Classification and Relief Characteristics of Northern Alaska's Coastal Zone

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ABSTRACT. Four main genetic coastal types are proposed to classify the shoreline of northern Alaska bordering the Chukchi and Beaufort Seas, which extends for more than 2,150 km. from Cape Thompson eastward to the Canadian border: *Land erosion* — coast marked by subaerial erosion of terrestrially shaped land forms and partly drowned by rise in sea level (8.9 per cent of coastline); *River deposition* — coast formed by fluvial deposition (19.9 per cent); *Wave erosion* — coast shaped primarily by marine agencies and exposed to the open ocean, being marked by coastal retreat and negligible nearshore deposition (37.5 per cent); *Marine deposition* — similar to preceding except nearshore sediment deposition is pronounced (33.7 per cent).

Four categories of coastal relief or sea cliff height associated with these coastal types are proposed: *Low relief* — less than about 2 m.; *Moderate relief* — about 2-5 m.; *High relief* — about 5-8 m.; *Very high relief* — greater than about 8 m. About 1,590 km. or 74 per cent of the coast has relief of 5 m. or less whereas mean relief or scarp height for the entire coast is about 4 m. In general mean scarp heights decrease to the east along the coastal plain.

RÉSUMÉ. *Classification et caractéristiques du relief de la zone côtière du nord de l'Alaska.* Pour classifier le rivage du nord de l'Alaska, qui s'étend sur plus de 2,150 km le long des mers de Tchoukotsk et de Beaufort depuis le cap Thompson jusqu'à la frontière canadienne vers l'est, l'auteur propose quatre types génétiques côtiers principaux: *Erosion terrestre* — côte marquée par l'érosion subaérienne de géoformes d'origine terrestre partiellement ennoyées par le relèvement du niveau marin (8.9 pour cent du trait de côte) ; *Accumulation fluviale* — côte formée de dépôts fluviaux (19.9 pour cent) ; *Erosion par les vagues* — côte formée surtout par des agents marins et exposés à l'océan, marquée par le recul de la côte et une sédimentation côtière négligeable (37.5 pour cent) ; *Accumulation marine* — semblable au type précédent, sauf que la sédimentation côtière est prononcée (33.7 pour cent).

L'auteur propose quatre catégories de relief côtier ou de falaise marine associés à ces types côtiers: *Relief bas* — moins de 2 m ; *Relief modéré* — environ 2-5 m ; *Relief élevé* — environ 5-8 m ; *Relief très élevé* — plus de 8 m. Environ 1,590 km ou 74 pour cent de la côte ont un relief de 5 m ou moins, alors que le relief moyen ou la hauteur de l'escarpement pour toute la côte est d'environ 4 m. En général, les hauteurs moyennes diminuent vers l'est le long de la plaine côtière.

РЕЗЮМЕ. *Классификация и характеристики рельефа береговой зоны северной Аляски.* Предложены сделующие четыре основных генетических типа побережья для классификации береговой линии северной Аляски, граничащей с Чукотским морем и морем Бофорта и протянувшейся более чем на 2 150 км от мыса Томпсона на восток к границе с Канадой. 1. Побережье, сформированное в результате субаэральной эррозии различных геологических форм суши и частично затопленное вследствие подъёма уровня моря (8,9 процентов береговой линии). 2. Побережье, образованное речными отложениями (19,9 процентов). 3. Побережье, подверженное эррозии волн, незащищённое от открытого океана и сформировавшееся преимущественно в результате морской активности (37,5 процентов). Для этого типа побережья характерно постепенное отступление берега и незначительные береговые отложения. 4. Побережье, аналогичное предыдущему, но с ярко выраженными морскими осадочными отложениями (33,7 процента).

В соответствии с этими типами побережья предлагаются четыре типа берегового рельефа или высоты морских скал: 1) низкий рельеф — менее 2м; 2) умеренный

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рельеф — около 2-5м; 3) высокий рельеф — около 5-8м; 4) очень высокий рельеф — более 8м. Около 1 590 км или 74 процента побережья имеет рельеф высотой 5м и менее, тогда как средний рельеф, или высота уступа для всего побережья составляет около 4м. В общем средняя высота уступа уменьшается к востоку вдоль прибрежной низменности.

INTRODUCTION

The shoreline of northern Alaska extends for more than 2,150 km. along the Chukchi and Beaufort Seas from Cape Thompson eastward to the Canadian border (Fig. 1). The edge of the mainland is commonly marked by an abrupt break in slope formed by eroding sea cliffs and bluffs comprised of perennially frozen bedrock and ice-rich sediments. Much of the coastline is cut by gullies and river valleys which extend up to tens of kilometres inland. Other coastal features include river deltas, barrier islands, beaches, spits, and dune fields.

For up to nine months of the year sea ice is frozen fast to the coast, essentially halting coastal erosion, near-shore sediment transport, and coastal modification. During the remainder of the year the ground surface and near-shore sea ice thaw, allowing mass wasting and slumping of thawed and frozen material along coastal cliffs, wave attack of exposed sections, pronounced coastal sedimentation (Hume and Schalk 1967), and rapid shoreline retreat (MacCarthy 1953; Lewellen 1970).

This paper proposes a genetic classification scheme for the northern Alaskan coast based on dominant geologic processes and proposes a categorization of the relief classes associated with the above coastal types.

The area discussed is part of two physiographic provinces: the low-relief, broad Arctic Coastal Plain and the rugged Arctic Foothills (Payne *et al.* 1951; Williams 1958; Wahrhaftig 1965). On the basis of geology, physiography, and recent marine processes, this shoreline can be grouped into six distinct geographic regions (Fig. 1).

Southern Foothills (Cape Thompson to Sapumik Ridge, about 192 km.): mainland characterized by nearly-continuous, steep bedrock sea cliffs with relief of up to 260 m. (at Cape Lisburne) and fronted by narrow beaches at the base of the cliff and across numerous stream valleys which intersect the coast. At Point Hope a cuspate foreland of essentially unbroken sand and gravel barrier islands outlines a broad river delta.

Northern Foothills (Sapumik Ridge to Panikpiak, about 82 km.): bedrock cliffs as in the Southern Foothills but relief is lower (up to about 75 m.). No offshore barrier islands or large river outlets are present.

Foothill Silt Surface of the Coastal Plain (Panikpiak to Utukok River, about 172 km.; O'Sullivan 1961): characterized by nearly-continuous sea cliff exposures of bedrock with relief of about 4 to 14 m. Northern portion is fronted by essentially unbroken barrier islands (relief less than about 3 m.) which enclose a shallow lagoon up to 7 km. wide.

Coastal Plain West of Point Barrow (Utukok River to Point Barrow, about 365 km.): characterized by nearly-continuous sea cliffs (relief up to about 12 m.) cut into perennially frozen bedrock and ice-rich sediments. Near Icy Cape and Point Franklin offshore barrier islands front the coast, enclosing shallow lagoons; elsewhere the cliffs are abutted by narrow beaches.

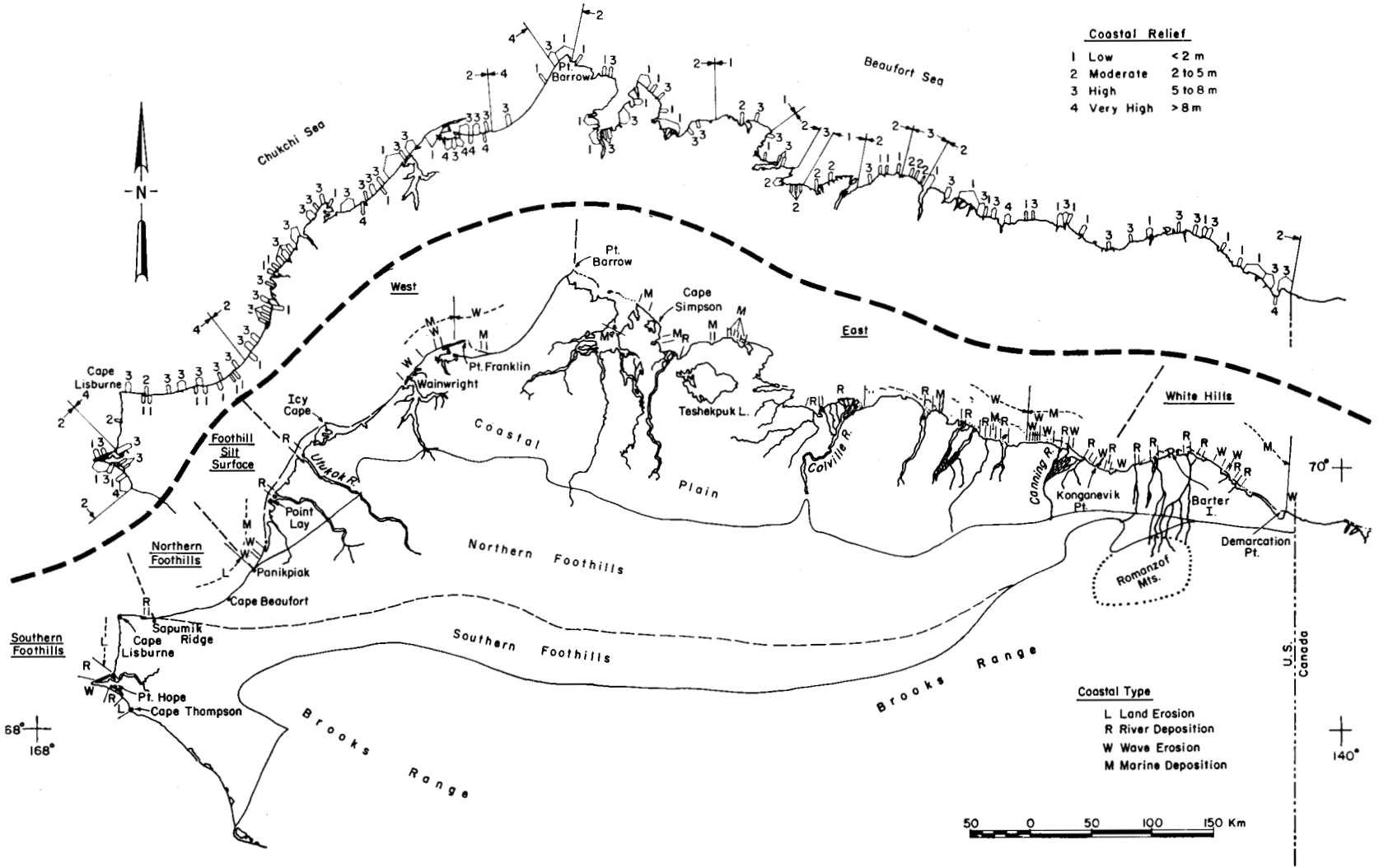

FIG. 1. Distribution of coastal relief categories (upper) and coastal types (lower) along the shoreline of northern Alaska.

Coastal Plain East of Point Barrow (Point Barrow to Konganevik Point, about 1,054 km.): much like preceding region except more strongly influenced by sea ice which remains close to shore about 10 months of the year. Many sections are fronted by low-relief barrier islands which enclose shallow lagoons. The shoreline is generally irregular because the retreating coast has intersected valleys and old "thaw" lakes (Carson and Hussey 1962) and because the land has been drowned by rising eustatic sea level (Creager and McManus 1967). Numerous large river deltas (relief less than about 3 m.) are also present.

White Hills section of the Coastal Plain (Konganevik Point to U.S.-Canadian border, about 290 km.): low sea cliffs along a shoreline which is somewhat straighter than that of the preceding region. The coast intersects the edge of a wide, broad alluvial fan sloping northward from the Romanzof Mountains and traversed by numerous braided river systems.

The information in this paper is based on topographic maps, field studies in the Point Barrow area, and vertical aerial photographs. Due to the paucity of spot elevations in coastal portions of the maps and the low relatively horizontal character of the coast, estimates of total coastal relief (or height of the sea cliff where present) could only be made to the nearest metre. The relief data were tabulated in increments of 0-1, 1-2, 2-3, 3-4, 4-5, 5-8, and greater than 8 m. for each of the six geographic regions. Mean scarp heights were calculated by weighting process, using mid-point values in the relief increments, and a value of 10.5 for the greater than 8 m. increments. The length of coast comprising each relief class was measured with a wheel-type map measuring device, to an accuracy of 0.5 to 3.0 per cent depending upon the irregularity of the coastline.

COASTAL CLASSIFICATION

Along the coast of northern Alaska four main genetic coastal types (following Shepard 1963) are recognized based on the dominant geologic processes acting on this environment:

Primary Coasts — configuration due to the sea coming to rest against a land-form shaped by terrestrial rather than marine agencies.

Land Erosion Coasts (L) — shaped by subaerial erosion and partly drowned by rise in sea level; characterized by a nearly-straight shoreline with steep, sheer sea cliffs and bluffs formed in bedrock; the cliffs are being eroded but at some locations are fronted by nearshore sedimentary deposits (barriers) which provide some protection from the open ocean; relief may reach several hundred metres.

River Deposition Coasts (R) — largely due to deposition by rivers acting to extend the shoreline; fluvial deltaic deposits consisting of multiple braided and branching river channels separated by sedimentary lobes; dune fields are present on some deltas where sedimentary deposits are not vegetated; channel banks are frequently steep; some sections are fronted by near-shore barrier islands; relief is generally less than about 4 m.

Secondary Coasts — coastlines shaped primarily by marine agencies but may have originally been primary coasts.

Wave Erosion Coasts (W) — coastlines which are exposed directly to the open ocean and along which marine deposition is negligible; characterized by sea cliffs

cut into perennially frozen bedrock and ice-rich sediments; cliffs are either undergoing marked erosion or are in a near-equilibrium condition and have a generally sheer and nearly-continuous appearance due largely to the effects of waves; may have a narrow beach at the base of the slope; relief generally less than about 11 m.

Marine Deposition Coasts (M) — coastlines similar to (W) in that they are prograded by waves and currents, but marine deposition is much more pronounced; fronted by nearshore sedimentary deposits (barrier islands and spits) that extend roughly parallel to the general coastal trend but are separated from the mainland by a relatively narrow body of water (usually less than about 5 km. wide); these barriers provide some coastal protection from the pack ice, waves, and currents of the open ocean; spits are common, frequently extending across river valleys and partially closing them, relief generally less than about 4 m.

The geographic distribution of these coastal types in northern Alaska is shown in Fig. 1. The total length of coastal segments by type is given in Table 1. Thus about 30 per cent of the coastline is shaped chiefly by terrestrial processes (primary) whereas 70 per cent is marine dominated (secondary).

TABLE 1. Length of coastal segments.

Primary Coasts		
Land Erosion Coasts (L)	191.9 km.	(8.9 per cent)
River Deposition Coasts (R)	429.2 km.	(19.9 per cent)
Secondary Coasts		
Wave Erosion Coasts (W)	807.6 km.	(37.5 per cent)
Marine Deposition Coasts (M)	726.9 km.	(33.7 per cent)
	2,155.6 km.	(100.0 per cent)

COASTAL MORPHOLOGY AND RELIEF

Most of this coastline is marked by an abrupt break in slope between the relatively horizontal terrain of the mainland and the gently-sloping sea floor (Hartwell 1972 and McIntire 1971). In bedrock areas this break is generally a steep sea cliff with loose talus material at its base. In areas of perennially frozen sediment which are exposed to direct wave attack along the coast, the relief is often sheer and is formed by slumping of large blocks of frozen sedimentary material. This is a result of both thermal and mechanical erosion along the base of the sea cliff and inland along the banks of estuaries and rivers where undercutting of the frozen sediments forms a "thermo-erosional niche" (Walker and Arnborg 1966). Such niches which are unique to this environment can form rapidly and may extend several metres under the bank, making the overhanging bank unstable and susceptible to collapse especially where ice wedges are intersected (Lewellen 1965). Thawing along the ice wedges which underlie the troughs of polygonal ground frequently causes the cliff to slump as large tundra blocks. At many locations the micro-relief along polygon margins is accentuated by erosion in the polygonal troughs at the edge of the main sea cliffs. Vegetation frequently hangs as a thin mat draped over the edge of the cliff.

Along the coastal plain the shoreline is retreating rapidly, even where sheltered from direct wave action (Lewellen 1970); but actual coastal relief remains about the same because the surface of the mainland is nearly level. The net effect of

continual cliff retreat is to form generally smooth coastlines with nearshore marine deposits such as beaches, spits, and barrier islands, like the coast near Barrow. Temporary protection from coastal retreat is provided by material which accumulates at the base of the main coastal slope. In the summer, slumped soil and tundra vegetation material protect the slope from direct wave attack. In the winter the seasonal cover of wind-blown snow dramatically alters the surficial geometry of the coastal features and masks the coastal relief by forming a gently-sloping ramp from the tundra edge down onto the frozen sea surface (Benson 1969). Such wedges of snow and ice tend to insulate the slope from thawing well into the summer melt season. Larger ramps usually develop along higher sea cliffs, affording somewhat greater protection from coastal retreat than in areas of low cliffs.

From topographic maps, field studies near Point Barrow during summer and winter, and vertical aerial photographs, four categories of coastal relief are proposed on the basis of snow-free conditions:

Low relief (less than about 2 m.; 568 km. or 26 per cent of the total coast); primarily associated with depositional features such as barrier islands and barrier spits along marine deposition coasts and across river valleys, deltas of river deposition coasts, and beaches which abut most of the coastline. This category also includes sections of sea cliffs along low points in the tundra surface (wave erosion coasts).

Moderate relief (about 2 to 5 m.; 939 km. or 44 per cent of total coast); primarily associated with sea cliffs or scarps along wave erosion coasts and the mainland of marine deposition coasts. These cliffs are undergoing some degree of erosion and form a generally sharp break along the edge of the flat tundra surface. Slopes and lateral characteristics are variable. Some cliffs are steep with nearly uniform slopes across long distances. Others are more irregular due to differential erosion along polygonal ground features and thawing of ice-bonded sediments.

High relief (about 5 to 8 m.; 341 km. or 16 per cent of total coast); found along the sea cliffs of land erosion coasts and wave erosion coasts. Because of bedrock control and protection by the large ramps of snow and ice which form in the winter, these cliffs are undergoing much more gradual erosion and slope retreat than moderate-relief areas. The cliffs are generally steep, sheer, and nearly uniform across long distances.

Very high relief (greater than about 8 m.; 226 km. or 10 per cent of total coast); primarily sea cliffs of land erosion coasts and several sections of wave erosion coast. Because of the bedrock control, the cliffs are generally steep and sheer, extending essentially unbroken across long distances; erosion and slope retreat proceed very slowly compared to the lower-relief coastal areas which lack bedrock control.

An additional 82 km. or 4 per cent of the coast is open water where streams, rivers and lakes are intersected by the ocean.

The regional distribution of relief classes is shown in Fig. 1 and Table 2. About 74 per cent of the coast has a scarp height of 5 m. or less; mean coast relief decreases to the east along the coastal plain.

TABLE 2. Distribution of coastal relief by geographic region; northern Alaska from Cape Thompson to U.S.-Canadian border.*

	Geographic regions													
	Southern Foothills		*Northern Foothills*		*Coastal Plain Foothill silt surface*		*Coastal Plain west of Pt. Barrow*		*Coastal Plain east of Pt. Barrow*		*Coastal Plain White Hills*		*Entire coast*	
Length of coast, km	192.3		82.3		171.7		365.1		1053.7		290.0		2155.7	
% of total coast	8.9		3.8		8.0		16.9		48.9		13.5		100.0	
Coastal relief, m														
0-1			1.5 km	1.8%	1.8 km	1.0%	25.0 km	6.9%	58.4 km	5.5%	24.7 km	8.5%	111.4 km	5.2%
1-2	41.8 km	21.7%	11.1	13.4	16.9	9.8	59.8	16.4	292.3	27.7	34.9	12.0	456.8	21.2
2-3	52.3	27.2			56.1	32.7	41.8	11.4	331.6	31.5	109.2	37.5	590.9	27.4
3-4					17.6	10.2	56.6	15.5	148.2	14.1	32.7	11.2	255.0	11.8
4-5							13.5	3.7	47.0	4.5	32.5	11.2	93.0	4.3
5-8	25.7	13.4	12.8	15.6	72.8	42.4	77.4	21.2	111.2	10.5	40.8	14.0	340.6	15.8
>8	71.0	36.9	56.6	68.8	2.3	1.3	84.5	23.2	8.0	.8	3.3	1.1	225.6	10.5
open water (window)	1.5	.7	.3	.4	4.2	2.5	6.5	1.8	57.0	5.4	12.8	4.4	82.4	3.8
Total $\leq$5 m	95.6 km	49.6%	12.9 km	15.6%	96.6 km	56.2%	203.2 km	55.7%	934.5 km	88.7%	246.8 km	84.8%	1589.5 km	73.7%
Mean coastal relief, m	5.8†		8.5		4.3		5.2		2.8		3.2		3.9	

*Compiled from U.S. Geological Survey topographic maps of scale 1:63,360.

†Mean relief of Southern Foothills is lower than Northern Foothills due to the cuspate foreland at Point Hope.

CONCLUSIONS

Four main genetic coastal types are found along the northern Alaska coast. Land erosion coasts are characterized by high to very high relief sea cliffs formed in bedrock. Wave erosion coasts have somewhat less relief with cliffs exposing perenially frozen bedrock and ice-rich sediments. These two types together comprise about 29 per cent of the coastline. Marine deposition coasts resemble wave erosion coasts in many ways except that pronounced coastal sedimentation has built protective barrier islands, beaches, and spits close to shore. River deposition coasts are fluvial deltaic deposits with low relief. These two types together comprise about 71 per cent of the coastline.

Four categories of coastal relief are identified in this region. Moderate relief (about 2-5 m.) predominates, comprising about 44 per cent of the coastline along sea cliffs and scarps of wave erosion coasts and the mainland of marine deposition coasts. Low relief (less than about 2 m.) is primarily associated with depositional features along the coastline such as barrier islands, barrier spits, river deltas, and beaches (about 26 per cent of the total coast). High relief (about 5 to 8 m.) is found along the sea cliffs of land erosion coasts and wave erosion coasts (about 16 per cent of coast) whereas very high relief (greater than about 8 m.) is confined to the highest portions of the sea cliffs along the same two types of coast (only about 10 per cent of coast). Four per cent of the coast is open water at the mouths of streams, rivers, and old thaw lakes. Mean coastal relief is about 4 m.

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REFERENCES

BENSON, C. S. 1969. *The seasonal snow cover of arctic Alaska.* Arctic Institute of North America, Research Report No. 51. 92 pp.

CARSON, C. E. and K. M. HUSSEY. 1962. The oriented lakes of arctic Alaska. *Journal of Geology,* 70: 417-39.

CREAGER, J. S. and D. A. MCMANUS. 1967. Geology of the floor of the Bering and Chukchi Seas — American studies. In: *The Bering land bridge,* ed. by D. M. Hopkins. Stanford: Stanford University Press. pp. 7-31.

HARTWELL, A. D. 1972. Coastal conditions of arctic northern Alaska. In: *Terrain and coastal conditions on the arctic Alaskan coastal plain.* U.S. Army CRREL Special Report 165. pp. 32-72.

HUME, J. D. and M. SCHALK. 1967. Shoreline processes near Barrow, Alaska — a comparison of the normal and the catastrophic. *Arctic,* 20: 86-103.

LEWELLEN, R. I. 1965. *Characteristics and rates of thermal erosion, Barrow, Alaska.* M.S. thesis, University of Denver, Denver. 181 pp.

————. 1970. *Permafrost erosion along the Beaufort Sea coast.* Denver: University of Denver. 25 pp.

MACCARTHY, G. R. 1953. Recent changes in the shoreline near Point Barrow, Alaska. *Arctic,* 6: 44-51.

MCINTIRE, W. G. 1971. *Arctic coastal processes and morphology — six month status report, 31 December 1971 — to U.S. Navy Office of Naval Research.* Baton Rouge, Louisiana: Coastal Studies Institute, Louisiana State University. 92 pp., mimeo.

O'SULLIVAN, J. B. 1961. *Quaternary geology of the arctic coastal plain, northern Alaska.* Ph.D. thesis, Iowa State University of Science and Technology, Ames. 190 pp.

PAYNE, T. G. *et al.* 1951. *Geology of the arctic slope of Alaska.* U.S. Geological Survey Oil and Gas Investigations Map OM-126. 3 sheets.

SHEPARD, F. P. 1963. *Submarine geology.* New York: Harper and Row. 557 pp.

WAHRHAFTIG, C. 1965. Physiographic divisions of Alaska. *U.S. Geological Survey Professional Paper* 482. 52 pp.

WALKER, H. J. and L. ARNBORG. 1966. Permafrost and ice-wedge effect on riverbank erosion. In: *Proceedings, International Conference on Permafrost, 11-15 November 1963, Lafayette, Indiana; National Academy of Sciences — National Research Council, Publication* No. 1287, pp. 164-71.

WILLIAMS, H. (ed.). 1958. *Landscapes of Alaska — their geologic evolution.* Berkeley and Los Angeles: University of California Press. 148 pp.