and river channels within the drainage basin and delta, the continuous permafrost elsewhere tends to isolate most potential sources of ground water from the river throughout the year. Beneath the river, irregular water depths break the continuity of the thaw bulb.

In this permafrost-dominated system, extreme seasonal changes occur within a few meters depth. Hydrologically, these seasonal changes can be arranged into four rather distinct---albeit highly variable---periods (table 1). Winter lasts about 8 months, and all surface water---except perhaps that from a few springs in the headwaters of the eastern tributaries of the Colville River---is frozen. Included are lakes, streams, rivers, the ocean, and water within the active layer. Summer, less than 3 mo long, occurs between the end of the flooding that accompanies breakup and the return of low temperatures that set the stage for freezeup. Both spring and fall are short. Nonetheless, spring, especially from the standpoint of geomorphology, hydrology, and near-shore oceanography, is by far the most important season.

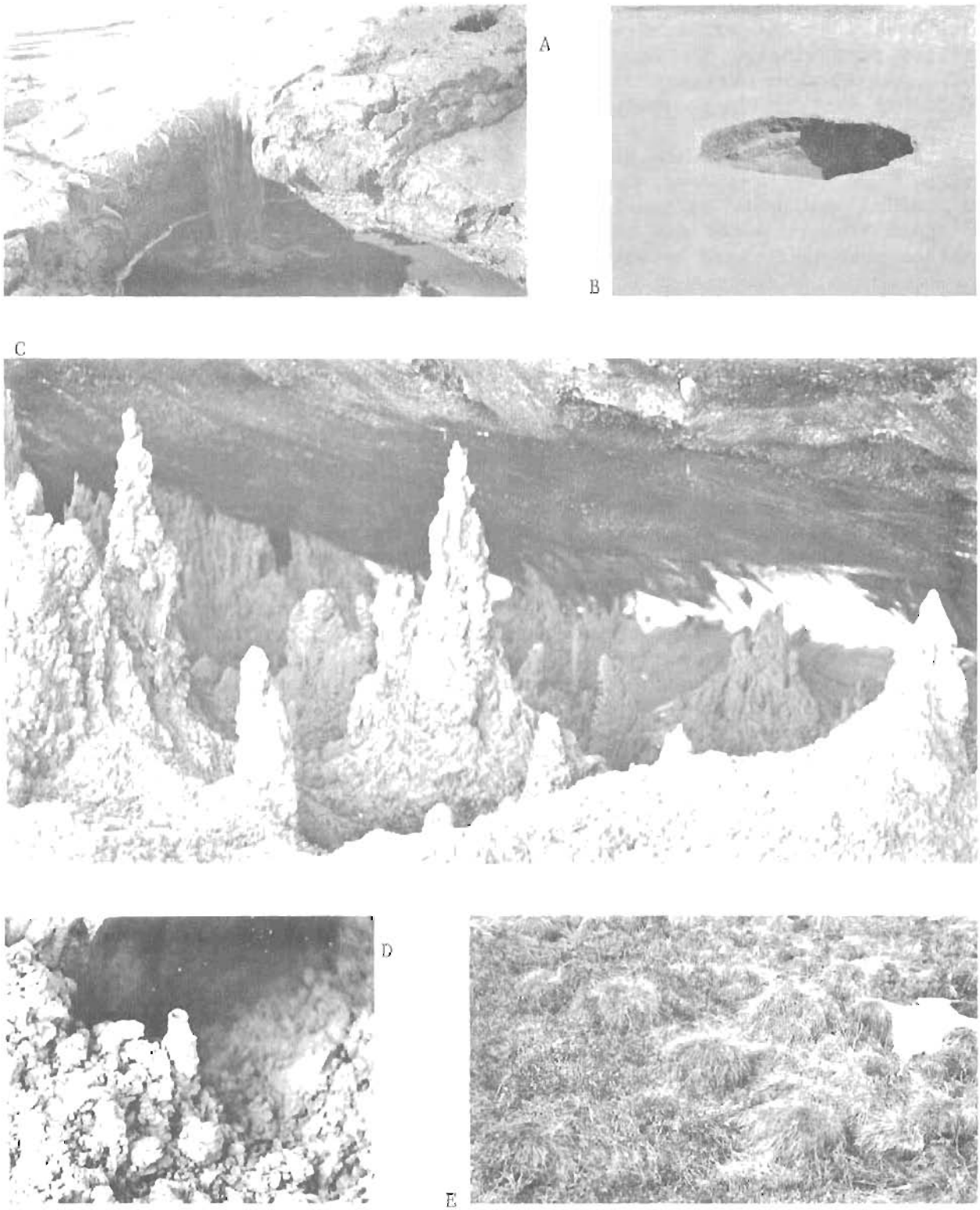


Figure 7. Microfeatures on the Colville River Delta, Alaska. A, bar drainage and plunge pool; B, bar-collapse feature; C and D, permafrost thaw-drip forms; and E, grass tussocks.

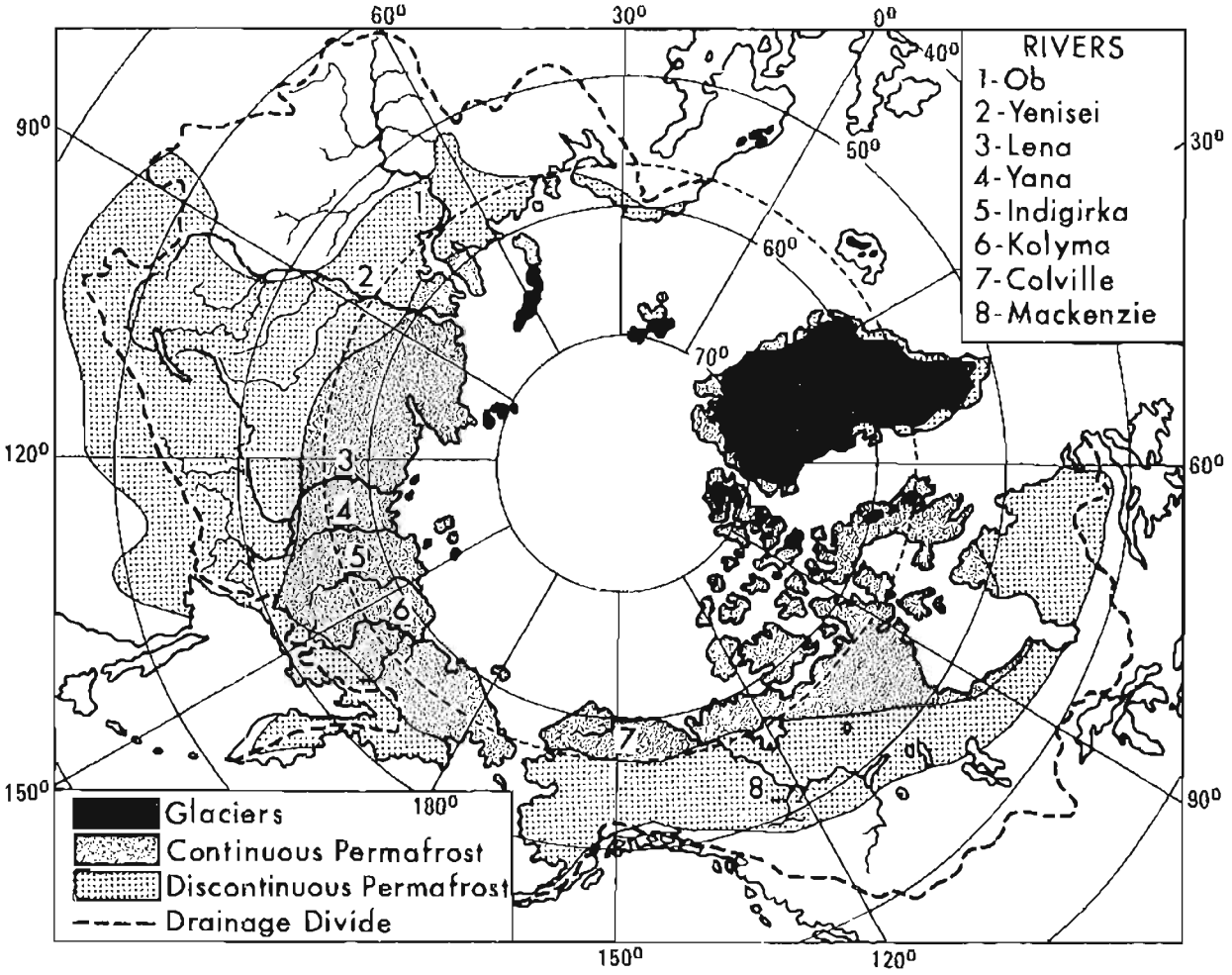


Figure 8. Location of arctic rivers relative to permafrost zones.

Winter

By the end of winter, three major conditions prevail within the delta. First, the entire area is snow covered, except for a few smooth surfaces such as mud flats or lake and river ice. Because of wind, deep snowdrifts develop along river and lake banks. The overall effect is to mask many surface forms and reduce local relief. Second, as river flow decreases, fresh water within distributaries is gradually replaced by seawater. The nature of this replacement can be determined by a vertical examination of river-channel ice (Osterkamp, 1972). In the most extreme cases, especially in the lower part of the delta, freshwater ice at the surface changes with depth to brackish ice, which in turn blends with saline ice that dominates the lower profile. The depth of river water at freezeup is a major influence on the distance seawater penetrates upstream and on the degree of isolation of water into pockets within the river. Extremely high salinities (50 to 60 ^{o}/oo) often occur within isolated pockets (Schell and Hall, 1972). Third, the active layer formed during the previous summer is virtually frozen. Thick sediments that slough to the bases of some higher river banks during summer are protected by deep snowdrifts during winter and probably do not freeze completely.

Table 1. Seasons in the Colville River Delta, Alaska, based on hydrologic characteristics.

Season	Initiated by	Characteristics	Approximate duration (wk)
Winter	Appearance of a solid ice cover		33
Early		Discharge under ice to ocean	
Late		No discharge under ice to ocean	
Spring	Appearance of meltwater		< 3
Prebreakup		Snow meltwater accumulating on and flowing over and under ice	
Breakup		Removal of ice from river	
Postbreakup		Flooding following breakup	
Summer	End of breakup Flooding	Dry periods Wet periods	12
Fall	Reduction of average air temperature to 0°C	Low air and water temperatures and low, stable stage	4

Spring

Most geomorphic activity within the delta is initiated in spring and is marked by the appearance of meltwater on river ice. Spring consists of three divisions: a) a prebreakup period, when meltwater accumulates on and flows over and under river ice, b) a breakup period, when river ice moves downstream, and c) a postbreakup period that lasts until river flooding ceases. The flooding sequence varies in time of initiation and duration. Several years of observation indicate that usually a rather rapid rise in river level is followed by breakup, which occurs at about the time maximum stage is reached. During or shortly after breakup, the stage drops relatively rapidly (fig. 9). Generally, this sequence occurs in about 3 wk, but the actual duration is affected by the rate and nature of snowmelt within the drainage basin.

Summer and Fall

Normally, river stage is low in summer and fall. Flow comes from the melting of snow that remains after the main snowmelt period, from precipitation in the drainage basin, from lake overflow across the tundra surface, and as ground water from a developing active layer. Stage also varies within the delta according to wind conditions and tidal variations.

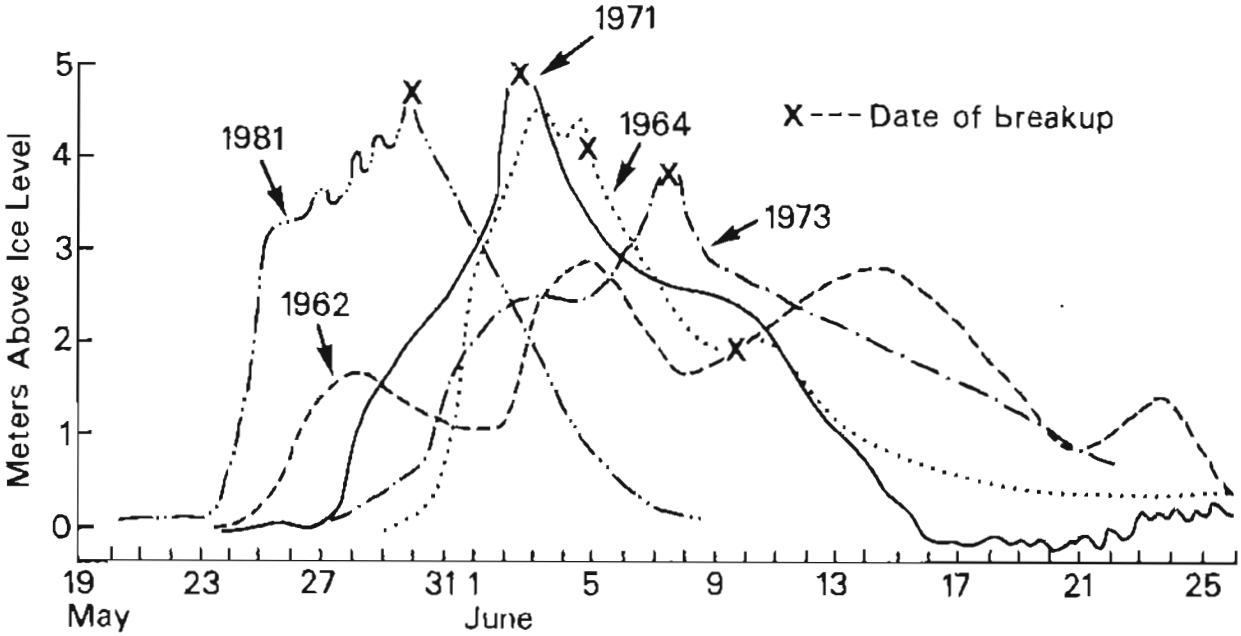


Figure 9. Stage variation during breakup in the Colville River Delta, Alaska.

Generally, lowest stages occur during late summer and fall, especially during the first days of freezeup.

DELTA PROCESSES AND PERMAFROST - SELECTED EXAMPLES

As suggested in the previous section, the delta is a dynamic feature despite the fact that during three-fourths of the year it is best described as dormant.

Temperature and Wind

During winter, the major processes operating in the delta are related to temperature, snow, and wind. With favorable temperature changes, frost cracking occurs, especially in recently deposited material. Frost cracking is aided by a thin snow cover, a condition that also favors modification by wind. Once wind has removed the snow from a sandbar or mud flat, deflation may occur, even if the sediment is frozen. Deflated material is then transported from the bar or flat to the snow-covered dunes or tundra surface. This process is especially common during the initial stages of melting---the thin snow cover over river bars melts first and, if winds occur at the same time, large volumes of sand may be moved. Stripes of wind-deposited sediment stretching across snow-covered surfaces are not an uncommon sight during May. In spring and early summer, wind is not an especially effective eroding or transporting agent because most source areas are either covered with floodwater or are very moist from previous flooding.

Flooding

Soon after the melting season is initiated and meltwater begins to accumulate, flow occurs above bottom-fast river ice and below floating ice. River ice, which averages about 1.8 m thick in the Colville River, causes a higher stage than would otherwise occur. This high stage raises the level at which the frozen river banks are melted and eroded by the flowing water. Such thermoerosion---especially effective on ice wedges and on sediment banks with a high ice content---is mainly responsible for creating the serrated form of peat-dominated banks (fig. 5B) and of thermoerosional niches (fig. 10) that are present in most banks, at least during flooding.

The size (height and depth) of niches, their duration, and their importance to bank recession are mainly dependent on bank composition, flood stage and duration, current velocity, and water temperature. The amount of niching varies from year to year and in some cases is cumulative, that is, notches that are deep enough are preserved by burial from one season to the next by sloughing from the bank above. In those years when the stage varies frequently during flooding, multiple niches usually develop (fig. 10C).

In the Colville River Delta, niches often become very large (fig. 10). Depths of over 8 m and heights of over 2 m are not uncommon in the Gubik Formation, which borders the west bank of part of the Nechelik Channel (fig. 10A).

Thermoerosional niching often leads to block collapse (fig. 10E), which is an important factor in bank retreat. In extreme cases, block collapse occurs along ice wedges after they are undercut. Such collapsed blocks begin to thaw on all sides and are rapidly reduced to pyramidal piles (fig. 10F), that are relatively easily eroded by subsequent floods.

Rapid thaw of permafrost exposed by niching continues after floodwaters subside, and the nature of thawing is responsible for the creation of unique microforms that are eventually buried by sloughing from the banks above.

Thermoerosion during flooding is responsible for much of the bank retreat that occurs in the delta. Because ice wedges are especially vulnerable to thawing, they often retreat more rapidly than the river banks in which they are situated. Along many banks, their retreat is responsible for draining the ponds in low-center polygons and for the eventual conversion from low-center to high-center varieties (fig. 5B).

Lake tapping (fig. 11) is the result of erosion in banks that separate lakes from river channels. This process is common within the delta and is followed by a distinct series of events. During initial draining, a plunge pool that develops at the lake entrance to the channel cuts deep into the permafrost (fig. 11B). After tapping, lake levels fluctuate with river stage. At low river stage, these lakes may be so shallow that permafrost begins to form and pingos may develop. Lake bottoms are frequently exposed, which favors the formation of ice wedges.

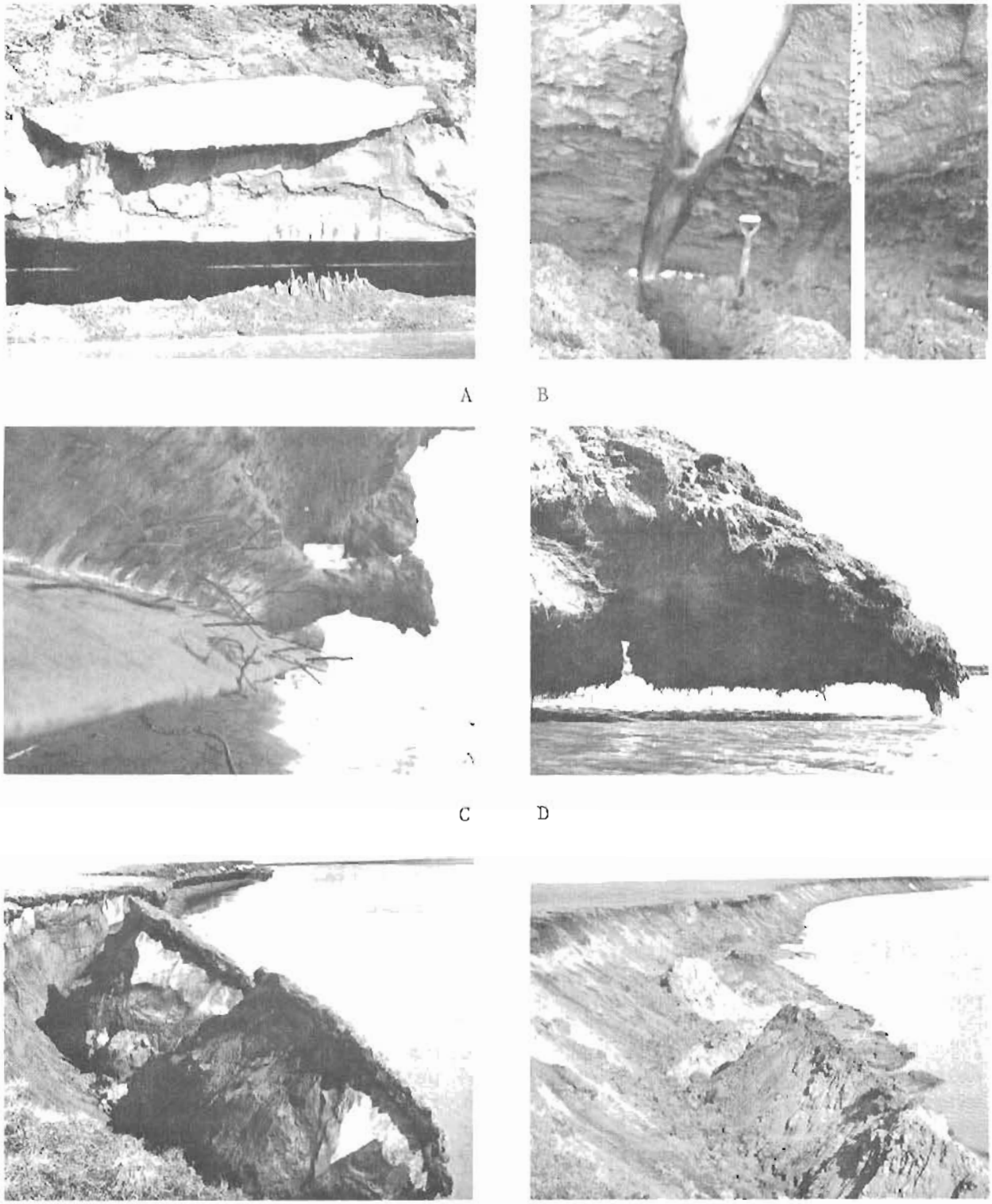


Figure 10. Thermoerosional niches and block collapse along the Colville River, Alaska.

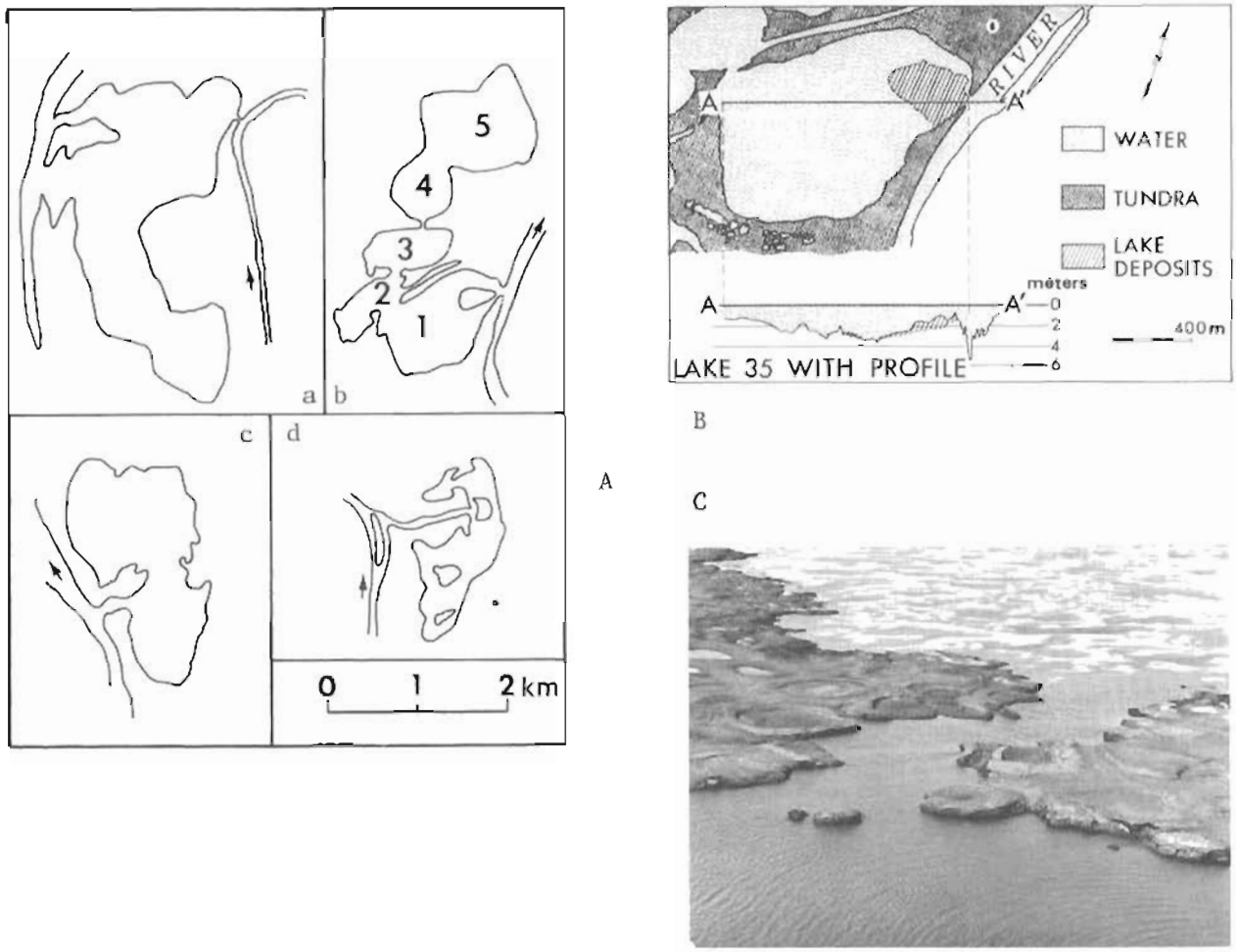


Figure 11. Tapped lakes near the Colville River, Alaska. A, four deltaic lakes illustrate changes since tapping; B, diagram of lake B-1 in figure 11A showing plunge pool and new lake delta; and C, connecting channel between lakes B-3 and B-4 in figure 11A.

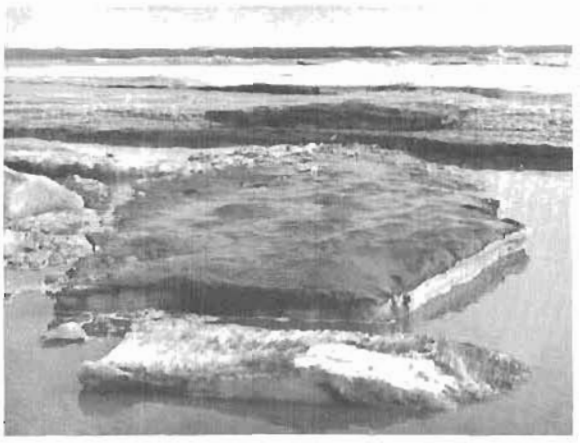
During breakup flooding, tapped lakes are also flooded. Most suspended load is deposited in the lake (figs. 11A and 11B), which acts as a settling pond. These lakes are eventually filled and become subaerial forms.

Deposition during flooding also occurs at other locations within the delta. Floodwaters often cover up to 65 percent of the delta (fig. 3). In extreme cases, floodwaters extend onto the tundra and over snow-covered surfaces. Sediment deposition may amount to more than 25 cm (fig. 12). Such zones of deposition, especially on point bars and in tapped lakes, have aggrading permafrost tables.

River Ice

River ice is important in delta development in several ways. During winter, ice that caps the river helps limit geomorphic activity. During the

A



B

Figure 12. Flood-stage deposition by the Colville River on (A) snow and (B) ice.

initial stages of breakup, water flows over it and deposition occurs on it (fig. 12B). When river ice begins moving, it is an important eroding, transporting, and depositing agent. River-ice dams may cause higher water levels than normal.

The effect of river ice depends to some extent on the nature of breakup. If the ice moves oceanward on rising water (which happens most of the time), it causes less erosion than if it moves at lower stages, when ice may become stranded. Many river banks, primarily those composed of peat, are shaved by ice contact (fig. 10D). Along many sections of the river, ice-push forms and stranded gravel accumulations are common along tops of river banks.

FIELD SITES ALONG THE NECHELIK CHANNEL

This part of the field guide deals with specific forms and processes examined along the field-trip route in Nechelik Channel (fig. 13). They are discussed below in the sequence numbered on the accompanying map. Because many forms and processes have already been analyzed, this section is mainly descriptive and historical and is designed to serve as a stimulus for discussion at the various stops.

STOP 1. NUIQSUT AND NUIQSUT AIRFIELD. Nuiqsut, a village on the upper Nechelik Channel of the Colville River, was founded in 1973 when a number of Eskimos moved east from Point Barrow. Nuiqsut grew rapidly from the tent village that was first erected. Today, only 10 yr later, it has over 300 people, nearly 100 buildings (fig. 13-1), a modern $11 million school, a heated water-storage tank, and a stable road system. The town continues to expand as new houses are constructed each year. Although the present village contrasts greatly with the former (mostly temporary) settlements and camp sites along the Colville River, the residents, nonetheless, engage in many of their traditional activities. Hunting, trapping, and fishing are common

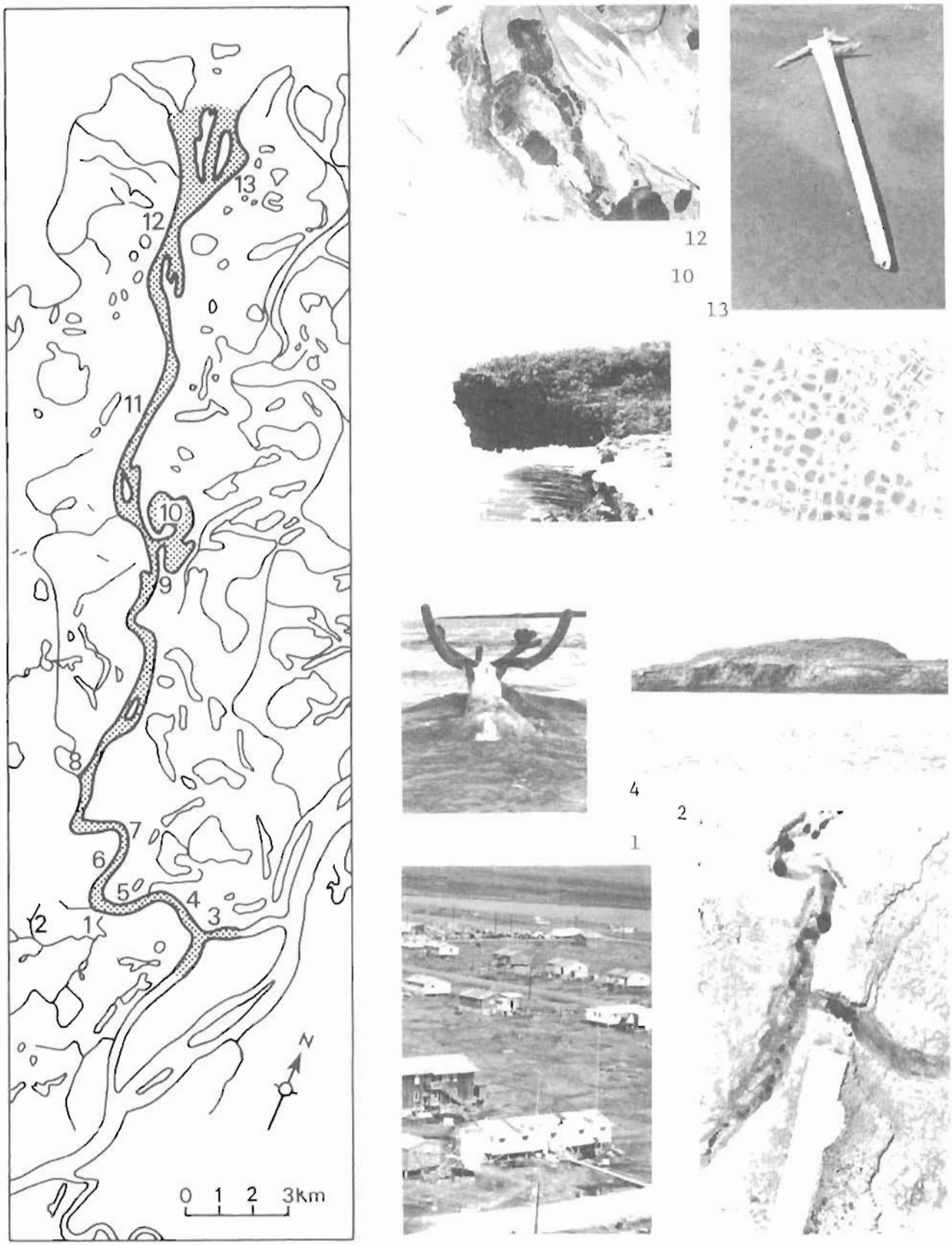


Figure 13. Map of field-trip stops and Colville River Delta features. Photographs 1, 2, 4, 10, 12, and 13 refer to respective field-trip stops.

endeavors. Although electricity is present, some ice cellars have been dug in permafrost for large-volume storage.

In 1981, construction began on the 1,550-m-long runway that now forms the southwest border of the village. Some 200,000 m^3 of sand and gravel were dredged from the thalweg of Nechelik Channel, pumped to the runway site, and placed directly on the tundra surface. This method of sand and gravel acquisition proved so successful that dredging continued during 1982. Gravel obtained from as deep as 20 m beneath the river was crushed and used as topping for the runway, and 500,000 m^3 of sand and gravel was stockpiled. It is too early to see the effects of runway construction on permafrost or the effect of dredging operations on the river. During construction, environmental damage to the tundra surface near the runway was minimal because of the effective control of runoff from the hydraulic operation.

STOP 2. ORIENTED LAKES AND BEADED DRAINAGE. The tundra surface on which the runway was placed is relatively level for 1,400 m from its eastern end so that the depth of fill is uniform. However, toward the western end of the runway the surface drops about 8 m to an elliptical thaw pond (fig. 13-2) that was formed during drainage of a large (2.5 km^2) oriented lake. The drained lake, almost a textbook example, displays the typical bordering platform and various stages in the development of ice-wedge polygons.

The drainage channel from the oriented lake is a tributary to a small (4-km-long) beaded stream that flows east from the tundra surface to the flood plain of Nechelik Channel. On the flood plain, the stream has a very angular course that has also served as the outlet for several other oriented lakes. Between the west end of the runway and the flood plain (approximately 2 km), the stream has more than 60 'beads,' which represent the junction of ice wedges (fig. 13-2).

STOP 3. PUTU CHANNEL. One meaning of the Eskimo word 'putu' is 'connection,' and Putu Channel is indeed the connection between the main channel and Nechelik Channel. It served as a major waterway between the two channels until a few years ago, when it became so shallow that boats could not use it during low water (fig. 14).

The direction of flow in Putu Channel reverses with a rise in river stage (fig. 15). During low and normal stages, the water flows east to west; during flood stage, flow is west to east. Because flow is eastward during breakup, much river ice that would normally flow down Nechelik Channel is returned to the main channel. Even more critical is the effect of stage reversal on sedimentation rates. Flooding that accompanies breakup is responsible for transporting about 75 percent of the annual sediment load that is carried oceanward. However, during times of flow reversal in Putu Channel, the carrying capacity is drastically reduced and deposition is heavy. Heavy deposition also occurs in slack-water areas dammed by ice jams.

At the western end of Putu Channel is a sand-dune system that formed when the channel was northeast of its present position. These dunes are typical of numerous stable dune systems in the delta. Swales within the dunes contain

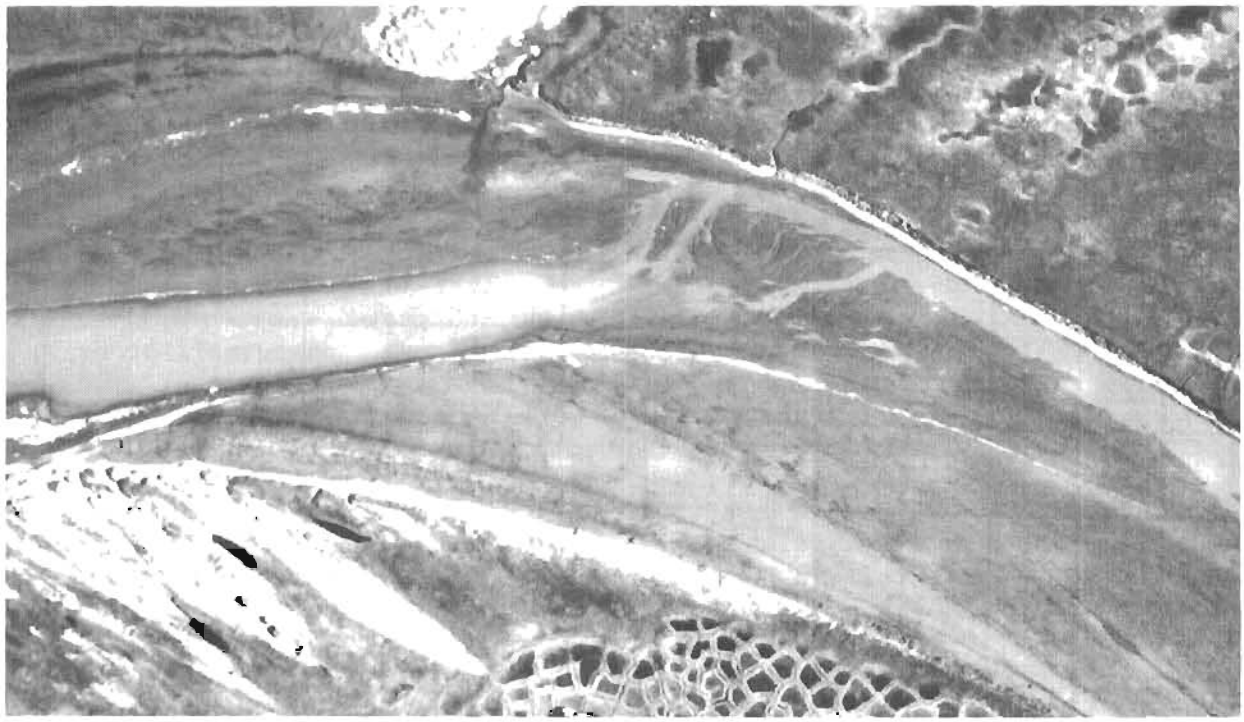


Figure 14. Putu Channel, bordering dunes, sandbars, and polygons, Colville River Delta, Alaska.

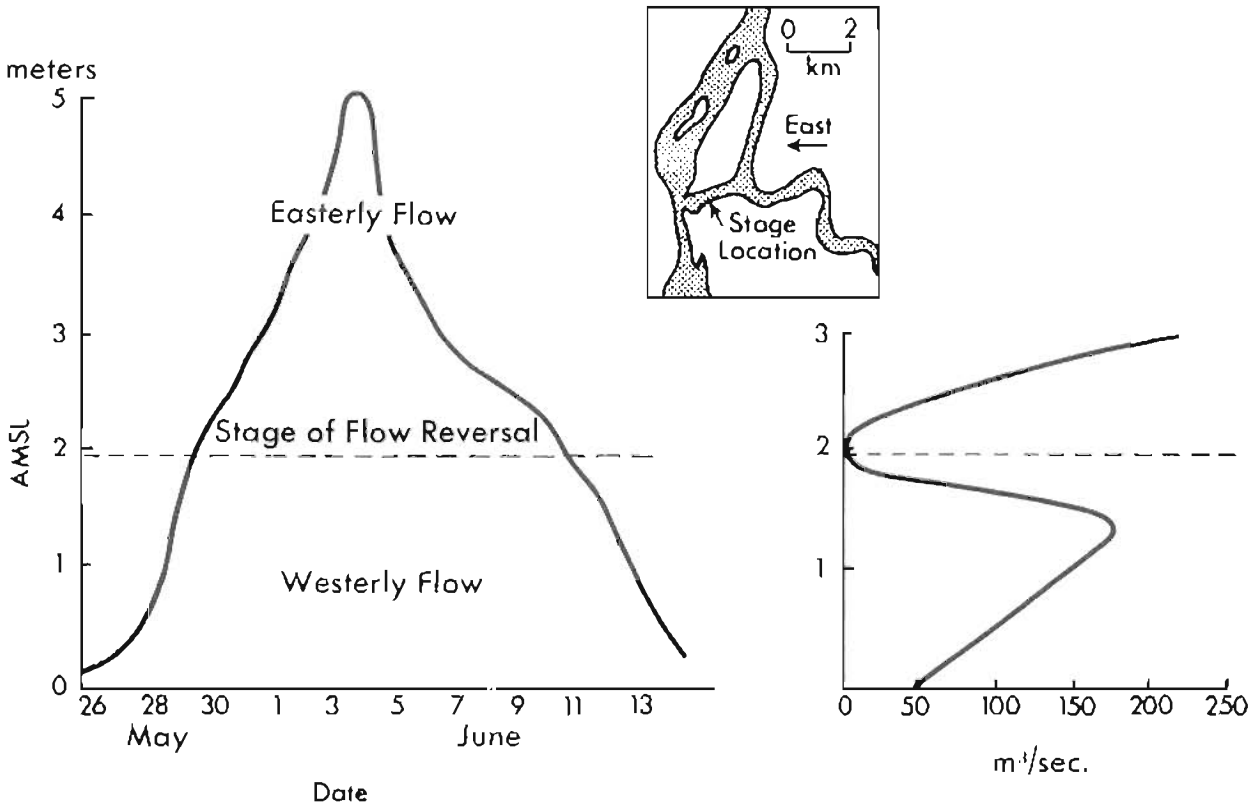


Figure 15. Stage and flow direction in Putu Channel, Colville River Delta, Alaska.

peat fillings (clearly visible between Stops 3 and 4) and support developing ice-wedge polygons. Peat and ice-wedge growth in the swales gradually reduces the local relief of these stabilized dune systems.

STOP 4. TAPPED LAKE, ERODING PINGO, AND THAW LAKES. Toward the north end of the western Putu dune system is the end of a former abandoned river channel (fig. 16). Since abandonment, this channel developed into an elongate lake that was subsequently tapped by the river and finally was the site of sedimentation during river flooding. The pingo and ice-wedge polygons that formed in the trough are being eroded. This example is one of the most dynamic sequences within the delta.

Before tapping, the lake basin was apparently a little more than twice as long as it is today and was only slightly curved. As Nechelik Channel migrated north (fig. 17A), it tapped the lake. After the lake drained, a pingo formed in the middle of the long, narrow basin, and lake filling began. Today, the migrating Nechelik Channel is eroding not only the lake bed it helped build, but also the pingo (fig. 17B). Erosion rates of the pingo and the adjacent basin fill are over 2 m per yr.

The relatively low lake bed still serves as a trapping area for river ice during breakup. Ice jams, which are frequent just downstream from this area, cause ice (some of it 2 m thick) to be forced about 1 km up the old channel, where it becomes stranded (figs. 11 and 18). Sand, gravel, and organic matter (peat shreds, grasses, willow trees) carried by the ice are deposited as it melts (fig. 18). Ice shove is a common process in this part of the river bank.

This basin is bordered on the north by a long, narrow dune ridge that parallels another former channel and another dune ridge (fig. 16). Within the dune ridge just north of the pingo are two thaw lakes that appear to be blowouts---possibly initiated by squirrel activity (fig. 19)---that have progressed to the stage where lakes have developed.

STOP 5. PEAT BANKS, ICE WEDGES, AND POLYGONS. One of the most common types of river banks in the Colville River Delta is composed of peat. Although they are most extensive along the east bank of the main channel, they also occur along Nechelik Channel. Peat banks contain the best developed ice wedges in the Colville River Delta (fig. 20), and the networks they form are quite conspicuous because they have low-center polygons with well-developed troughs. Many polygons near Stop 5 are permanent ponds 1 to 2 m deep.

Erosion along this bank is typical of peat banks in the delta. Ice wedges recede at a faster rate than the peat that separates them. At the bases of these wedges, where undercutting has occurred, ponds usually develop and tundra mats drape down over the upper wedges (fig. 20B). As summer progresses, parts of these peat 'curtains' fall into the pond beneath. Ice wedges in this section of the delta are wide enough to be exposed throughout the summer.

This bank shows both the minimal notching that normally occurs in peat banks and the 'shaved' character of the peat surface (fig. 20A). Large quan-

Figure 16. Pingo, stranded ice in former river channel, stabilized dune bands, and flooded ice-wedge polygons, Colville River Delta, Alaska.

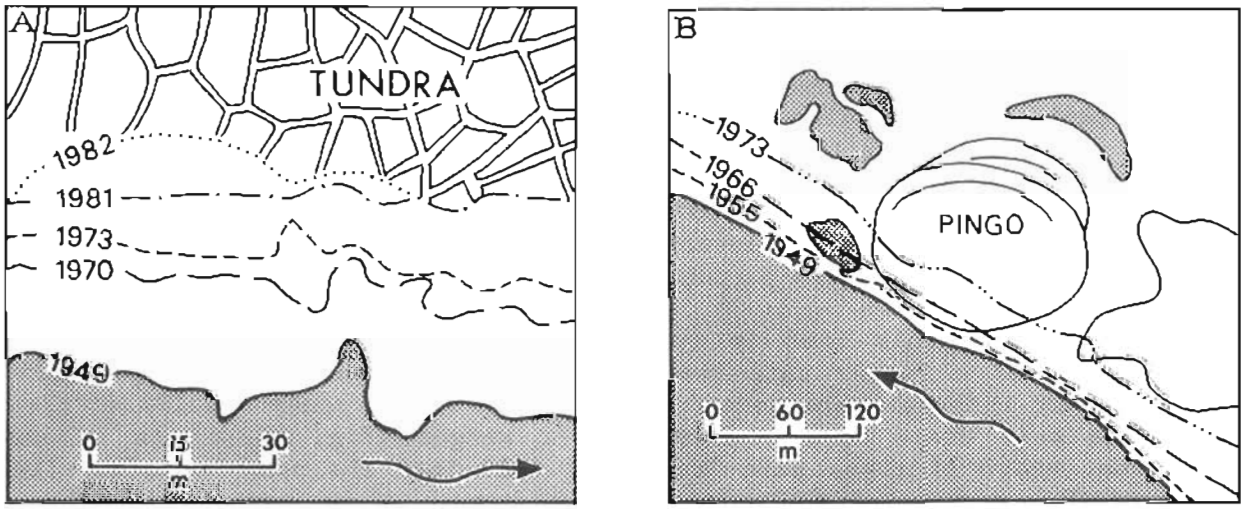


Figure 17. Erosion of (A) river bank in Gubik Formation and (B) pingo shown in figure 16.

Figure 18. Stranded ice illustrating ice thickness, ice shove, and ice transport of organic debris.

Figure 19. Ground squirrel, a common inhabitant of the delta.

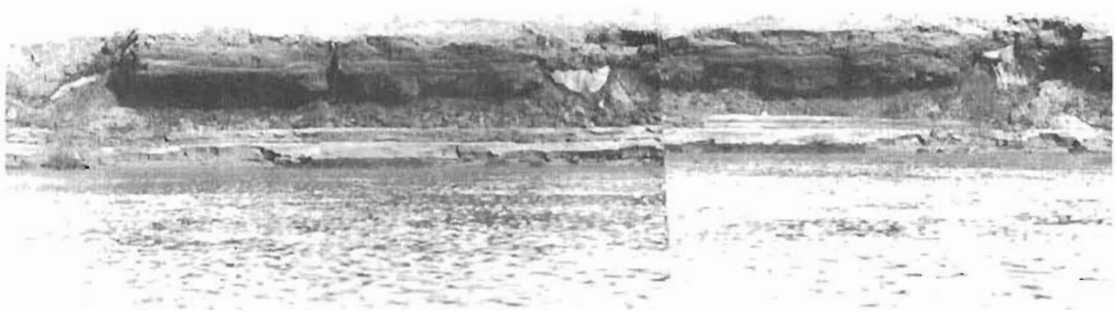
tities of peat are contributed to the river, as evidenced by the abundance of peat in grab-bucket samples from the bottom of the river.

Although these peat banks are up to 5 m above normal river level, they are occasionally overtopped during breakup flooding. On the top, driftwood, pebbles, and ice-shove features are common.

STOP 6. GUBIK FORMATION. Site 6 is one of two locations where Nechelik Channel is eroding directly into the Gubik Formation, which here is composed of a heterogeneous mixture of silts, sands, gravels, and boulders (fig. 21). The formation also contains the fossil remains of trees no longer growing in the drainage basin and of extinct animals such as mammoth and mastadon. Fragments of mammoth tusks that look like pieces of coal are commonly found along the river banks.

Banks cut into the Gubik Formation range from 8 to 10 m above normal river level and immediately after breakup display vertical cliffs with prominent ice wedges (fig. 5C). Because of the ice-rich nature of the sediments, the rate of retreat of both the wedges and the surrounding material is about the same.

A distinctive characteristic of this type of bank is the frequent development of deep thermoerosional niches during flooding and their subsequent block collapse. Because of the sediment-rich nature of the permafrost, sloughed material from the banks quickly covers the niches and the ice wedges each summer (figs. 10F and 22). Retreat along this bank has averaged over 1 m per yr during the past 30 yr, or the equivalent of the width of the channel every 100-120 yr.



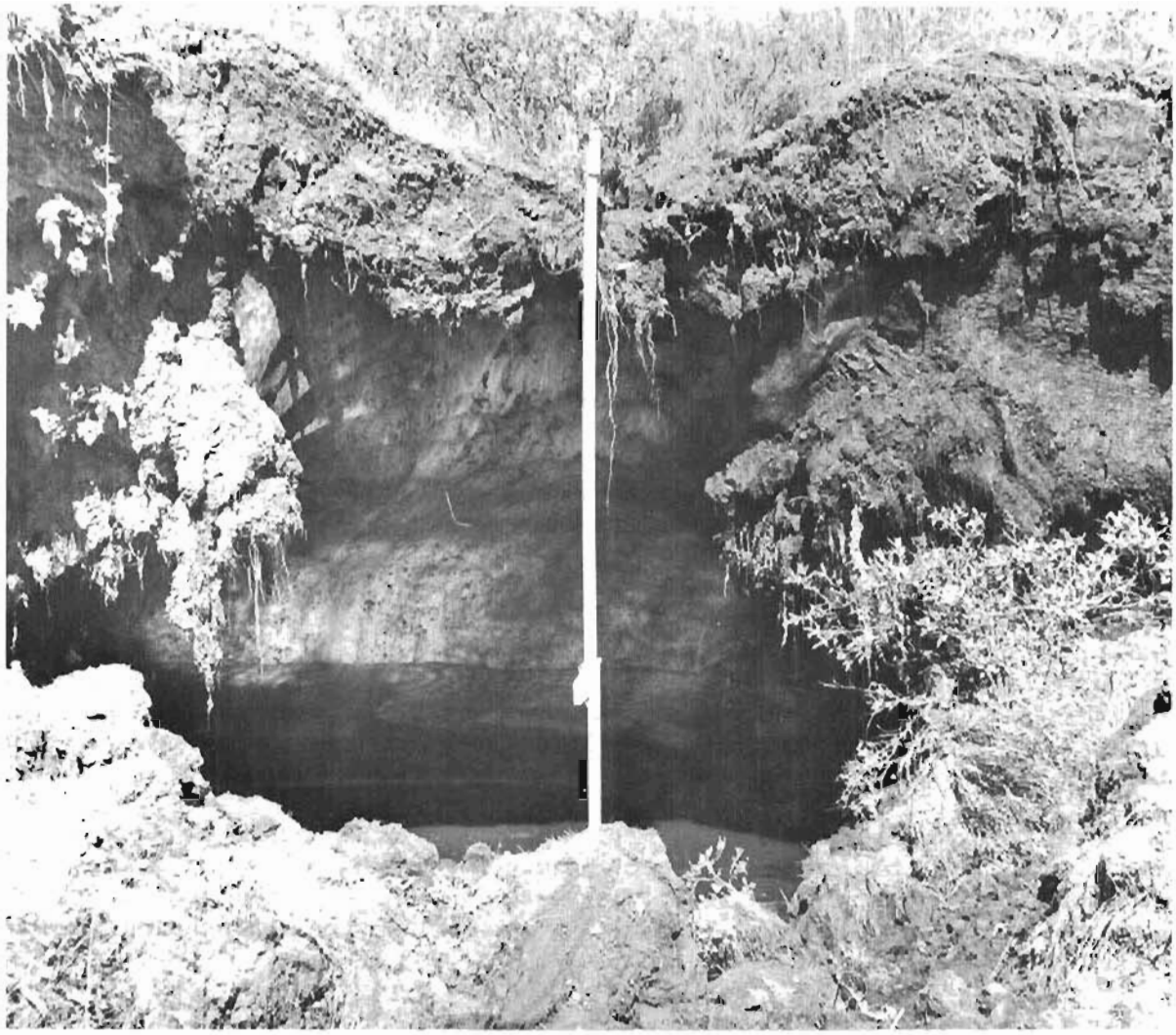


Figure 20. Ice-wedge erosion, tundra-mat collapse, and 'shaved' peat bank, Colville River Delta, Alaska. A, river view of peat bank and ice wedges; and B, closeup of ice wedge showing basal pond.

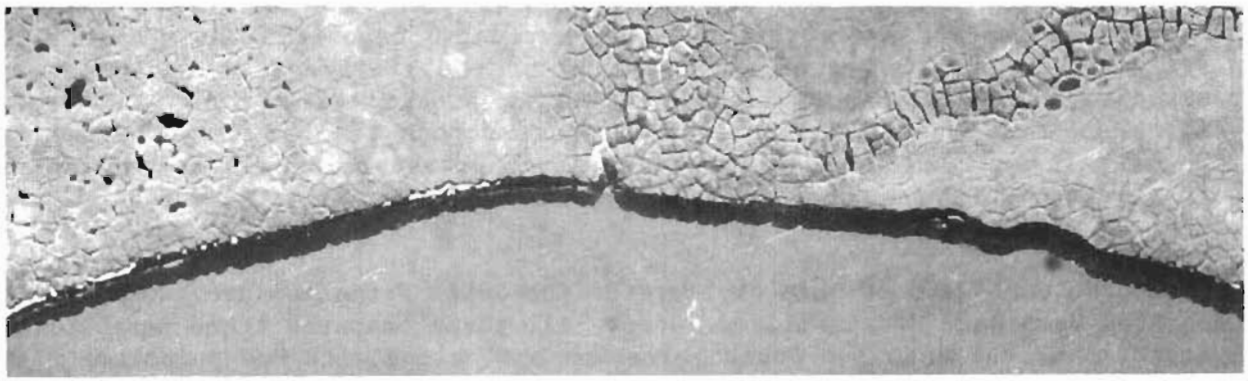


Figure 21. Gubik Formation, cutbank, and ice-wedge polygons, Colville River Delta, Alaska.

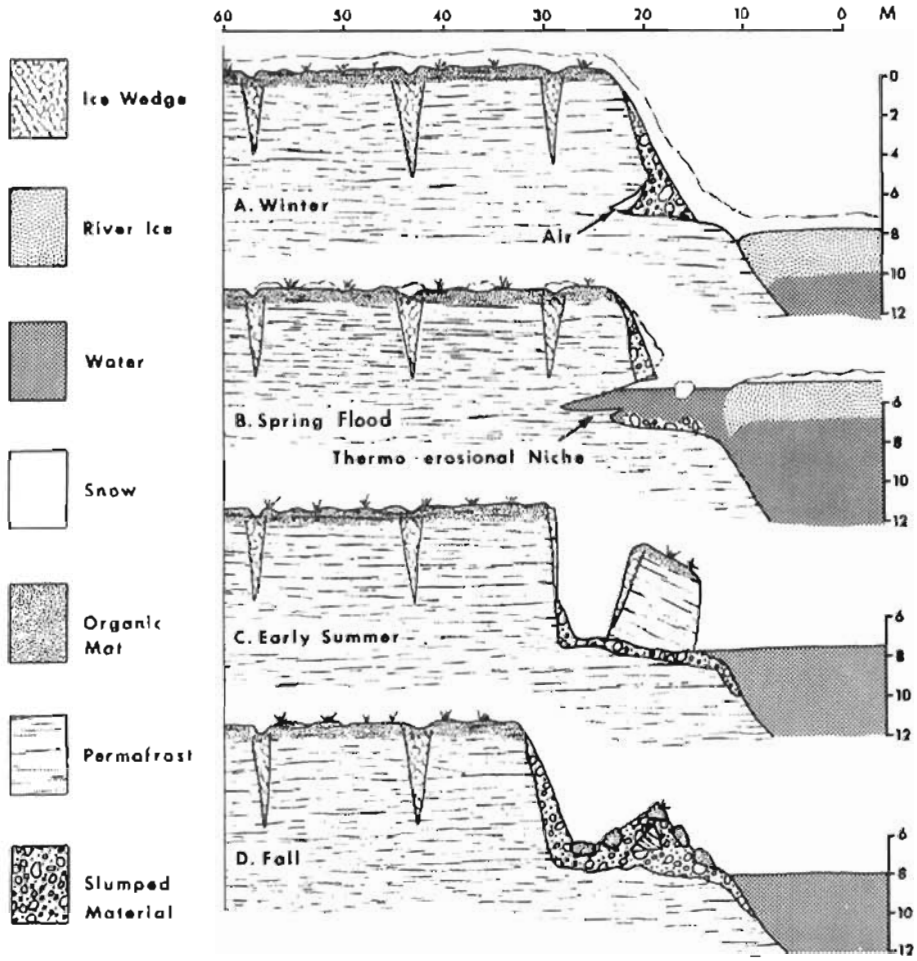


Figure 22. Schematic diagram of river-bank erosion in the Gubik Formation, Colville River Delta, Alaska.

Across from the outcrop of the Gubik Formation is a point bar that is advancing at the same rate that the bank recedes. Deposition of sediment on parts of this bar, based on measurements of the thickness of sediment deposited on snow, is as much as 15 cm during breakup (fig. 12A). However, remnant snowmelt runoff and surface drainage across the bar (fig. 6C) carry much of this sediment back to the river after breakup. Such over-bar transport is often intense enough to create small fan deltas along the edge of the river.

At the north end of this exposure of the Gubik Formation are two terraces separated by a band of stabilized dunes. All three features trend parallel to a former bank cut into the Gubik Formation and, along with the point bar with which they merge, represent changes that occur as the river channel shifts. The relative ages of these surfaces can be discerned by comparing the degree of ice-wedge development and sand dune stability across the point-bar system.

STOP 7. TAPPED LAKE AND LAKE FILL. Situated between two peat banks is the eroding fill of a former lake, which is at about the same stage of development as the tapped lake at Stop 4. Since original tapping, lake fill has been intensive. However, the near-river part of the drained lake is building up more rapidly than the part farthest from the river, and a lake is present at nonflood stage. It is either a remnant of the former lake (because the original lake was deeper at the time of tapping than the river at low stage) or a new lake (because of the natural-levee deposition at its present entrance). Flowing across the stretch of lake bed that now forms the river bank is a lake-drainage channel that carries snowmelt, ice meltwater, and river water that enter the basin during flooding. The bank is rapidly eroding and clearly shows the sediment banding that represents selective deposition. A traverse normal to the river bank crosses a surface sequence that extends from thick, newly deposited sediment with buried vegetation through a zone of less deposition, where buried vegetation is growing up through the new deposits, to a good stand of marsh grasses, and finally, lake water.

STOP 8. SLOUGH ENTRANCE, WILLOW VEGETATION, AND TURF-HOUSE SITE. Location 8 is the entrance to a slough that meanders across delta fill until it reaches the Gubik Formation and flows in a former major channel that eventually rejoins the Nechelik Channel (fig. 13). The surface north of the slough is a relatively level plain with numerous ice-wedge polygons and low belts of sand dunes. A vast field of dwarf willow trees extends to the northwest.

This location was used as a house site and, although erosion of the bank has been quite extensive, the foundation of at least one turf house remains. The house was built on a low sand-dune ridge that extends inland from the river bank. Turf blocks and corner logs of the house are still in place.[3]

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[3] In discussing the turf houses, State of Alaska archeologist R.D. Shaw said that visitors to the sites are encouraged to respect the cultural remains and to avoid disturbing them. "Several state and federal laws prohibit disturbing archeological and historical sites," he said.

The bank face illustrates a variety of deltaic environments and processes. The west bank of this section of Nechelik Channel is mainly peat, although dune sand and highly organic silt are interspersed. In some locations, dune sand overlies peat deposits. Wind scour and squirrel activity are evident. Exposed willow roots (some of which are as long as 12 m) are common because of bank retreat.

STOP 9. SAND DUNE AND TURF-HOUSE SITE. Just south of Lake Nanuk is a high, stabilized dune band that is being eroded by the river. It is high enough to trap drifting snow during winter, and snow drifts remain in this dune area into July (fig. 23). Within the swales of this dune system, ice-wedge polygons have formed, some with surface evidence of only one or two polygon widths. Linear lakes are also present in some swales.

This dune is the highest point in the area and has frequently served as a camp site. The remains of turf houses that were supposedly constructed by reindeer herders during the early 1900s, when domesticated herds were maintained in the delta, are present.

This vantage point also provides a good view of the tundra to the southwest, where a number of pingos are visible.

STOP 10. LAKE NANUK. Lake C in figure 11A is a diagram of Lake Nanuk, which is one of the more recently tapped lakes in the delta; tapping occurred prior to the first aerial photography (1943). Since then, the entrance to the lake has nearly doubled in width, and the area of the delta forming in the lake has increased severalfold.

The north bank of the entrance is subject to severe erosion (fig. 13-10). In addition to the development of thermoerosional niching by floodwater and the high-sediment component of deposits beneath the surface, ice gouging is intensive.

Another feature of lake tapping that is illustrated in Lake Nanuk is the fluctuation of lake levels with changes in river stage. At low river stage, much of the lake bottom is exposed. The area of exposed bottom has increased because of deposition by the river during the years since tapping. These bottoms then become sources for wind-transported sand that is carried, in the case of Lake Nanuk, onto the tundra surface separating it from the river.

The entrance to Lake Nanuk is another ideal location for a camp site. Fishing is good and the site is used frequently for drying fish. However, because of rapid erosion of the most ideal camping site, many cultural remains have been lost to the river.

STOP 11. LOW TUNDRA SURFACE. The tundra surface lowers near the front of the delta. Peat is the common bank material. As in peat banks elsewhere, erosion progresses most rapidly along ice wedges normal to the banks. Then shearing occurs along the low banks between these indentations, leaving low narrow terraces (fig. 24). Floods frequently overtop this bank, and driftwood is occasionally carried inland 50-100 m, although most of it is stranded near the bank (fig. 24).

Figure 23. Stop 9: Sand dune, remnant snowdrift, and sandbar, Colville River Delta, Alaska.

In this part of the delta, polygonal structures are not especially conspicuous. Ice wedges are as much as 45-50 m apart.

STOP 12. NIGLIK. Niglik (the Eskimo word for 'geese' which, when said quickly, sounds like a goose call) is one of the most famous locations along the north coast of Alaska. It was often the meeting and trading place for Eskimos who came east from Barrow and those who came downriver from inland areas. Campsites abound along the bank, although extensive erosion has destroyed many of them.

A recent report from the North Slope Borough (1979) notes that "Siberian goods, brought overland from the Sisualik trading site near present Kotzebue, continued their way into the Canadian Arctic from Niglik. Even after the arrival of commercial traders, the Niglik trade fairs continued, incorporating modern trade goods with traditional ones until the early decades of this century."

For the last 35 yr or so, this location has been the home of the Woods family, to whom this guidebook is dedicated. During this period, the family depended to a large extent on caribou and fish, both of which were stored in ice (permafrost) cellars (fig. 25). Until recently, driftwood collected along the river served as fuel. Although the Woods family lives in Nuiqsut today, they still maintain their house at Niglik.

Figure 24. Low, flat, tundra surface illustrating stranding of driftwood and bank erosion.

STOP 13. ORIENTED LAKES AND MACKENZIE RIVER DRIFTWOOD. Niglik is situated at the northern edge of the most northerly of the oriented lakes bordering the western side of the delta. It was drained in the past by the river. Across the channel from Niglik is another section of former oriented lakes, the remnants of which still remain. Much of this area is low enough to be flooded, especially during storm surges from the sea. When these surges occur, logs from Canada are frequently carried onto the low surfaces.

Northwest of Stop 13 is an extensive (over 15 km^2) flat that has formed at the mouth of the Nechelik Channel (fig. 26). Composed of fine-grained materials, this flat serves as the source region for a suite of dunes that is forming locally.

By this time you have probably noticed the presence of the 'Alaska State Bird' (fig. 27). Take as many samples home as you wish. (There is no bag limit.)

Figure 25. Permafrost cellar at Niglik overlooking the mouth of the Nechelik Channel.

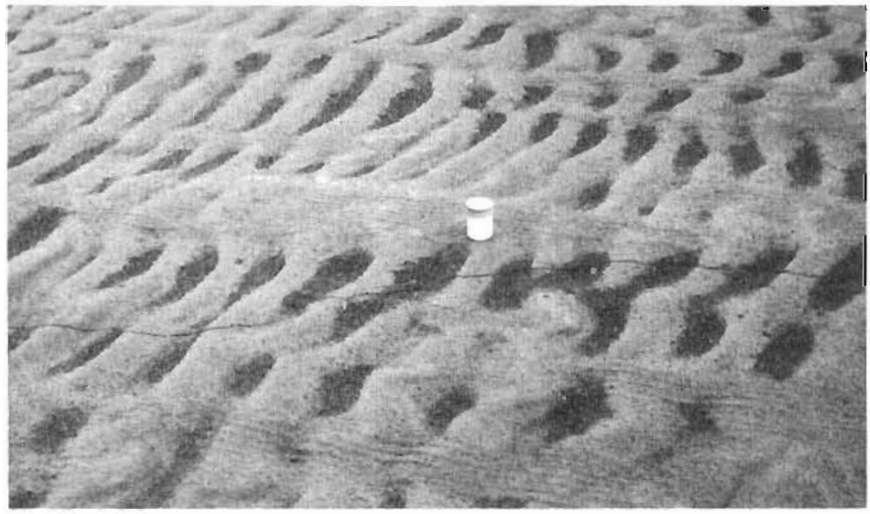

Figure 26. Silt flat with trapped organic matter at the front of the Nechelik Channel.

Figure 27. Mosquitoes, one of the most common forms of life in the delta during the months of July and August. The parka is typical of those issued by NARL---the former Naval Arctic Research Laboratory.

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