Short-Term Climate Changes and Coastal Erosion, Barrow, Alaska

JAMES D. HUME,[1] MARSHALL SCHALK[2] and PATRICIA W. HUME[3]

ABSTRACT. Records of shoreline and bluff positions in the vicinity of Barrow, Alaska, have been obtained from aerial photographs and taped measurements for intervals between 1948 and 1969. Although the source material in the bluffs is frozen and masses of pure ice are present, temperature and rainfall data fail to show any marked correlation with the retreat of the bluff face or with the retreat of the fronting or downdrift beaches. Removal of beach material for construction and frequency of storms from the west do show a relationship. Recorded retreats of the bluffs up to 3 m. per year and of the beaches up to 4 m. per year have resulted where there has been excessive beach borrow or where a series of severe storms have attacked the coast.

RÉSUMÉ. *Changements climatiques à court terme et érosion côtière, Barrow, Alaska.* Entre 1948 et 1969, à partir de photos aériennes et de levés sur le terrain, les auteurs ont recueilli à intervalles des données sur la position du rivage et d'escarpements au voisinage de Barrow, Alaska. Bien que le matériel des escarpements soit gelé et truffé de masses de glace pure, les données de température et de pluie ne montrent aucune corrélation avec le retrait des escarpements ni avec le recul des plages adjacentes; mais l'enlèvement du matériel et la fréquence des tempêtes venues de l'ouest montrent cette relation. On a enregistré des retraits de 3 m par an au front de l'escarpement et jusqu'à 4 m par an pour les plages où il y a eu départ de matériel ou lorsqu'une série de tempêtes venues de l'ouest a attaqué la côte.

РЕЗЮМЕ. *Короткопериодические изменения климата и береговая абразия у Барроу (Аляска).* Повторные аэрофотосъемки и измерения на местности доставили материал для оценки смещений береговнх обрывов и пляжей в районе Барроу (Аляска) за период с 1948 по 1969 г. Несмотря на то, что обнажающиеся в обрывах отложения находятся в мёрзлом состоянии и содержат включения чистого льда, скорость отступания берегов района не коррелируется ни с ходом температур воздуха, ни с ходом жидких осадков. Зато разрушение пляжей и отступание береговых обрывов демонстрирует явную связь с интенсивностью забора береговых песков и галечников для строительства и с повторяемостью западных штормов. Там, где воздействие таких штормов было сильным и разработки пляжей значительными, береговые обрывы отступали со скоростью до 3 м/год, а пляжи — до 4 м/год.

INTRODUCTION

The northern Alaskan coastal area (Fig. 1) is a drowned coastal plain composed of the Pleistocene and Recent Gubic formation. The composition of the Gubic formation sediments influences the local type of shoreline. Where the sediments are sand and gravel, beaches can form; where they are clay and silt, waves and currents remove the sediment in suspension and no beach results. This balance

[1]Tufts University, Medford, Massachusetts.
[2]Smith College, Northampton, Massachusetts.
[3]Londonderry, New Hampshire.

between wave erosion and size of material is similar to that reported by Mackay (1963) for areas further east. Near Barrow itself, deltaic, cross bedded units up to 4 m. thick occur a few hundred metres southwest of the village. With relatively coarse sizes of material available there, coastal erosion has resulted in a sand and gravel beach backed by eroded bluffs 6 to 8 m. high. Littoral transport, particularly that generated by storm winds from the west, has built Point Barrow, a spit temporarily separated from the mainland (Hume and Schalk 1967). Observations indicate little contribution of sediment to the Barrow region from further southwest because beaches in that direction are narrow or missing.

Previous coastal investigators include Leffingwell (1919), McCarthy (1953), Rex (1964), Hume and Schalk (1964b) and Lewellen (1970). McCarthy remeasured the position of 7 bench marks in the Barrow area which were near the shoreline. His data showed an average retreat of 0.7 m. per year during a 6-year period. Lewellen, using aerial photographs of Elson Lagoon, showed the average rate of erosion was 2.8 m. per year. Coastal sediments of Elson Lagoon, in contrast to those immediately southwest of Barrow village, are chiefly clays and silts, erode easily, and form no beaches.

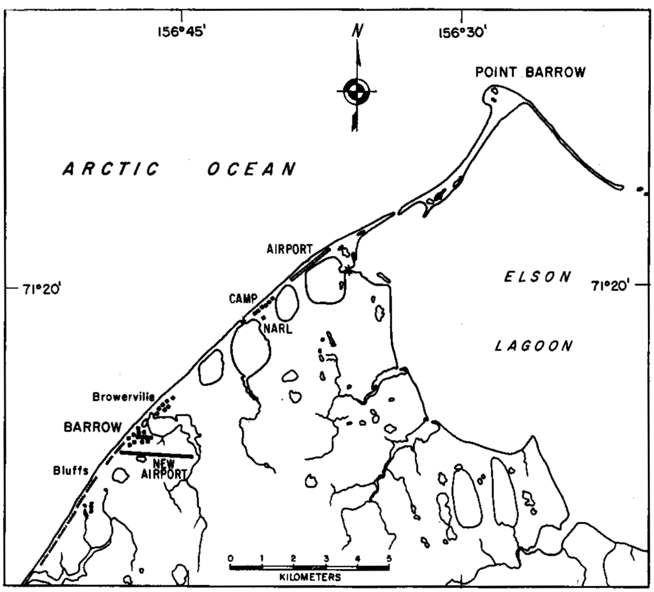

FIG. 1. Index Map.

NATURAL PROCESSES NEAR BARROW

Coastal erosion resulting in retreat of the shoreline southwest of Barrow village is a three-step mechanism. Sediment has to be melted from the bluffs, carried to the wave zone or beach, and removed by the waves. Near Barrow, permanently frozen ground extends to a depth of about 500 m. The summer temperatures usually result in a melted surface zone of about 0.3 m. on the tundra and 1.5 m. on the beaches. Therefore most of the source material for the beach and littoral system is a resistant rock with ice as the cement. Before waves can erode and transport it in significant quantities, it must be melted. Frozen ground is melted to some degree directly by insolation, by warm air, meltwater from snow, rain and ocean water. Ideally measurements of incident solar radiation would be desirable, but as these are not available, we will use average melt-season air temperatures as an index of year-to-year thermal climatic variation.

Once the Gubic formation is melted, it slumps and is transported to the beach where waves can finally act on it. The movement of the sediment to the beach can be by solifluction, rainwash, or gravitative collapse. Where the beach is wide, rainwash and solifluction are important. Where the beach is narrow or absent, storm waves can reach and undermine the bluffs resulting in collapse (Fig. 2). Melting is often more rapid along ice wedges resulting in isolated blocks of frozen ground falling outward into the water or on the beach (Leffingwell 1919, Lewellen 1970). The sediment in the blocks then melts further, breaks up and because most of it is fine, is carried away in suspension.

FIG. 2. Wave undermined blocks of frozen ground. Elson Lagoon, 18 km. southeast of Barrow.

Wave transport along the Barrow beaches, whether backed by bluffs or not, is very similar to that in temperate regions. The wave action and longshore current do the work but, because the ocean has pack ice in it much of the time or is completely frozen, the transport is far less. In addition, ice grounded on the beaches acts temporarily as a breakwater. At Barrow, an average of slightly over 9,000 cu. m. are transported yearly northeast along the beaches. Half of this is added to the Point Barrow spit, much of the clay and silt escaping from the beach system (Hume and Schalk 1967).

A positive factor, but one of extreme variability, is that of beach nourishment by ice pushing sand and gravel up on the beach above normal water level. During some years calculations for certain sections of beach in the area indicate up to 10 per cent of the material above sea level was moved up onto the beach by ice action (Hume and Schalk 1964a). Especially in the bluff section, an ice year which leaves ice solid on the beach from the water's edge to the cliff face discourages both melting and slumping at the toe of the bluff.

EFFECTS OF CONSTRUCTION

Borrowing of beach sediment at Barrow for construction purposes has been going on since at least 1945. During the summers of 1961 and 1962, measurements showed how the removal in 1961 of about 30,000 cu. m. of beach sediment resulted in an average retreat of the shoreline in the borrow area of 3.1 m. (Hume and Schalk 1964b). The beach from which the sediment was removed lay chiefly between Browerville and Camp. Some borrow came from the Camp section itself. During the late 1960s, construction of a new airport, large enough for jet aircraft, involved the removal of most of the coarse sediment from the beach southwest of Barrow village for about 4 km. Retreat of the shoreline and bluffs occurred as a result of this borrowing (Fig. 3).

FIG. 3. Aerial view of the bluffs near the village recently settled. One building collapsed and one has been moved from the bluffs as a result of the 1968 storm. The beach formerly was 30 m. in width at this point. Photo taken in August 1969.

SHORELINE CHANGES

Our observations of coastal changes are summarized in Table 1. The division into sections of the coast was based on geologic and geographic criteria. The bluff section is typical of the source area whereas the Barrow-Browerville, Camp, and Airport sections are settled areas where the beach is backed by low tundra. The periods selected were determined by the availability of aerial photographs.

Our data show that the rate of change of coastal position varies greatly. High rates occurred during the 1948-1962 and 1968-1969 seasons whereas low rates of erosion occurred during the intermediate time periods. These differences in

TABLE 1 Shoreline changes

Section of Coast	*1948-1962*[1]	*1962-1964*[2]	*1964-1968*[3]	*1968-1969*[4]	*Total Loss metres*
Bluffs: Shoreline	−4.6 m./yr.	+0.6 m./yr.	−0.7 m./yr.	−2 m./yr.	69
Bluff line	−3.0 m./yr.	−1.0 m./yr.	−0.3 m./yr.	−3.0 m./yr.	47
Barrow-Browerville	−2.6 m./yr.	−4.4 m./yr.	−1.1 m./yr.	−4.8 m./yr.	55
Browerville to Camp	−0.2 m./yr.	+0.7 m./yr.	−0.2 m./yr.	+0.5 m./yr.	4
Camp	−2.7 m./yr.	−0.3 m./yr.	no change	+3.5 m./yr.	35
Airport	−4.2 m./yr.	+0.95 m./yr.	−0.2 m./yr.	−3.7 m./yr.	59

[1]Based on measurements from aerial photographs, 17, measurements; [23]Both aerial photographs and taped distances used, 44 + 17; [4]All taped distances but some were from points identified on aerial photographs: 71 taped distances.

erosion rates could be the result of variation in summer temperature, summer rainfall, and the number of storms occurring during times when the ocean was free of ice. Also important are the times when large volumes of beach deposits, particularly the larger sizes, have been used for construction purposes. Variations at different localities during any one period also occur and are probably related to the type of shoreline, size of material at that locality, and the presence or absence of offshore bars. Table 2 summarizes the meteorological factors for the time intervals used in Table 1.

TABLE 2 Meteorological data[1]

	1948–1962	*1962–1964*	*1964–1968*	*1968–1969*
Average Temperature during June, July and August	2.6°C.	3.0°C.	2.4°C.	3.7°C.
Precipitation[2] in June, July and August	6.7 cm.	9.4 cm.	4.8 cm.	1.9 cm.
Number of west wind storms[3]. Open water	30	2	3	1
West wind storms per year. Open water	2.15	1	0.75	1

[1]Based on U.S. Weather Bureau Records (1948-69); records kept by the Naval Arctic Research Laboratory; U.S. Navy (1962-68); Reed (1958); U.S. Hydrographic Office (1958); Hume (1963); MacGinitie (1955); Rex (1964); Schalk (1957); Wilimovsky (1953).
[2]Per season.
[3]Wind velocities over 32 km./hr.

Between 1948 and 1962, changes took place at a more rapid rate than in any other period known to us. In the bluff section, retreat of the shoreline took place more rapidly than the collapse of the bluffs resulting in a general narrowing of the beach. In the other areas, the shoreline also retreated. The rates of loss were probably lowered between Browerville and Camp and in front of the Camp because offshore bars occur there. Early knowledge of bars is lacking, but Schalk (1957) described the appearance in 1954 of the bar off Camp. Recent measurements show that this bar is growing northward into the Airport section, but is also moving closer to land. Very low bars have also been observed at times off Barrow village. Associated with the time of rapid erosion are many effective storms, over 2 a year, relatively low temperature, and high rainfall.

During the intermediate time intervals, in general, rates of erosion of both the bluffs and shoreline were low. Uniquely rapid erosion did occur in front of Browerville and Barrow and may be related to earlier loss of beach in the bluff section. There may have been less material available for transportation to the Barrow area than could be removed. Correlating with this period of slow change are few storms, about 1 per year, and both low and intermediate temperatures and rainfall.

During the most recent interval, erosion rates increased along sections of the coast lacking well-developed offshore bars. Where the bars were present, the beaches either grew or suffered little change. The rate of retreat reached its highest near the native villages partly because of a major storm in September 1968, and partly because much of the sand and gravel had been removed from the bluff section for construction. Normally sand from the beaches near the bluffs would have been available to replace that moved northeast from the village. This same removal of beach in front of the bluffs may also have made the bluffs particularly susceptible to erosion. In both 1968 and 1969, ice lenses were visible in several places along the bluffs showing that the insulating cover was gone. This varied period of change corresponds to one strong storm with wind velocities of 55 km. per hour, low temperatures, and low rainfall.

SUMMARY

If we exclude the 1968-1969 dates, the period when the beaches were influenced far more than at any other time by man's engineering, we see that the storms are the critical factor in both bluff erosion and retreat of the shoreline. Melting is important in that it releases sediment to the beach system, but the waves and their currents finally do the removing. Waves during the high stand of sea level accompanying major storms also speed melting of the bluffs by exposure of new frozen ground. Rainfall may help transport the melted sediment to the beach but variations in this are unimportant because gravity would serve even without rain.

What is going to happen in the future, particularly to Barrow village? This depends on which set of conditions is "normal", two storms per year or one; we do not know. Meteorological records for Barrow have been kept for over 50 years but ice data are not so complete. Distance to the pack ice is critical to the question. Certainly coastal retreat will continue but whether it continues at the rate of 1 or 4 m. per year is unknown. The village will probably have to be moved sometime in the future; when depends chiefly on the weather, but also on man's use of beaches. The present policy of the Director of the Naval Arctic Research Laboratory to prohibit removal of beach material under his jurisdiction should be extended to all areas near and southwest of settlements.

ACKNOWLEDGEMENTS

Support has been provided by the Arctic Institute of North America under contractual arrangements with the Office of Naval Research. Field support was provided by the Naval Arctic Research Laboratory. The director, Max Brewer, the assistant director John Schindler, the staff, and investigators were all very helpful.

The staff of the United States Weather Bureau at Barrow and Robert I. Lewellen provided valuable data. Winston Yelland, Robert MacDonald, Thomas Benner, Donald Biederman, Geoffrey W. Smith, and George Denton, all Tufts University students, have helped with field work. Aerial photographs taken in 1962 were provided by Jerry Brown of the Cold Regions Research and Engineering Laboratory.

REFERENCES

HUME, J. D. 1963. Sediment transportation near Barrow, Alaska. Arctic Institute of North America Project ONR-259, 282, 309. Final Report, 76 pp. Unpublished manuscript.

HUME, J. D. and M. SCHALK. 1964. The effects of ice-push on arctic beaches. *American Journal of Science,* 262: 267-73.

HUME, J. D. and M. SCHALK. 1964. The effects of beach borrow in the Arctic. *Shore and Beach,* 32: 37-41.

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

LEFFINGWELL, E. DEK. 1919. The Canning River Region, Northern Alaska. *U.S. Geological Survey Professional Paper* 109. 251 pp.

LEWELLEN, R. I. 1970. Permafrost erosion along the Beaufort Sea Coast, Denver, Colorado: Geography and Geology Department, University of Denver, 25 pp.

MACGINITIE, G. E. 1955. Distribution and ecology of the marine invertebrates of Point Barrow, Alaska. *Smithsonian Miscellaneous Publications,* 128. 201 pp.

MACKAY, J. R. 1963. Notes on the shoreline recession along the coast of the Yukon Territory. *Arctic,* 16: 195-97.

MCCARTHY, G. R. 1953. Recent changes in the shoreline near Point Barrow, Alaska. *Arctic,* 6: 45-51.

REED, J. C. 1958. History of the exploration, Pt. 1 of Exploration of Naval Petroleum Reserve No. 4 and Adjacent Areas, Northern Alaska, 1944-53. *U.S. Geological Survey Professional Paper* 301. 192 pp.

REX, R. W. 1964. Arctic beaches, Barrow, Alaska. In: Papers in Marine Geology, R. L. Miller, ed., New York: The Macmillan Company. pp. 384-400.

SCHALK, M. 1957. Beach and nearshore studies, Point Barrow, Alaska, conducted during the period July 1954-January 1957. Woods Hole Oceanographic Institution Reference No. 57-43. Unpublished manuscript, 57 pp.

U.S. HYDROGRAPHIC OFFICE. 1958. Oceanographic atlas of the Polar Seas, Part 2 Arctic, *H.O. Publication* No. 705, 149 pp.

U.S. NAVY. 1962-1968. Birds Eye Reports, Oceanographic Prediction Division.

U.S. WEATHER BUREAU. 1948-1969. Local climatological data, Airport Station, Barrow, Alaska.

WILIMOVSKY, N. J. 1953. Inshore temperature and salinity data during open water periods, Point Barrow, Alaska, *Stanford University Natural History Museum, Technical Report 4,* 14 pp.