UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

COASTAL PROCESSES AND COASTAL EROSIONAL HAZARDS TO THE CAPE KRUSENSTERN ARCHAEOLOGICAL SITE

By

David M. Hopkins

Open-file report
77-32

Menlo Park, California
1977

COASTAL PROCESSES AND COASTAL EROSIONAL HAZARDS TO THE CAPE KRUSENSTERN ARCHAEOLOGICAL SITE

by

David M. Hopkins
U.S. Geological Survey
Menlo Park, CA 94025

Cape Krusenstern, a sharp inflection in the coast of the Chukchi Sea forming the north portal to Kotzebue Sound (fig. 1), is a broad, accretionary beach-ridge plain which contains an exceptionally complete and well-studied record of Arctic prehistory spanning the last 4,000 years (Giddings, 1960). Cape Krusenstern National Monument is proposed to protect this important archaeological resource from inadvertent damage or destruction.

The beach-ridge plain is a depositional feature formed of sand and gravel brought by beach drift from a more northern source. Moore (1960) has suggested that the sand and gravel comprising Cape Krusenstern came predominantly from cliffs near Cape Thompson, some 100 km to the north. What would be the consequences, if the source of sediment were reduced or cut off by construction, for example, of a harbor or jetty at Kivalina?

It is the purpose of this report to examine the recent coastal history and the contemporary coastal processes between Cape Krusenstern and Cape Thompson in an effort to evaluate the possible effects at Cape Krusenstern of a disruption in the southward sediment drift. The report is based upon four days of helicopter-supported field work during the period August 3-6, 1976, supplemented by study of maps and air photos. The report was written for the use of the Alaska Task Force of the

National Park Service. Field work was carried out as part of a larger study of the proposed Monument by Robert Belous, National Park Service, and Douglas Anderson, Brown University. In undertaking this study and this report, I benefited from discussions with my Geological Survey colleagues, Ralph Hunter and Abby Sallenger.

Previous work.--Extensive archaeological excavations by J. L. Giddings and his co-workers (Giddings, 1960) have made Cape Krusenstern a major archaeological resource containing a more or less complete history of coastal occupation during the past 4,500 years. Because their maritime economy required that aboriginal Eskimo communities locate as close as possible to the beach, the individual beach ridges at Cape Krusenstern can be approximately dated by their occupation remains. Thus, the archaeological studies have also provided valuable historical information on coastal processes and the evolution of the Cape Krusenstern beach-ridge complex during the last 4,500 years.

The archaeological information from Cape Krusenstern was used by G. W. Moore in a series of pioneering papers on Arctic beach processes (Moore, 1960, 1966; Moore and Giddings, 1961; Moore and Giddings, unpub. map given here as fig. 2). In his 1960 paper, Moore showed that the beach ridges provide information about sea-level history. The oldest beach ridges are partly submerged, and sea level was at least 3 m lower than at present when they were formed. Moore went on to suggest that especially high beach ridges such as the one occupied by the Ipiutak culture about 2,000 years ago may have formed at a time when sea level was slightly higher than at present, but this idea is not generally accepted. Other workers have shown that beach ridges are formed by the onshore migration of submerged offshore bars during storm surges in which sea level is temporarily raised in response to lowered barometric pressure and strong onshore winds. Temporary rises in sea level as great as 4 meters have been recorded during storm surges along the shores of northern Bering, Chukchi, and Beaufort Seas. The accretion of a beach ridge and its ultimate height are governed by the height of sea level during the storm surge, by the intensity of wave attack, and by the volume of sediment that has accumulated nearshore. Thus, differences in the heights of individual Cape Krusenstern beach ridges do not provide a record of eustatic sea-level fluctuations, although the semi-submerged condition of the oldest beach ridges does reflect the fact that sea level was several meters lower 3,500 to 4,500 years ago.

Moore's and Giddings' unpublished map (fig. 2) shows that the accretion of beach ridges on the south side of Cape Krusenstern has been interrupted, from time to time, by short periods of erosion which are recorded by discordant relationships in which younger beach ridges truncate older ones. Erosion, when it has taken place, has resulted in removal of segments of southeast trending beach ridges north of present-day Cape Krusenstern proper, followed by accrual there of a series of south-trending beaches. Moore and Giddings (1961) suggest that the erosion and ensuing shifts in the locus of accrual of beach ridges has been the result of a series of shifts in the direction of storm winds. However, the series of erosional events followed by shifts in locus of deposition might have been caused, instead, by episodic interruptions or reductions in the sediment supply. Some of the large, rectangular lagoons (for example, Kotlik Lagoon, Imik Lagoon) look like truncated thaw lakes. Possibly the erosional episodes record occasions when the retreating coast breached large thermokarst lakes. Southward sediment drift might then have been disrupted or substantially diminished until a spit and then a barrier bar could be built across the new embayment.

In his 1966 paper, Moore postulated that the segment of the coast between Cape Thompson and Sheshalik Spit forms a single beach-drift cell which is supplied almost exclusively by erosion of the 20 km of cliffed coast near Cape Thompson. If Moore were completely correct, then an interruption in beach drift at any point along the coast south of Cape Thompson would result, sooner or later, in erosion at Cape Krusenstern. Despite some local evidence to the contrary, Moore is probably correct in concluding that net beach drift is southward and eastward throughout the Cape Thompson-Sheshalik Spit segment of the Chukchi Sea coast. However, the system contains several important sources of sediment in addition to the cliffs near Cape Thompson.

Identification of sediment sources is aided by knowledge of the regional geology. The bedrock geology of the region from Point Hope to the Noatak River has been mapped at scale 1:250,000 by I. L. Tailleur (unpublished compilations) and summarized at scale 1:1,000,000 by Beikman and Lathram (1976). A photogeological map of the surficial geology of the Cape Krusenstern region was compiled at scale 1:250,000 by D. M. Hopkins and summarized at scale 1:2,500,000 by Coulter and others (1965).

Description of the coast between Cape Thompson and Cape Krusenstern.--Cape Krusenstern lies about 150 km southeast of Cape Thompson and about 75 km west of Sheshalik Spit (fig. 1). The coast from Cape Thompson to Cape Krusenstern describes a broad, shallow arc concave toward the Chukchi

Sea, interrupted by short, sharp convexities at Cape Thompson and Battle Rock and by broad, rounded convexities at Cape Seppings and Kivalina. Bedrock cliffs and steep gravel bluffs front the coast almost continuously through a 20-km stretch of coast from Cape Thompson to Kisimilok Mountain, and low bedrock cliffs extend along the coast for about a kilometer at Battle Rock. Bluffs a few meters high cut in silt, sand, and pebbly sand occupy a few kilometers of the coast in various places between Rabbit Creek and Krusenstern Lagoon. Elsewhere, the coast is low-lying and devoid of erosional bluffs.

Two-thirds of the coast consists of barrier bars backed by lagoons. The beaches and barrier bars generally consist of a single ridge ranging from 100 to 200 m in width. Dunes are rarely present. In many places, the rear parts of the barrier bars show wash-over channels and storm-surge deltas as well as grooves and ridges that result from ice-push. The rear parts of the beaches commonly support a halophyte flora consisting chiefly of *Elymus mollis*, *Lathyrus maritimus*, and *Chrysanthemum arcticum*, but areas that have not been affected by salt water for many decades support a dry-tundra matte of prostrate heaths and willow and birch shrubs, and areas that have been subjected to wash-overs within the last couple of years are nearly bare. Although all of the species comprising the halophyte flora reach their climatic limits hundreds of kilometers north of Cape Thompson, the vegetation cover on back beaches and barrier bars grows sparser, and bare area grow more extensive as one proceeds northward. This observation, coupled with the northward increase in the morphological evidence of recent wash-overs, seems to indicate that the beaches are flooded with increasing frequency as one progresses northward.

Older beach ridges are generally lacking except in the giant Cape Krusenstern complex, but a single old beach ridge extends behind the modern beach for about one kilometer along the north end of Ipiavik Lagoon, and two older ridges are present behind the modern beach for several kilometers north of the north entrance to Kivalina Lagoon (fig. 3). Examination of the well-dated Cape Krusenstern beach ridge complex shows that beach ridges in this region can be approximately dated on the basis of whether or not they are semi-submerged and according to the degree of development of the ice-wedge network. The older beach ridge along Kivalina Lagoon and the old beach ridge at Ipiavik Lagoon have ice-wedge networks indicative of an age of one to two thousand years. The younger and more seaward beach ridge along Kivalina Lagoon has a series of old house pits whose form indicates that they were built between 1400 and 1500 A.D. (Douglas Anderson, oral commun., 8/5/76).

The lagoon shores of the barrier bars commonly display their own systems of beach ridges, built partly by waves and partly by ice-push from the lagoon side. The north ends of Krusenstern, Imik, and Kotlik Lagoons are filled in by a series of broadly arcuate beach ridges. Ice-wedge development and the semi-submerged condition of the northernmost and oldest ridges in each set indicate that they were formed earlier than 3,500 and perhaps as early as 4,500 years ago. These oldest beach ridges are sharply truncated by the ocean beach, but the younger lagoon beach ridges in each set curve more sharply and become tangent to the modern barrier bar.

Sources of sediment.--The Cape Krusenstern beach-ridge complex consists largely of gravel. The sand-sized component may be derived from points as far north as Cape Thompson, but the gravel component must originate south of Kivalina, because the ocean beach in front of Kivalina Lagoon consists of sand with very few pebbles.

Large quantities of sandstone, chert, and limestone--the predominant components of the Cape Krusenstern beach sediment (Moore, 1966)--are supplied by bedrock cliffs at Cape Thompson and by bluffs cut in Pleistocene gravel and colluvium between Ogotoruk Creek and Kisimilok Mountain (fig. 1). However, the same suite of rocks is also added in several other places. Limestone is supplied by the coastal cliffs at Battle Rock and by bluffs cut in Pleistocene beach gravel and colluvium that extend a few hundred meters to the north and south. Trails of gravel can be seen extending diagonally across the beach from low bluffs cut in alluvium south of Rabbit Creek and from bluffs cut in Pelukian interglacial beach deposits north of Krusenstern Lagoon (fig. 3).

Some gravel is added to the beach from the nearby sea bottom. Moore minimized the possible importance of movement of material from shallow nearshore waters onto the beach, but I have seen clear evidence of the capacity of storm waves to erode pebble-sized particles from the nearshore bottom and to move them onshore. Abundant, large, discolored fossil mollusk shells appear after storms on the beach at Cape Krusenstern and in many places between Cape Espenberg and Shishmaref on the north coast of the Seward Peninsula (south of the area of fig. 1). The fossil mollusks include species that no longer live in the Chukchi Sea, and they differ in color from the shells of mollusks of the modern infauna with which they are mingled on the beach. The stained fossil mollusk shells are obviously derived from marine deposits of the Pelukian (last interglacial) transgression, but no Pelukian deposits are exposed above sea level in the places named. It is clear that the fossil mollusk shells have been ripped up and transported onshore from submarine outcrops of Pelukian deposits.

Gravel evidently also enters the Cape Thompson-Sheshalik Spit beach-drift system as a result of erosion at and below beach level of onshore alluvial fans, outwash deposits, and deltas. Coastal convexities at Cape Seppings and just south of Kivalina River testify to the importance of the alluvial fans of the Singoalak and Wulik Rivers as sediment sources. Although the Singoalak River is a small, short stream, Creager and McManus (1966) mapped a large area of gravel offshore near Cape Seppings, indicating that the Singoalak River fan extends seaward as a relict bottom deposit, constituting an additional potential additional source of supply. Gravel is also added by the retreat of the shore through alluvium and glacial-outwash gravel at the mouths of Agagrak, Rabbit, and Kilikmak Creeks.

Direction of coastal drift.--As Moore (1966) showed, the direction of beach drift varies from one day to another during the open season, depending upon the orientation of incoming waves relative to the coast. However, net drift over a period of years can be inferred on the basis of direction of displacement of river mouths and lagoon outlets and on the basis of direction in which submerged offshore bars diverge from the strand. Some insight can also be gained by examining the direction in which distinctive pebbles trail and the directions in which beach sediments grow finer from points of sediment input; however, the frequent temporary reversals in direction of beach drift make these indicators less definitive.

Morphological indicators, directions of drift of distinctive pebbles, and directions of fining indicate clearly that net beach drift is southward and eastward along most segments of the coast between Cape Thompson and Sheshalik Spit, but northward drift is suggested locally. During my overflights in August, 1976, morphological indicators suggested recent northward drift along short segments of the coast to the north and south of Cape Seppings and, more surprisingly, along most of the 40-km segment of coast from Ipiavik Lagoon to the northern inlet of Kivalina Lagoon (fig. 3).* The gross morphology of the coast makes Ipiavik Lagoon--at the center of the sweeping concave arc between Cape Thompson and Cape Krusenstern--an unlikely place for a divergence in the direction of coastal drift, and further work will be required before the direction of net beach drift in the Kivalina Lagoon-Ipiavik Lagoon segment can be considered to be firmly established. The question is important, because if beach drift is either northward or nearly neutral in that sector, then a perturbation of the beach drift north of Ipiavik Lagoon would have little effect upon the beach regime at Cape Krusenstern.

An indication of the amount of coastal retreat possible during a single storm is provided by thermokarst features seen at the rear of the beach south of Rabbit Creek during early August, 1976. In my experience, Arctic beaches display thermokarst collapse features only in newly formed areas in front of recently and rapidly eroded coastal bluffs. Quaternary

* After completing this report I noticed that my field maps record clear morphological evidence of westward beach drift along 6 km of coast from Tukrok Creek toward Cape Krusenstern (fig. 3). This observation seems to lend support to Moore's inference that changes in wind regime may be responsible for shifts in sites of deposition and erosion in the Cape Krusenstern beach-ridge complex.

sediments in coastal bluffs generally contain ice wedges which fill polygonal systems of frost cracks. If the bluffs are less than 5 m high, the wedges generally extend below beach level. During periods when the bluff is retreating slowly, the ice wedges thaw more rapidly than the adjoining frozen sediments. Small tundra streams develop along the ice wedges, accelerating removal of the ground ice, and the turf then collapses into the resulting trenches, creating ice-wedge pseudomorphs which may persist as recognizable features on scoured beach surfaces. During intense storms, however, the coastal bluffs may retreat quickly and in toto, leaving the roots of ice wedges to persist beneath the newly formed beach. The wedge ice then thaws out and forms polygonal collapse trenches in the beach next to the freshly exposed bluff. One may conclude that the bluff has recently retreated by an amount equal to and probably exceeding the width of the belt of collapse trenches. Based on this criterion, bluffs carved in Pleistocene sediment south of Rabbit Creek retreated at least 2 meters during a 1975 storm surge.

The amount of shoreline retreat over a longer period can be estimated by reconstructing the position of the ocean beach when the truncated beach ridges at the north ends of Krusenstern, Kotlik, and Imik Lagoons were formed. If the arcuate lagoonal beach ridges originally extended seaward with the same radius of curvature to a point where they were tangent to the barrier bar of the time, then the shoreline has retreated 500 to 600 m in the 3,500 to 4,500 years since the earliest beach ridges were formed. Retreat rates of 10 to 20 m per century are suggested. These figures seem entirely reasonable in the light of the evidence at Rabbit Creek for coastal retreat of 2 m or more during a single recent storm.

Differential erosion since sea level approached its present position, 3,500 to 4,500 years ago, has converted a former limestone hillock into the Battle Rock headland by eroding the softer Pleistocene alluvium and beach gravel 250 m landward at the southern, downdrift end of the bedrock bluffs. A small but unknown amount of coastal retreat has taken place on the headland itself, so that the total amount of coastal retreat by erosion of soft sediments south of Battle Rock must be somewhat greater than 250 m during the last 3,500-4,500 years.

We may now attempt to reconstruct the position of the shoreline 3,500 years ago (fig. 3). This moment is chosen because the rapid post-glacial rise in sea level had slowed several centuries earlier. Sea level stood only a few meters below its present position, and sufficient time can be assumed to have elapsed so that a nearly straight coast had developed as a result of truncation of headlands and construction of barrier bars across embayments.

A beach ridge bearing the remains of a 3,500-year-old settlement marks the former position of the shoreline inland from present-day Cape Krusenstern. From Krusenstern Lagoon to the north end of Ipiavik Lagoon, the shore evidently stood several hundred meters seaward of its present position. The presence of ancient beach ridges indicates that the shoreline at the north ends of Ipiavik and Kivalina Lagoons has changed very little within the last one or two thousand years, and we shall assume that in these places the position of the shore has been more or less constant for the longer period of 3,500 years. The remaining segment of the coast between Ipiavik and Kivalina stood an unknown distance seaward from the present shore.

There are too many uncertainties in our reconstruction of the position of the 3,500-year-old shoreline to justify a quantitative comparison, but it is clear that the volume of material contributed to the beach system by coastal retreat between Kivalina and Krusenstern Lagoon is of the same order of magnitude as the quantity of material deposited in the Cape Krusenstern beach-ridge complex.

Conclusions.--Despite the anomalous evidence of northward beach drift from Ipiavik to Kivalina Lagoon, the Chukchi Sea coast between Cape Thompson and Sheshalik Spit probably constitutes a single beach-drift cell in which sediment is gradually and intermittently transported southward and eastward. The barrier bars in this system are transmission belts for sediment. If the sediment supply were disrupted, somewhere updrift, the barrier bars would retreat lagoonward synchronously with a rapid erosional retreat of the nearby low-lying mainland coast. Disruption of sediment supply updrift would not result in breaching of barrier bars and opening of lagoons to the sea.

Sediment is contributed to the Cape Thompson-Sheshalik Spit beach system in many places. The contributions are probably cumulative. The northward narrowing of the barrier bars, thinning of the beach vegetation, and intensification in the frequency of inundation probably reflects beach starvation--the effects of inadequate sediment supply and consequent rapid coastal retreat in the more northern sectors. Coarse debris supplied between Cape Thompson and Kisimilok Mountain and at Cape Seppings is largely reduced to sand by the time it reaches Kivalina, and the gravel component of the Cape Krusenstern beach-ridge complex is evidently mostly derived from sources south of Kivalina. Sediment supplied during the last 3,500 years by coastal retreat between Kivalina and Krusenstern Lagoon may be equal to the quantity of sediment deposited during the last 3,500 years in the Cape Krusenstern beach-ridge complex.

Construction of a jetty or harbor between Cape Krusenstern and Ipiavik Lagoon would disrupt southward sediment drift and would eventually result in erosion at Cape Krusenstern. The response time cannot be predicted with data presently available. The extent of erosion would depend upon the duration of sediment disruption and upon the success of countermeasures such as possible attempts to pump sediment past the disrupting structure. The several episodes of erosion recorded by discordances in the beach-ridge sequence at Cape Krusenstern resulted from natural perturbations in the sediment drift that lasted for decades or possibly centuries (fig. 2); they provide a guide to the probable consequences of an artificial disruption. The narrow neck of land connecting Cape Krusenstern with the mainland coast to the north would be inundated by storm surges more frequently, and it would be displaced toward the lagoon. However, it would not be breached, and Krusenstern Lagoon would not be converted into an open embayment. The south-trending beach ridges to the north of Cape Krusenstern would be eroded and their rich archaeological record would be destroyed, but the east-trending beach ridge complex east of Cape Krusenstern would be unaffected.

The possible effects of an artificial disruption to the beach drift in the area between Ipiavik Lagoon and Kivalina cannot be evaluated without more careful study, because the direction of net beach drift is not firmly known.

Construction of a harbor or jetty at Kivalina or at some point further north would have little or no effect at Cape Krusenstern. The diminishment in sediment supply would be compensated by accelerated coastal retreat nearer to the site of the disturbance.

REFERENCES CITED

Beikman, H. M., and Lathram, E. H., 1976, Preliminary geologic map of northern Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-789.

Coulter, H. W., Hopkins, D. M., Karlstrom, T. N. V., and others, 1965, Extent of glaciations in Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-415.

Creager, J. S., and McManus, D. A., 1966, Geology of the southeastern Chukchi Sea, in Wilimovsky, N. J., and Wolfe, J. N., eds., Environment of the Cape Thompson region, Alaska: U.S. Atomic Energy Comm., p. 755-786.

Giddings, J. L., 1960, First traces of man in the Arctic: Sci. American, Nov. 1960, p. 10-19.

Moore, G. W., 1960, Recent eustatic sea-level fluctuations recorded by arctic beach ridges: U.S. Geol. Survey Prof. Paper 400-B, p. 335-337.

_____1966, Arctic beach sedimentation, in Wilimovsky, N. J., and Wolfe, J. N., eds., Environment of the Cape Thompson region, Alaska: U.S. Atomic Energy Comm., p. 587-608.

Moore, G. W., and Giddings, J. L., 1961, Record of 5,000 years of Arctic wind direction recorded by Alaskan beach ridges [abs.]: Geol. Soc. America Spec. Paper 68, p. 232.

FIGURE CAPTIONS

Figure 1. Index Map.

Figure 2. Beach ridge sequence at Cape Krusenstern. Numbered areas represent sequences of parallel beach ridges separated from one another by discordances which represent short erosional episodes. A profile through showing heights and ages of beach ridges and approximate duration of erosional intervals is given at the base of the figure. This figure was originally compiled by G. W. Moore and J. L. Giddings.

Figure 3. Shoreline morphology and history, Noatak Quadrangle, Alaska. Shoreline morphology of the proposed Cape Krusenstern National Monument (area enclosed by heavy lines) and surrounding areas. This is an overlay for the Noatak Quadrangle (1:250,000) (U.S. Geological Survey, 1955).

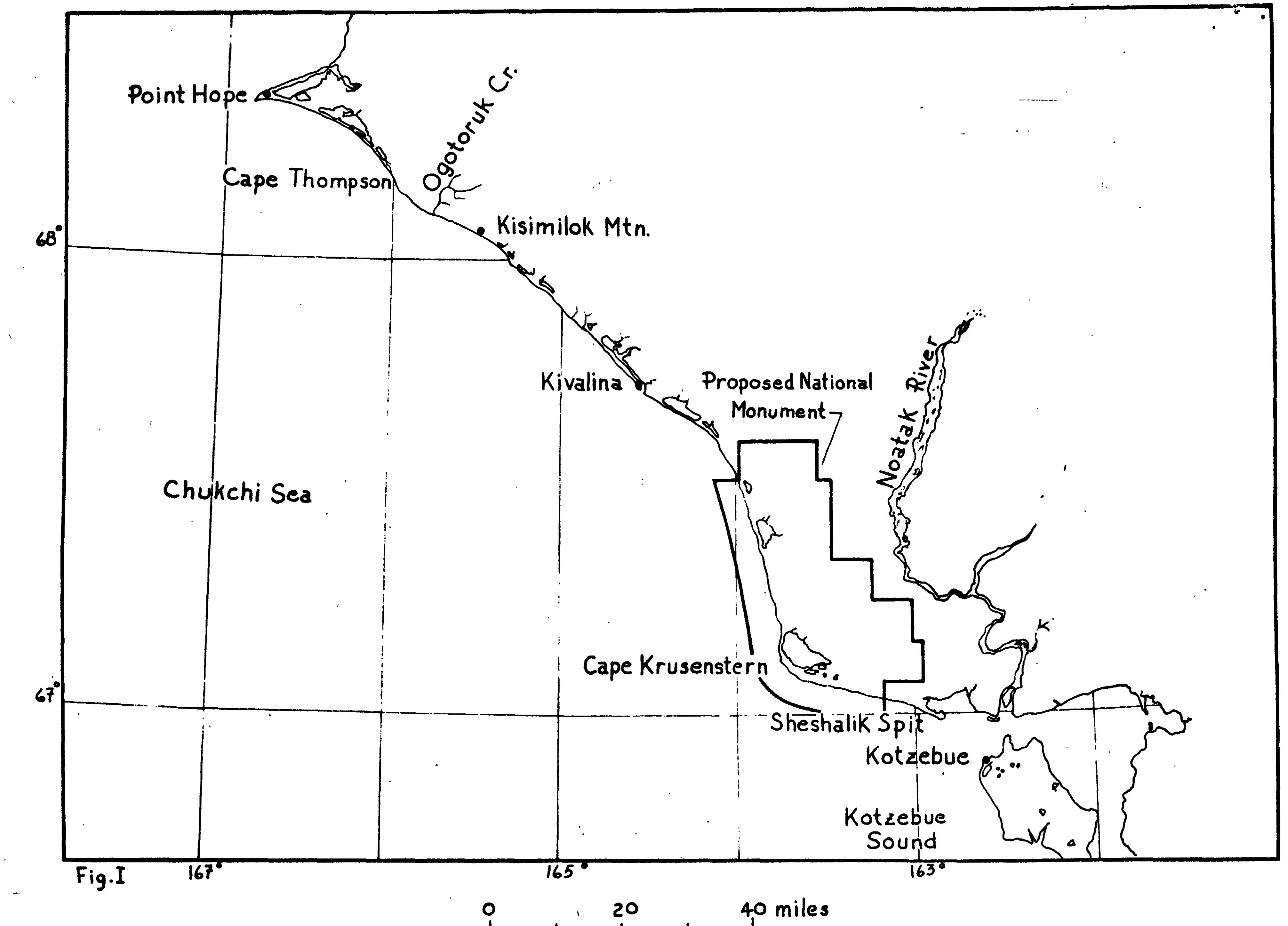
Point Hope
Cape Thompson
Ogotoruk Cr.
Kisimilok Mtn.
Kivalina
Proposed National Monument
Noatak River
Chukchi Sea
Cape Krusenstern
Sheshalik Spit
Kotzebue
Kotzebue Sound
68°
67°
167°
165°
163°
0
20
40 miles

Fig. I

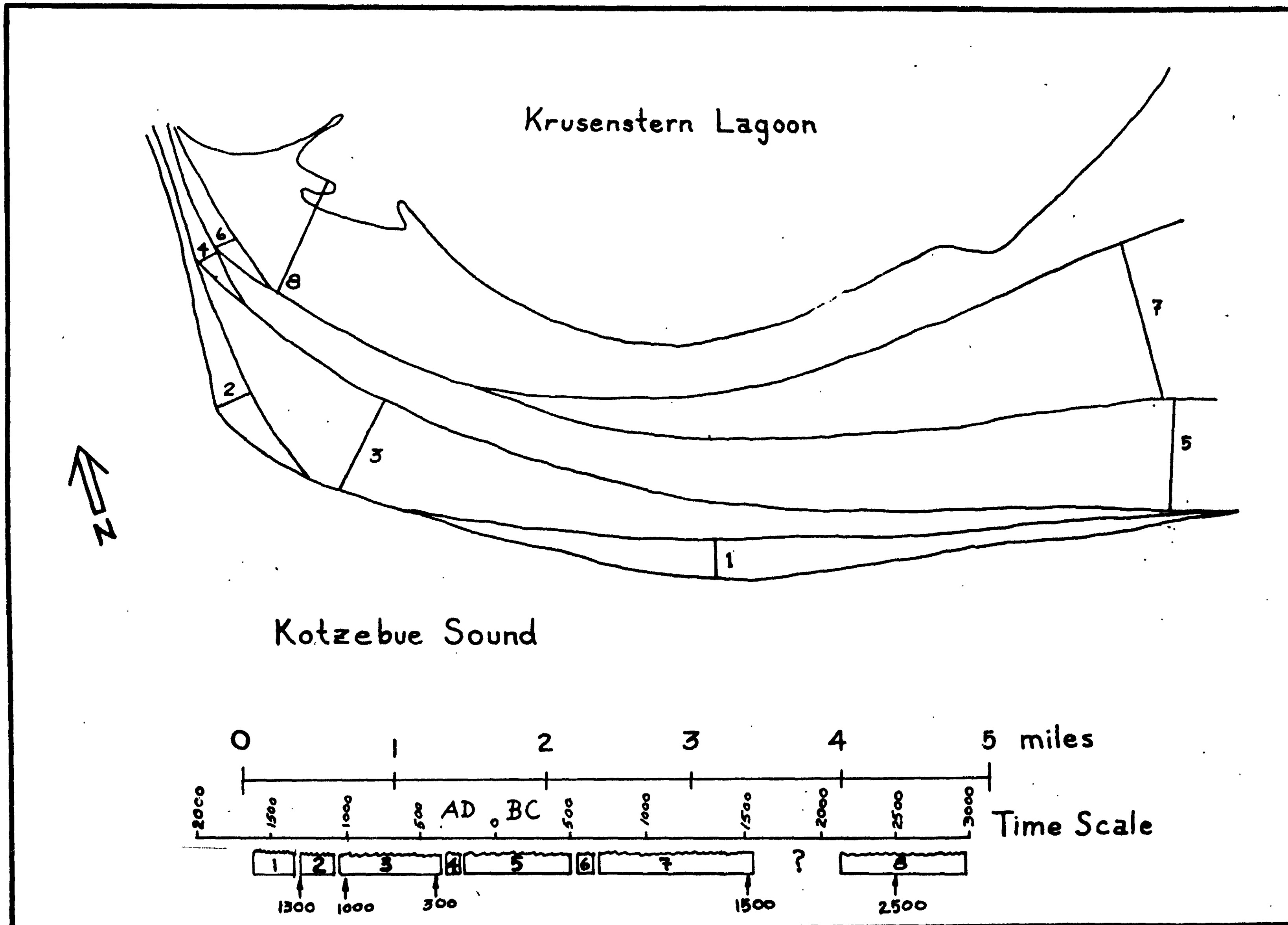
Krusenstern Lagoon
Kotzebue Sound
N
1
2
3
4
5
6
7
8
0
1
2
3
4
5 miles
Time Scale
2000
1500
1000
500
AD
0
BC
500
1000
1500
2000
2500
3000
?
1300
1000
300
1500
2500

Fig. II