DISTRIBUTION AND CHARACTER OF NALEDS IN NORTHEASTERN ALASKA

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Abstract

An examination of the distribution of river naleds seen in Landsat satellite imagery and high- and low-altitude aerial photography of Alaska's North Slope indicates that these features are widespread east of the Colville River and less abundant to the west. Where naleds occur, stream channels are wide and often form braided channels. Their distribution can be related to changes in stream gradient and to the occurrence of springs. Large naleds, such as on the Kongakut River, often remain through the summer melt season to form the nucleus of icing in the succeeding winter. Major naleds also are likely to significantly influence the nature of permafrost in their immediate vicinity. The map of naleds may serve as a guide to the occurrence of year-round flowing water, a sparse commodity in northern Alaska.

Introduction

Repetitive Landsat-1 imagery can be used for seasonal observations of naleds on a regional scale. Although the existence of naleds on the North Slope of Alaska (Fig. 1) has been known for some time (Leffingwell, 1919), regional mapping and seasonal monitoring have not been attempted. Here, we present a study of the distribution, longevity, and character of arctic river naleds and speculate on their causes and effects, and also their importance to human development in the region.

Icing refers to the process of progressive ice growth or accretion on a frozen surface. It is an imprecise term, in that it is also used to designate many other phenomena of the Arctic. In reference to arctic rivers, it has been used to designate both the processes of ice buildup and the actual body of ice thus formed (Carey, 1973). Equivalent terms are the Russian "naled" and the German "aufeis", both of which refer to the physical feature formed. We suggest that "icing" be used for the process and "naled" for the feature formed. Thus, naleds are formed by icing.

The type of icing with which we are concerned occurs when water repeatedly or continuously emerges onto the land or ice surface during the winter periods of subfreezing temperatures and freezes in successive layers. This water may seep from the ground, from a river, or from a spring (Carey, 1973; Anisimova et al., 1973; Hopkins et al., 1955). Thus, naleds may be classified genetically as ground- , river- , or spring-naleds, although most result from a combination of these factors.

Russian studies (Anisimova et al., 1973) have shown that in some river basins in northeastern Siberia naleds accumulate up to 25-30% of the annual volume of river flow and up to 60-80% of the subsurface drainage. Naleds commonly form year after year in the same locations, generally with the same shape and size. River flood plains commonly are widened as spring floodwaters are forced to flow around naled mounds. The same studies also indicate that the size and location of naleds are a function of (1) discharge source (stream, groundwater, or spring), (2) hydrostatic head, and (3) geologic setting.

Naleds that appear to persist and continue to grow throughout the winter indicate usable fresh water sources (Hopkins et al., 1955). Considering the present rapid development of the arctic region and the scarcity of fresh water, knowledge of the distribution and character of naleds could have important implications. In addition, construction projects such as roads are affected by both naturally occuring naleds and those induced by development activities (Anderson et al., 1973). Potentially, any alteration of a balanced hydrologic-permafrost-geologic regime may induce icing conditions and cause naleds to form. In areas where naleds extend to the coast, as in the Icy Reef area (Fig. 4), they have definite influence on the deltaic and coastal-marine processes.

Background Information

The North Slope of Alaska falls into three major physiographic provinces (Wahrhaftig, 1965; Figs. 1 and 2): (1) the Arctic Coastal Plain, (2) the Arctic Foothills Province, and (3) the Brooks Range. The coastal plain is a broad, flat tundra surface with numerous lakes that includes the deltas and streams draining the higher terrain to the south. West of the Colville River the streams are meandering, while to the east braiding is more common. The Foothills Province is characterized by rolling terrain with some bluffs along the river courses. Most of the known springs occur in this province, where abrupt decreases in river gradients occur. Both the Arctic Coastal Plain and the Foothills Province narrow toward the east, where the Brooks Range approaches the coast near the Canadian boundary. The Brooks Range is the source for all of the major north-flowing rivers.

The seasonal freeze-thaw cycle controls the development and dissipation of river ice in northern Alaska. All of the rivers of the North Slope flow in the zone of continuous permafrost (Walker, 1974). River ice forms during mid to late September, after mean temperatures are below 0°C.. By the end of December when temperatures are often below -20°C, river ice is commonly more than 1 metre thick. Ice continues to thicken to a maximum of about 2 metres until May, when temperatures rise above freezing and the melt season begins. During late May and early June, thawing proceeds rapidly; flow begins on top of river and sea ice, and eventually most of the river ice breaks up and flows downstream (Walker, 1974). During summer, temperatures are above freezing and streamflow is unimpeded by ice.

Two conditions must be met before icing occurs and a naled forms. First, there must be a source of flowing water beneath a surface whose temperature is below 0°C. Second, there must be a barrier to the flow of water that forces it to the surface. These barriers are commonly provided by the total freezing of the river cross section, ground freezing, or reduction in aquifer permability owing to permafrost or outcrops of impermeable strata (Sokolov, 1973; Carey, 1973).

River naleds develop after the formation of the seasonal ice cover (Carey, 1973). If water remains unfrozen below the ice cover in the stream channel or in an alluvial layer above the permafrost or bedrock, it will continue to flow as long as water is supplied to the system. If flow is sufficiently restricted, as by a sudden change in stream gradient, or by a decrease in the permeability or thickness of the channel fill, water is forced upward over the river ice. Continuing or subsequent overflows build sheets of fresh ice over the original naled surface. The total thickness may reach 5 to 6 metres under such conditions (Péwé, 1973; Williams, 1953, 1970).

Methods

Imagery from the multispectral scanner (MSS) of the Landsat-1 Satellite was used to delineate naleds on the North Slope of Alaska and adjacent areas of Canada. Our study area extends from the coast to about 200 km inland. Imagery was received from late July 1972 through the fall of 1973, except during the polar night (mid-October through late February). Thus, it was possible to monitor one seasonal cycle of river icing and to compare naled remnants during August and September 1972 with those of 1973.

Satellite imagery covered the study area at 18-day intervals. Overlap of successive images often provided three consecutive days of coverage of a given location. However, since delineation of ground features is dependent on the absence of cloud cover, the frequency of observations was often limited by weather conditions.

Each image covers an area approximately 100 nautical miles (185 km) square at a scale of about 1:1,000,000. This scale enables us clearly to identify naleds larger than about 300 metres square. Smaller naleds are discernible when high contrast between ice and tundra or water and snow exists.

The scanner operates in four spectral bands: band 4, 500-600 nm (green), band 5, 600-700 nm (red), band 6, 700-800 nm (visible-near IR), and band 7, 800-1100 nm (near IR). One image is taken in each band for every satellite pass.

During the summer months, bands 4 and 5 show the greatest contrast between the naleds, the unfrozen channels, and the surrounding tundra. On these images, naleds appear white, channels and deltas are light toned, and the higher ground a darker shade (Figs. 7a, d). During the winter, band 7 shows the greatest contrast between the naleds and the snow-covered tundra and stream channels (Fig. 7b). In these images fresh ice or water appears dark and the surrounding terrain white, except where relief is sufficient to produce shadows.

Additional information was available from a high-altitude U-2 flight of 21 June, 1974 (NASA Flight No. 74-101). This flight utilized a RC-10 camera with color infrared film at a flight altitude of 65,000 ft (19.9 km) on flight lines north and south over the Sagavanirktok River and east and west across the middle of the Arctic Coastal Plain.

Distribution of Naleds

River naleds detectable on Landsat-1 imagery during late winter are shown in Figure 2. The Colville River is the largest river in the study area. A cursory inspection of imagery of rivers west of and including the lower Colville showed almost no naleds, with the exception of a possible naled along the Ikpikpuk River (approximately 155°W long), about 40 km from the coast (for example, see image 1257-21463).

East of the Colville River, most of the larger streams between the Anaktuvuk and Firth Rivers show naleds in the Foothills Province (Fig. 2).

The larger deltas also commonly show naleds. Fewest naleds occur in the reaches between the foothills and the river mouths.

The downstream ends of naleds are diffuse and feathery, presumably because surface flow continues downstream for varying distances after initial overflow. These downstream tails may extend for considerable distances and interconnect naleds. For instance, the Canning River shows almost one continuous naled from the Brooks Range to within about 10 km of its mouth (Figs. 2 and 3).

The distribution of naleds shows good correlation with that of the shallow reaches of braided streams (Figs. 2 and 4). Naleds may be the cause or the result of the braiding. During summer, the elevated surfaces of naled remnants may divert channels around ice patches. Once formed, the shallow channels readily freeze down to the bottom, creating conditions favorable to blocking the underflow and forcing overflow. On the other hand, low-altitude aerial photographs show channels dissecting naleds subsequent to spring flooding (Figs. 4 and 5), indicating that naleds do not always cause stream diversion.

A comparison of known perennial springs (Childers et al., 1973) with the sites of river naleds shows that all of the springs correspond to locations of naleds (Fig. 2). Naleds may indicate other unmapped springs, especially in areas with no apparent upstream water sources (Williams and Van Everdingen, 1973). Presumably, perennially flowing springs exist at or upstream from such naleds.

Development of Naleds

Landsat imagery from mid-September to the shut-off of the cameras for the arctic night in late October 1972 does not show new naled development.

Many rivers were still flowing at this time, indicating that the basic requirements of an initial ice cover and water flow barrier had not yet been met.

During the period from the first 1973 imagery in early March until spring breakup in June, many naleds increased in size. However, some were apparently unchanged throughout this part of winter, indicating that their water sources were cut off, had greatly decreased flow, or were frozen prior to March.

During the first week of August 1973, weather conditions permitted excellent coverage of most of the study area by Landsat imagery. At this time, remnants of most of the larger naleds are visible (for example image numbers 1376-21112, 1378-21164, 3 and 5 August). They are considerably less extensive than the winter naleds, and some undoubtedly melted before autumn freeze-up. The largest naleds of the previous winter, such as on the Kongakut-Sagavanirktok and Canning Rivers, still had remnants in September (for example image numbers 1410-20533, 1414-21162). It is probable that these large naleds persist for more than one season under favorable conditions. Such naleds would result in lower ground temperatures below than in adjacent terrain not covered by reflecting ice during summer. This would in turn promote early icing in the following winter. Thus, long-lived naleds may be self-perpetuating.

Naleds on the Kongakut River

The delta of the Kongakut River (Kangikat on some charts) located in the Arctic Wildlife Refuge (Fig. 2) repeatedly came to our attention during the icing study. Naleds on this river are particularly large (Figs. 4 and 5) and long lived. The delta ice buildup commonly extends into the lagoon seaward of the delta front and out to Icy Reef. This interaction of river icing with the marine environment and delta front is unique along the Alaskan coastline.

Icy Reef was named by the Franklin expedition in August 1826, when heavy ice outside the reef necessitated dragging boats over the mudflats at the mouth of the Kongakut River to Beaufort Lagoon (Leffingwell, 1919). Leffingwell's description thus indicates that the name did not result from the extension of naleds into the lagoon.

Naleds were present on the delta throughout the year of our Landsat coverage (Figs. 6 and 7). During the winter of 1972-73 the naleds increased in size (Figs. 6c,d), starting sometime after September and continuing through March, 1973. (April and May images were cloudy). Beginning with the start of the thaw season in late May and continuing until mid-August, the naleds shrank to about one-tenth their former extent (Figs. 6e,f,g,h, and 7c,d). It appears that the delta naled was unchanged from mid-August to mid-September, 1973 (Figs. 6a,b,h,i).

During the winter of 1973, the naled extended into the lagoon in front of the delta (Figs. 6c,d; 7b). An image obtained about two weeks after the initiation of river flow (Figs. 6e and 7c) indicates that naleds remained in the lagoon through the flooding period. Field observations during August 1972 and September 1973, as well as the Landsat imagery shown in Figures 6g,h,i and 7a, d showed no ice in the lagoon during these periods. Low altitude imagery in early August 1973 (Fig. 4) shows naled ice on the delta front abutting the lagoon. During field operations in late August of 1971, ice was observed in the lagoon behind Icy Reef. According to the Coast Pilot (U.S. Dept. Commerce, 1964), ice is commonly present in the lagoon behind Icy Reef throughout the summer.

In trying to explain the lagoon ice seen in 1971 and reported in the Coast Pilot, we considered that the coastline may have retreated very recently off the Kongakut River, and that permafrost may be near the surface of the lagoon, thereby enhancing the summer occurrence of ice by lowering the water temperature in the lagoon. A comparison of Leffingwell's (1919) map of the coastline, which is quite accurate in most areas, with the modern maps, suggests such a retreat of the coastline over a period of about 35 years. However, further investigations of aerial photography taken during the past 20 years and modern coverage suggest that the early maps are in error and that the coastline is rather stable.

It has become apparent from the study of Landsat imagery that river icing is an important factor influencing the marine processes along the delta front of the Kongakut River. A comparison of 1972 and 1973 imagery in mid-August and early September shows little difference in the size of the Kongakut River naled, although channel patterns on it are somewhat different (Figs. 6a,b,h,i; 7a,d). In years following extensive icing the lagoon in front of the delta remains ice-covered through the summer. The fact that naleds on the delta last through the summer makes them the logical sites for icing during the succeeding winter.

Climate and Naleds

In order to assess the effect of weather conditions on the size of naleds, monthly rainfall and snow accumulation data for the nearest weather station (Barter Island) were analyzed for 1971, 1972 and 1973 (U.S. Dept. Commerce, 1971-1973).

Heavy summer precipitation would presumably promote icing during the following winter by creating an abundant ground water supply. In contrast, the insulating effect of heavy snowfall during the early winter winter would decrease the growth rate of river ice cover, thus producing unfavorable icing conditions. Heavy snow cover late in the winter may extend the period of icing by preserving lower temperatures in the ground, but according to Carey (1973), this insulating effect is less important than rain and snow conditions during the preceding summer and early winter.

During the two seasons studied, the influence of varied summer precipitation was apparently balanced by opposing snowfall conditions. Precipitation was much greater than average during the summer of 1971 and below average the following summer season. Groundwater conditions would therefore have been more favorable for naled development during the winter of 1971-72 than in the following winter. On the other hand, snowfall was heavier during the early winter of 1971 than during the same period in 1972, which would have insulated the ground and led to less favorable icing conditions in 1971-72. Finally, snowfall during late winter was greater in 1972 than in 1973, which would have been more favorable to 1971-72 icing.

Because of the contrasting and balancing climatic influences during 1971-1973, it is not possible to evaluate the impact of climate on naled growth with our present information. There appears to have been no significant difference in the area of naleds remaining during the two summers of Landsat observations (Figs. 6b,i; 7a,d). In order to assess the variability in weather and icing conditions, several more seasons would have to be studied. Furthermore, considering the abundance of springs in the Arctic, the influence of seasonal variation in precipitation patterns on spring and groundwater flow needs to be evaluated. Spring discharge may be relatively constant from season to season and from year to year owing to reservoir storage. Furthermore, there may be a considerable time lag between recharge of the reservoir and spring discharge.

Discussion

Naleds on the North Slope of Alaska are widespread but are concentrated east of the Colville River, at the heads of deltas, and where streams leave confined mountain channels. The Colville River has few naleds and almost none along the lower two thirds of its course. One might assume that there is continuous flow to the sea along the channel under the ice or within the river bed. The work of Walker and others (Arnborg and others, 1966; Walker, 1974) has indicated that the delta channels are below sea level and are connected to the sea, even at the maximum ice growth. Walker's work also shows that saline water extends upstream for 60 km below the ice cover. This would suggest either that there is no continuous source of water in the drainage basin of this large system, or that the river flow is so greatly reduced in volume and force that it can be accommodated in a thin layer between the ice and an intruding salt water wedge. Measurements at three locations along the lower Colville above the delta showed no flow in April 1975 (Joe Childers, U.S. Geological Survey, personal comm., 1975). This and the apparent lack of springs along this river (Fig. 2) suggests that there may be virtually no winter freshwater flow in the Colville River system. This would be significant in any search for a year-round water supply.

Pumping from a river with little or no winter recharge could result in salt water intrusion, or the depletion of stagnant freshwater pools.

Pumping down of freshwater pools in March 1976 for the Prudhoe Bay Oil Field Complex from the Sagavanirktok and Kuparuk Rivers has already forced overwintering fish to retreat to isolated pockets within the river bed (Terry Bendock, Alaska Department of Fish and Game, personal comm., 1976). The Sagavanirktok River has numerous naleds (Fig. 2) suggestive of year-round water recharge, although the water depletion rate by pumping near Prudhoe suggests little or no flow reaches this far downstream in late winter.

Naleds influence the ground temperature, permafrost, and channel form in such a way as to favor the continued development of naleds at the same locations. In the long summer days, when ground temperatures are raised and the surficial thaw layer is formed, much of the incoming solar energy is reflected from the naled surface. Therefore, ground temperatures would be lower and the active layer above the permafrost thinner in the immediate vicinity of naleds. This in turn would enhance icing in the same area during the following freeze season.

The morphology of North Slope streams where icing occurs is strongly influenced by the naled masses. Spring flooding and subsequent flow are consequent upon the relief surface present in the spring. Thus, under some conditions much of the spring floodwater is initially forced to detour around elevated naled surfaces, causing the channels to widen. Consequently, most of the braided sections of streams and rivers shown in Figure 2 are probable locations of recent or present-day naleds. Once formed, the braided channels are favorable sites for continued icing. The wide shallow flow favors rapid freezing to the bottom in the fall and early winter.

Naleds on the deltas appear to be dissected readily by the seasonal river flow (Fig. 4), although the location of the dissection may differ from year to year (Figs. 6b,c; 7a,d). Floodwaters are often high enough to overtop the naled. The flow then seeks low areas within the naled that form the forerunners of dissecting channels.

Naleds that extend into the lagoon off the delta of the Kongakut River are bounded on the seaward side by Icy Reef, a barrier beach (Figs. 4, 6 and 7). New lagoon ice floats during the fall freezeup; however, where it is depressed by naled tails as winter proceeds, it rests on the bottom. Subsequently, a mound of ice develops, covering the delta and lagoon (Fig. 6c). During the flooding of the river, water flowing over this mound will bypass the delta and lagoon to a point beyond the barrier island. Since most of the river sediment load is transported at this time (Walker, 1974), the sediments will also bypass the delta and lagoon.

During glacial episodes along the arctic coast of Alaska, the climate was colder and dryer (Hopkins, 1967). Thus, it is presumed that less surface water would have been available, the flow season would have been shorter, and the depth of winter freeze greater. The latitudinal depression of isotherms suggests that naleds of the type found in the Arctic today would probably have been more widespread at lower latitudes. Naleds along the arctic coast would have been unaffected in areas where thermal springs exist. In general, naled development would probably have been enhanced by the shorter thaw season and the greater probability that naleds would last from one year to the next, but hindered by the lesser amounts of precipitation.

The map of naleds (Fig. 2) is also a map of potentially useful fresh-water sources. The map may also serve as a guide in the planning of future construction, which might interact with the hydrologic regime to create problems. Naled areas indicate nearby springs that are overwintering sites for some fish species (Childers and others, 1973) and are therefore important in the biological regime of the Arctic. The scarcity of naleds west of the Colville River suggests limited water resources or extensive unimpeded groundwater flow. Considering the importance of developing a water supply in the Arctic, further investigation in this area is needed.

Conclusions

1. Naleds on the North Slope of Alaska are widespread but are concentrated east of the Colville River, primarily where the streams leave the confined mountain channels and at the heads of deltas.
2. Some larger naleds can last through the summer melt season to form the nucleus of naleds that grow during the following years, although channels commonly dissect the naleds during the melt season.
3. The deflection of spring floods around naleds may commonly cause shallow braided channels to develop.
4. Some naleds are, and others may be, the site of groundwater discharge in the form of springs. They are thus potential sources of year-round fresh water.
5. Precipitation patterns should affect icing patterns unless naleds are fed by bedrock springs. The major controlling climatic factors tended to cancel each other in the two years studied, and the influence is as yet unknown.

Acknowledgments

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References

Anderson, D. M., McKim, H. L., Crowder, W. K., Haugen, R. K., Gatton, L. W., and Marlar, T. L., 1973, Applications of ERTS-1 imagery to terrestial and marine environmental analysis in Alaska; in Third ERTS-1 Symposium, v. 1, Section B, NASA, Goddard Space Flight Center, Washington, D.C., Proceedings, p. 1575-1605.

Anisimova, N. P., and others, 1973, Groundwater in the cryolithosphere; Akademiya Nauk SSSR Sektisiya Nauk o Zemle, Sibirskoye, II Mezhdunarodnaya Konferentsiya po Merzlotovedeniyu (USSR Academy of Sciences, Earth Sciences section, Siberian Branch, Second International Conference on Permafrost), Lectures and Reports, No. 5, Yakutsk Book Publishing Co., Yakutsk, USSR, 172 p.

Arnborg, Lennart, Walker, H. J., and Peippo, Johan, 1966, Water discharge in the Colville River Alaska, 1962, Geografiska Annaler, v. 48, ser. A, p. 195-210.

Carey, K. L., 1973, Icings developed from surface water and ground water; Cold Regions Science and Engineering Monograph III-D3, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 65 p.

Childers, J. M., Sloan, C. E., and Meckel, J. P., 1973, Hydrologic reconnaissance of streams and springs in eastern Brooks Range, Alaska - July 1972; U.S. Geological Survey, Water Resources Division, Basic-Data Report, Anchorage, Alaska, 25 p.

Hopkins, D. M., 1967, The Cenozoic history of Beringia - A synthesis; in D. M. Hopkins, ed., The Bering Land Bridge; Stanford University Press, Stanford, CA., p. 451-484.

Hopkins, D. J., Karlstrom, T. N. V., and others, 1955, Permafrost and groundwater in Alaska, U.S. Geological Survey Professional Paper 264-F, p. 113-146.

Leffingwell, E. DeK., 1919, The Canning River region, northern Alaska, U.S. Geological Survey Professional Paper 109, 251 p.

Pewe, T. L., 1973, Permafrost conference in Siberia; Geotimes, v. 18, no. 12, December, p. 23-26.

Sokolov, B. L., 1973, Regime of Naleds; in Anisimova, N. P., Ground water in the cryolithosphere, p. 98-106.

U.S. Department of Commerce, 1964, United States Coast Pilot 9, Pacific and Arctic coasts, Alaska, Cape Spencer to Beaufort Sea, U.S. Government Printing Office, p. 285.

U.S. Department of Commerce, 1971, 1972, 1973, Local Climatological Data, Annual Summary, Barter Island, Alaska, U.S. Department of Commerce, National Climatic Center, Asheville, N.C., 4 p.

Wahrhaftig, Clyde, 1965, Physiographic divisions of Alaska: U.S. Geological Survey Professional Paper 482, 52 p.

Walker, H. J., 1974, The Colville River and the Beaufort Sea: Some interactions; in Reed, J. C., and Sater, J. E., eds., The coast and shelf of the Beaufort Sea, Arctic Institute of North America, Arlington, Virginia, p. 513-540.

Williams, J. R., 1953, Icings in Alaska, 1949-1950; Engineering Intelligence Division, Engineering Notes No. 32, 23 p.

Williams, J. R., 1970, Groundwater in permafrost regions of Alaska; U.S. Geological Survey Professional Paper 696.

Williams, J. R., and van Everdingen, R. O., 1973, Groundwater investigations in permafrost regions of North America; A review, <u>in</u> North American contribution, Permafrost, Second International Conference, National Academy of Sciences, Washington, D. C., Proceedings, p. 435-446.

Figure Captions

Figure 1. Physiographic diagram of study area. Diagram by Tau Rho Alpha.

Figure 2. Distribution of naleds in northeastern Alaska from Landsat imagery. Contours in metres. Spring locations from Childers, Sloan, and Meckel (1973).

Figure 3. Naleds on lower Canning and Sagavanirktok Rivers on April 19, 1973. Landsat images no. 1270-21175 and 1270-21181.

Figure 4. Naled on Kongakut River Delta, near international boundary, August 2, 1973. (Photo courtesy of Andrew Short, Louisiana State Univ., Inst. of Coastal Studies).

Figure 5. U-2 photographic mosaic taken June 21, 1974, of naleds along the Kongakut River.

Figure 6. Development and decay of the delta and lagoon naled on the Kongakut River Delta. Data from Landsat images no. 1308-20424, 1050-20541, 1228-20435, 2147-20493, 1318-20426, 1356-20542, 1374-20541, 1390-20423, 1409-20475.

Figure 7. Comparative Landsat imagery of the naleds on the Kongakut River Delta, September 1972 through September 1973. Landsat images no. 1050-20541, 1228-20435, 1318-20476, 1409-20475.

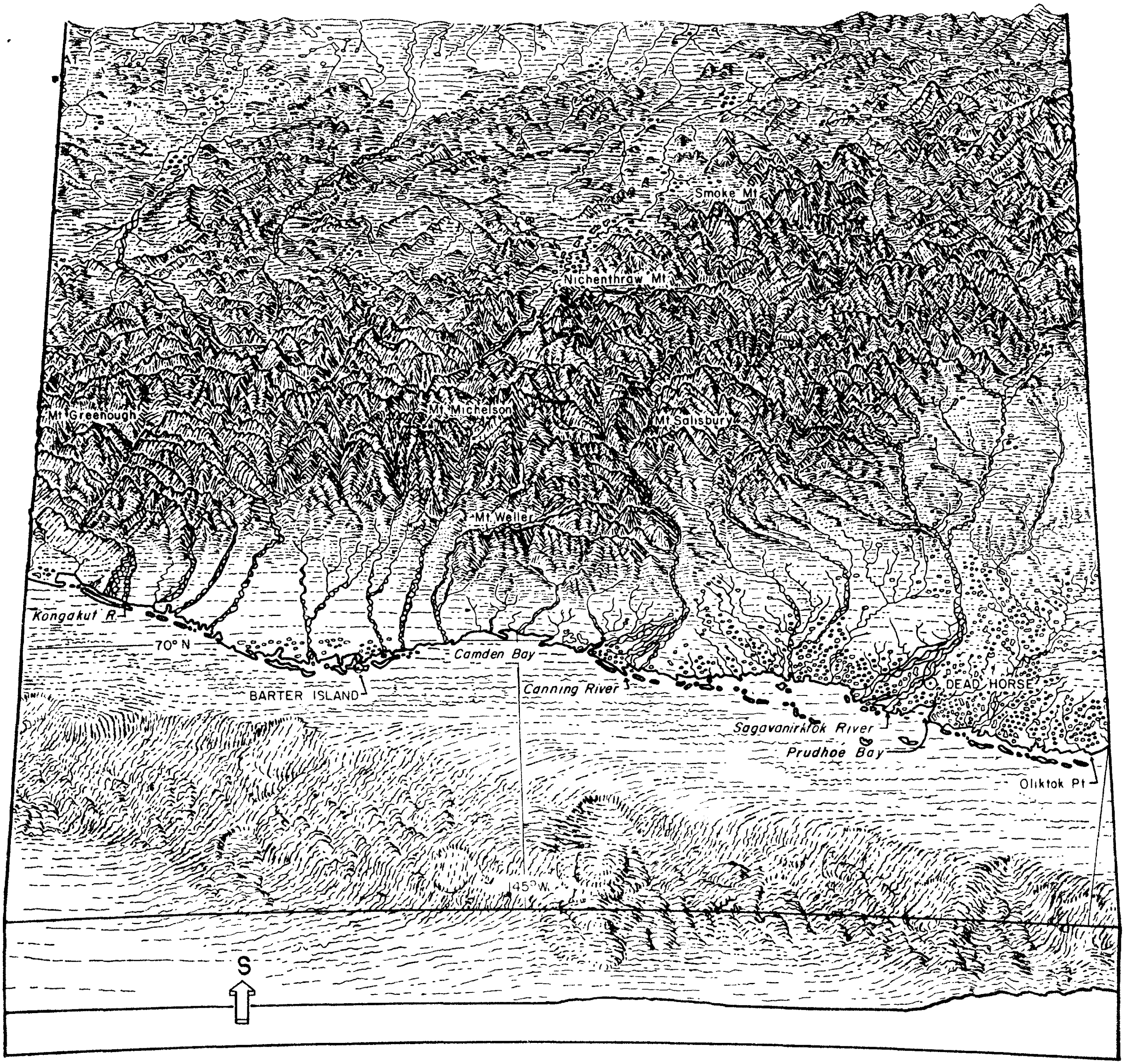
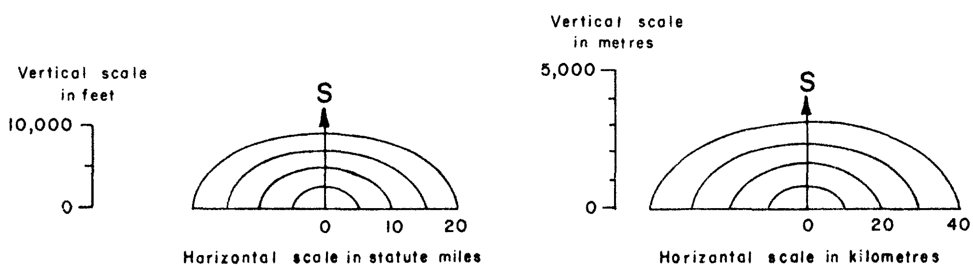


Figure 1.

VERTICAL EXAGGERATION 7:1



SCALE

Physiography by Tau Rho Alpha

Coast and Shelf of Northeastern Alaska

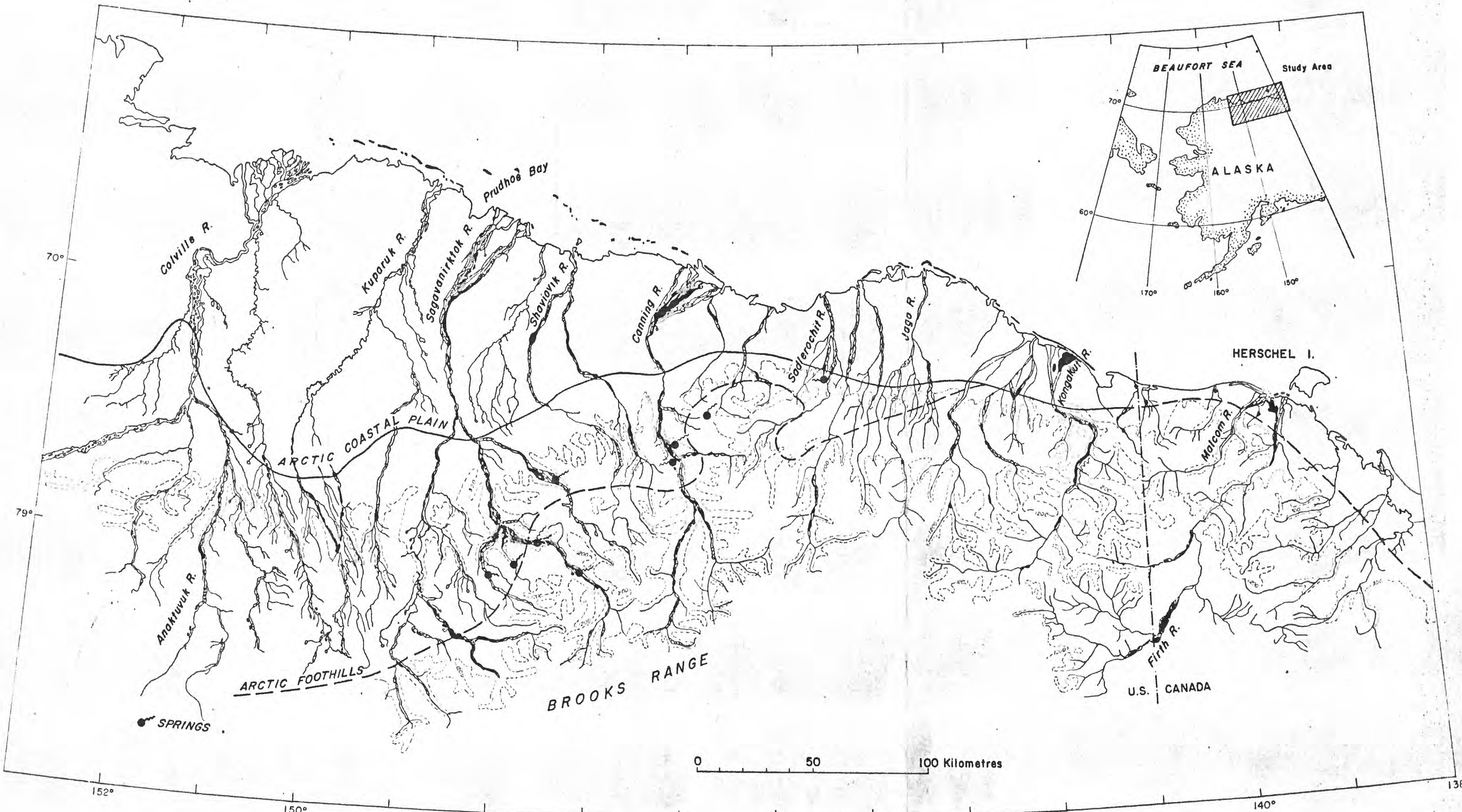

BEAUFORT SEA
Study Area
ALASKA
70°
60°
170°
160°
150°
Colville R.
Kuparuk R.
Sagavanirktok R.
Prudhoe Bay
Shaviovik R.
Canning R.
Sadlerochit R.
Jago R.
Kongakut R.
HERSCHEL I.
Malcom R.
Firth R.
U.S.
CANADA
ARCTIC COASTAL PLAIN
ARCTIC FOOTHILLS
BROOKS RANGE
Anaktuvuk R.
SPRINGS
0
50
100 Kilometres
70°
79°
152°
150°
148°
146°
144°
142°
140°
138°

Figure 2.

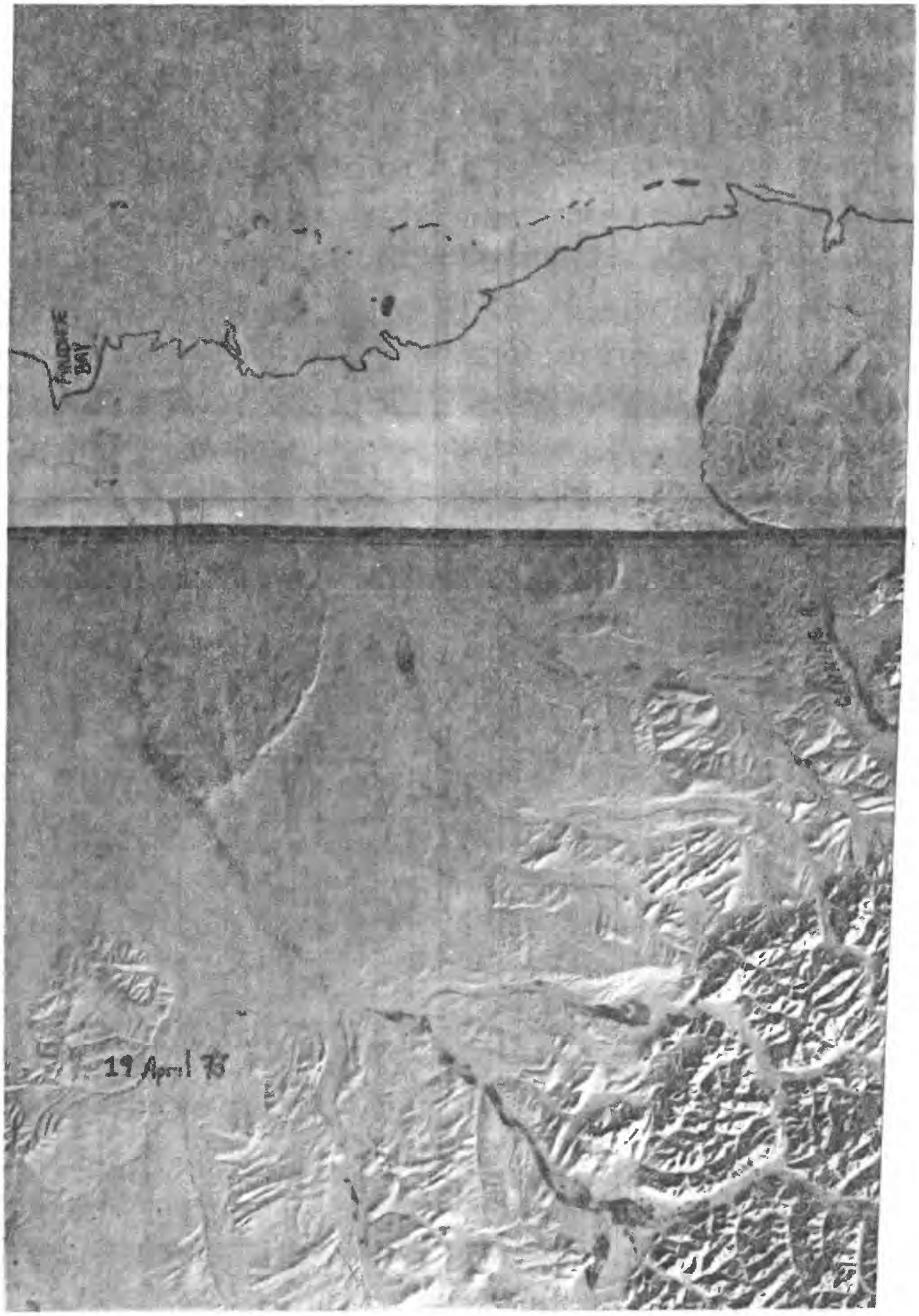


Figure 3.

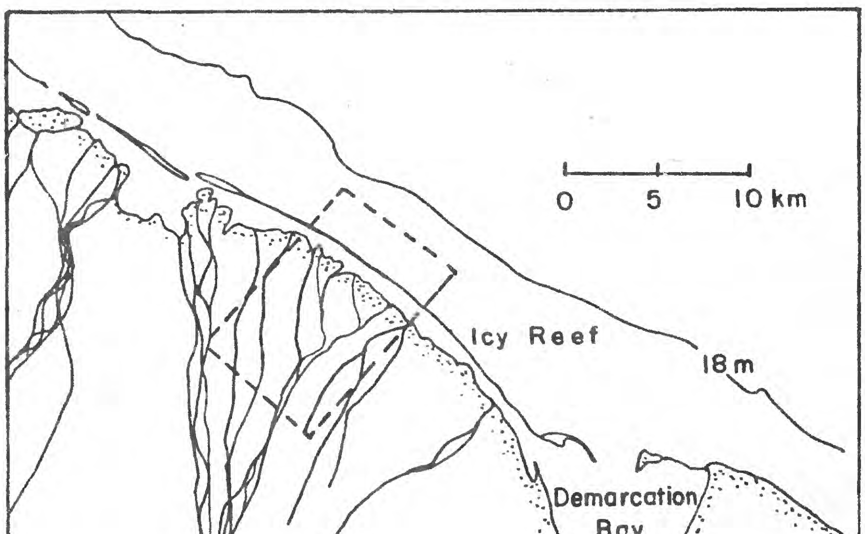
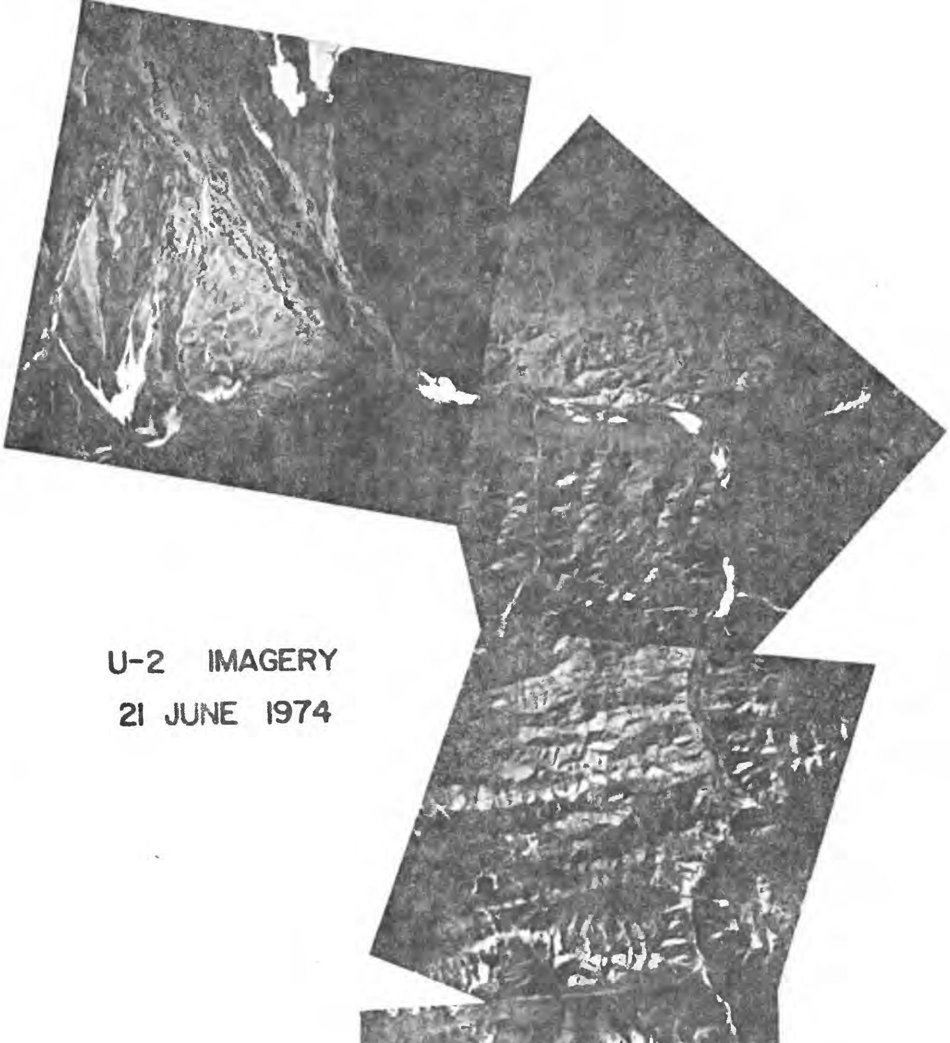


Figure 4.



U-2 IMAGERY
21 JUNE 1974

KONGAKUT RIVER

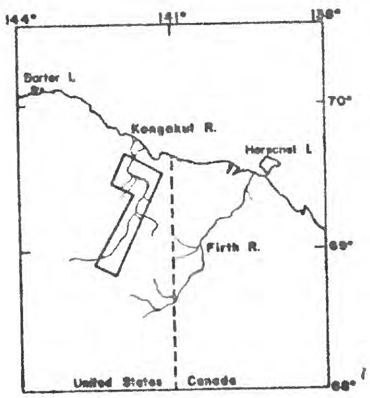


Figure 5.

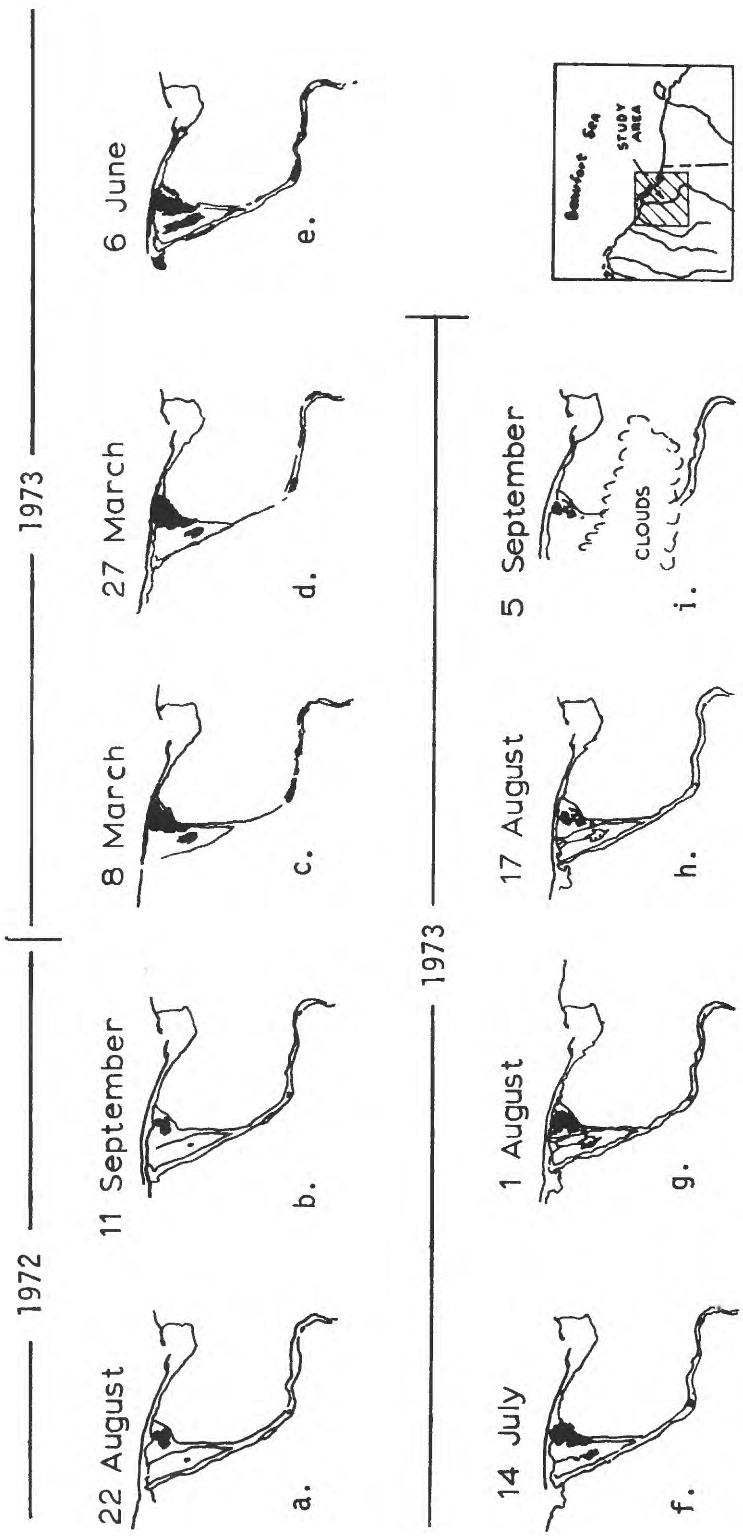
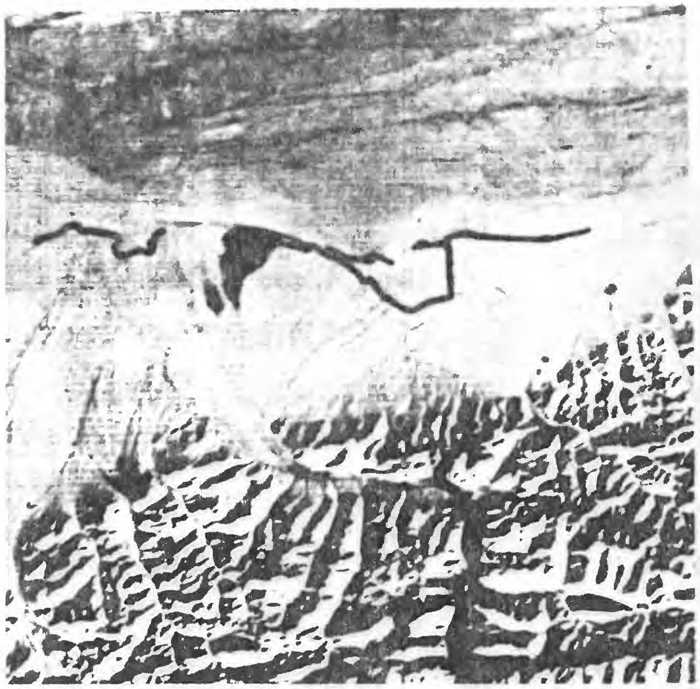
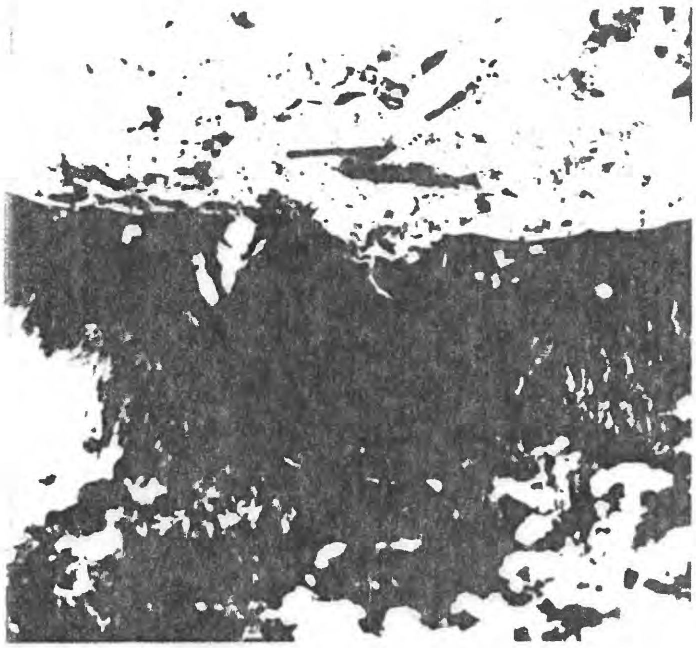

1972
1973
22 August
11 September
8 March
27 March
6 June
a.
b.
c.
d.
e.
1973
14 July
1 August
17 August
5 September
f.
g.
h.
i.
CLOUDS
Beaufort Sea
STUDY AREA

Figure 6.

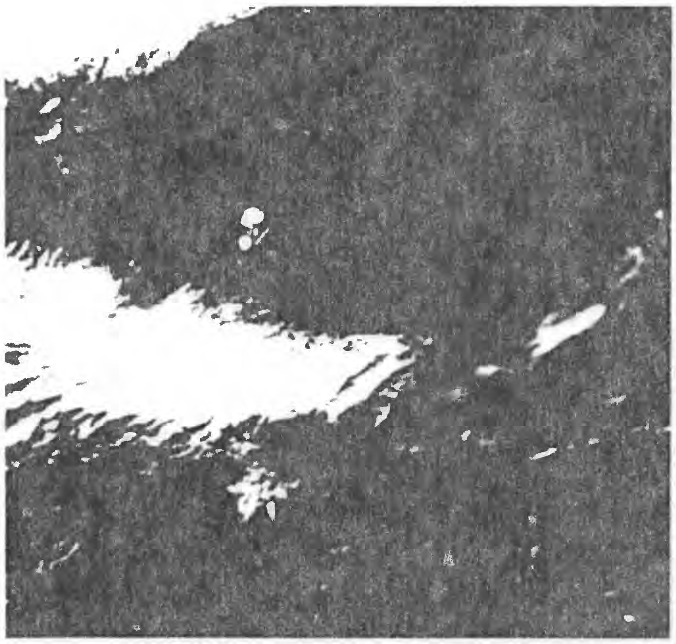
a. 11 SEPT 72



b. 08 MAR 73



c. 06 JUNE 73



d. 05 SEPT 73

Figure 7.