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DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

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GEOLOGICAL AND ANTHROPOLOGICAL CONSIDERATIONS IN RELOCATING SHISHMAREF, ALASKA

By
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CONTENTS

Abstract 1
Introduction 1
Geologic and geographic background 1
  Geographic setting: tidal range and storm climatology 1
  Storm frequency and erosion in Shishmaref 3
  History of settlement on the Shishmaref barrier islands 4
  Geologic history of Sarichef Island 4
The coastal erosion problem and community response 6
  Recent history of coastal erosion and protection at Shishmaref 6
  Previously proposed hazard-management alternatives 9
Geologic map of parts of the Shishmaref A-3, B-3, and Teller D-3 Quadrangles 9
Geological and engineering properties of suggested relocation sites 10
  Ear Mountain 10
  Tin Creek 10
  Five Mile Bluff 10
Anthropological and economic considerations in relocating Shishmaref 13
  Subsistence pattern and industrial base 13
  Sanitary and health problems 13
  Buildings and structures 13
  Alternatives 13
    Option 1: Living with the 'mobile' Sarichef Island 13
    Option 2: Moving to another barrier island 14
    Option 3: Relocating to the mainland 14
      Five Mile Bluff (Nunatak) 14
      Tin Creek 14
      Ear Mountain 15
      Serpentine River Delta 15
      Singeak 15
Summary and recommendations 15
  Community surveys and studies 16
  Water consumption and water resources 16
  Geotechnical studies 16
Acknowledgments 16
References cited 16

FIGURES

Figure 1. Shishmaref region and location of study area 2
2. Surficial-geologic map of Sarichef Island 3
3. Photographs of Shishmaref revetment 8

TABLES

Table 1. Radiocarbon ages from Sarichef Island 5
2. Description and engineering properties of geologic units shown on sheet 1 11

SHEET
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Sheet 1. Geologic map of portions of the Shishmaref A-3, B-3, and Teller D-3 Quadrangles, Alaska

GEOLOGICAL AND ANTHROPOLOGICAL CONSIDERATIONS IN RELOCATING SHISHMAREF, ALASKA

by
Owen K. Mason[1]

ABSTRACT

The barrier-island village of Shishmaref, Alaska, is threatened by high-intensity storms that are continually eroding the low dunes on which the village is built. The community has pursued several short-term solutions since the threat was recognized in the 1950s. Relocation to the mainland appears to offer the best long-term solution. Aerial-photograph interpretation and limited field research were conducted to assess alternative sites for village relocation. Three sites—all on the mainland—were examined at the request of the City of Shishmaref: (a) the north slope of Ear Mountain, (b) several terrace locations along Tin Creek, and (c) the high bluff locally referred to as Nunatak or Five Mile, which is 5 mi (8 km) southwest of the present village on Shishmaref Inlet. Each of these sites presents serious engineering or access problems. Site-specific geotechnical studies are recommended to assess construction feasibility and design constraints. The past experience of erosion control and the subsistence needs of the community are important considerations for any relocation decisions.

INTRODUCTION

The island community of Shishmaref, on the northwest coast of Alaska (fig. 1), is annually threatened by storm surge and may face destruction by incremental bluff erosion, which may intensify if greenhouse effects cause sea level to rise. One response to the severe erosion problem involves relocating the village to the Seward Peninsula mainland. In 1995 the Alaska Division of Geological & Geophysical Surveys received state funding to conduct a brief reconnaissance of the sedimentary characteristics and engineering properties of an area encompassing several possible relocation sites suggested by the City of Shishmaref. Some considerations of subsistence activities are included in the analysis.

GEOLOGIC AND GEOGRAPHIC BACKGROUND

GEOGRAPHIC SETTING: TIDAL RANGE AND STORM CLIMATOLOGY

Shishmaref is on Sarichef Island in the central part of the southwest-northeast-oriented Shishmaref Barrier Island chain along the Chukchi Sea (fig. 1). The sandy Shishmaref barriers extend more than 60 mi (100 km) enclosing several lagoons on northwest Seward Peninsula. Sarichef Island, measuring 4.5 mi (7 km) by 1.2 mi (2 km), is the smallest of the barrier islands. Two tidal inlets define the north and south margins of the island and represent its most important attribute in terms of travel for subsistence pursuits. The incremental effects of tides and storms have deposited a considerable amount of sand at the inlet margins. The resulting unvegetated tidal flats produce the dumb-bell-shaped bulge at the ends of Sarichef Island. The southern half of the island is low lying and marsh covered. Grass-covered dunes transgress older marsh deposits and form a succession of low dunes that splays to the northeast along the margin of the northern tidal flat. The highest dunes are 26 ft (8 m) above mean sea level. The cemetery and church area are at this highest elevation on the fourth dune landward (fig. 2). The island is underlain by 30 to 50 ft (9 to 15 m) of permafrost; the active layer is estimated at 1.6 to 5.0 ft (0.5 to 1.5 m) below the surface (Wheaton, 1980; Peratrovich and Nottingham, 1982, p. 4). The erection and subsequent heating of buildings generally deepens the active layer, leading to the thawing of permafrost. In turn, the thawing of permafrost may foster erosion of the dunes (Peratrovich and Nottingham, 1982).

The southern Chukchi Sea is microtidal and ice covered for up to 9 months a year. Despite this, the Shishmaref barriers are a wave-dominated system, subject to the onslaught of storm waves during the open-water season, which starts in June or early July and can extend through November. Mean higher high water (MHHW), determined by using the elevation of wave-carried drift debris, is estimated at 2.5 to 3.3 ft (0.75 to 1.0 m) at Shishmaref (Peratrovich and Nottingham, 1982, p. 7). Prevailing coastal currents along the Shishmaref barriers are from southwest to northeast, the result of both geostrophic inflow from the Bering Strait and tidal currents (Naidu and Gardner, 1988). Temporary reversals in current direction occur under the influence of storms.

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Persistent low-pressure systems produce high wave energies and elevated water levels that undercut the 16- to 26-ft-high (5 to 8 m) dunes on Sarichef Island. In most years, shorefast ice protects Shishmaref from some effects of the highest astronomic tides in spring, but not necessarily those in autumn. Autumn storms (September to early November) offer the greatest erosion threat because the dunes are unfrozen at depth and protective shorefast ice (if present) can be easily ruptured. This combination can produce strong and persistent waves, a several-meter surge elevation of sea level, and large-scale block collapse of bluff sediments. Moreover, the effects of storms are not limited to one quadrant of the compass. Storms that start with southeasterly winds can shift about the northwest side, as in both 1973 (State of Alaska, 1974a) and during an anomalous storm in late October 1995 (videotape by City of Shishmaref, October 1995). Thus, the island can be hit twice—from one direction and then another—by the effects of a single storm.

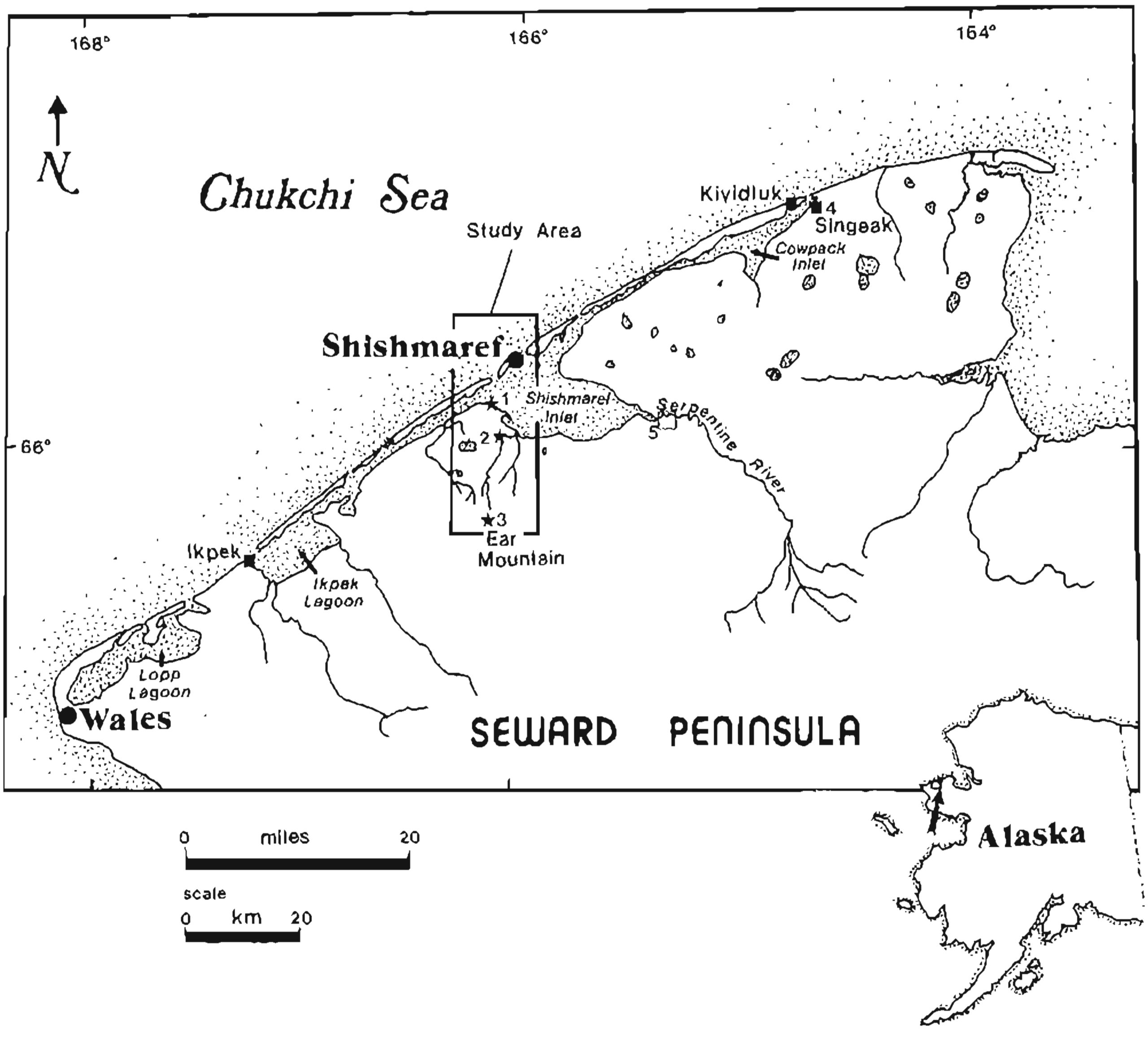

Figure 1. *Shishmaref region and location of study area included in geologic map (sheet 1). Sites considered for relocation are: 1–Nunatak or Five Mile; 2–Tin Creek; 3–Ear Mountain. Several other possible locations are also noted, including 4–Singeak and the 5–Serpentine River delta.*

that of the Nome coast, but its opposite coastal orientation probably produces differing effects.

No detailed field studies document the rate of coastal erosion for Sarichef Island. Photogrammetric studies for several parts of the Shishmaref barrier chain by Jordan (1988, p. 344) inferred erosion rates between 1.7 ft/yr (0.53 m/yr) to the south and 4.1 ft/yr (1.25 m/yr) in the north part of the chain. Erosion rates may be higher on Sarichef Island because greater tidal energies are exerted on the island (Jordan, 1988, p. 345). This rate may have accelerated during the last 20 yr partly because of human impact associated with both the thaw of permafrost underlying the dunes and an 'edge-around' erosive effect due to emplacement of a revetment in the early 1980s.

Although storms can pummel Sarichef Island with considerable fury, virtually all buildings in Shishmaref survived the 'storm of the century' in October 1973. Very few, if any, buildings were destroyed.

HISTORY OF SETTLEMENT ON THE SHISHMAREF BARRIER ISLANDS

The record of human occupation on the Shishmaref Barrier Islands is limited to the last several hundred years. Archaeological reconnaissance by the National Park Service during the mid-1980s failed to discern any occupation on the Shishmaref barrier islands before A.D. 1400, but this may not reflect prehistoric population density (Schaaf, 1988). The absence of past settlements reflects the poor preservation potential due to the dynamic geomorphology of the barrier-island chain (Jordan, 1990). Another consideration may be the limited number of active inlets that provide corridors for travel to and from the shallow and often intractable lagoons. Settlement history may parallel the opening and closing of inlets along the chain. Evidence of numerous 19th- to 20th-century settlements on the islands remains (Schaaf, 1988); many locations are still used in subsistence pursuits on a seasonal basis (Sobelman, 1985).

At present, Shishmaref ('Qikiqtuk,' or island, in Inupiat) is the only year-round settlement on the barrier islands (pop. 433, 1990 census, but currently estimated at more than 500 by the City of Shishmaref). This ivory-carving, subsistence-hunting community includes a diverse assortment of structures, mostly plywood cabins, some more than 40 yr old. Use of the present town site is comparatively recent. According to Russian accounts, old Shishmaref, located 1.2 mi (2 km) northeast, was occupied as early as 1816 and remained so throughout the 19th century (Ray, 1964). On the basis of archaeological comparisons with type artifacts from the Kobuk River sequence (J.M. Schaaf, oral commun., 1995), occupation may have been as early as A.D. 1600. The present location assumed importance as a gold-rush supply center during the decade 1900-1910 after the establishment of a post office (Koutsky, 1981). Inupiat hunters continue to occupy a variety of camps north and south of Shishmaref; as stated, some were year-round settlements in the 19th century (Ray, 1964). The introduction of an industrial economy has meant increased centralization and permanence, including a large school built in the 1970s, an electric generator, and numerous multistory commercial and government buildings (fire station, city hall, stores).

GEOLOGIC HISTORY OF SARICHEF ISLAND

As with most barrier islands worldwide (Davis, 1994), Sarichef Island is eroding on the seaward side and rolling over toward the mainland. Geologic data on the history of Sarichef Island are limited to stratigraphic sections and radiocarbon ages from the erosional cutbanks surrounding the island (unpub. data, 1992, 1993; table 1). Two ages published in Sainsbury (1967a) are excluded from consideration because of the large imprecision associated with the ages[2].

Sarichef Island lies between two wide tidal channels and consists of a series of in-filled storm-surge channels and overwash fans. Four depositional units are evident on aerial photos of Sarichef Island and reveal previous topographic configurations (fig. 2). The core of the southwest part of the island is composed of washover and channel-fill deposits that lack high dunes (unit I). The rest of the island consists of three sets of superimposed dunes and swales that formed at the margins of tidal or surge channels. The sequence of deposits associated with three abandoned surge channels or inlet-marginal dunes (units I-III) progresses older to younger from south to north, based on calibrated radiocarbon ages (table 1) of grass from stabilized surfaces that postdate dune growth adjacent to abandoned storm-surge channels. Using this time line, the location of the two tidal channels may have varied 0.6 to 1.2 mi (1 to 2 km) from present during the last 2,000 yr.

The southern part of Sarichef Island is the oldest part of the island (fig. 2, unit I), whereas the younger dune ridges (units II to IV) are time transgressive and formed as channels filled with sand. The three succeeding Sarichef Island deposits (units II-IV) are, for the most

[2]Sainsbury's (1967a, p. D209) two radiocarbon ages on peat or driftwood from the Shishmaref cutbank have 200-yr sigma (450 ± 200 yr B.P. (W-1778) and 200 ± 200 yr B.P. (W-1771). The two ages are statistically too vague to be very meaningful. The radiocarbon ages, while valid, simply reveal calibrated ages of about 700-0 yr B.P.

STORM FREQUENCY AND EROSION IN SHISHMAREF

Using meteorological data and wave-frequency equations, Jordan (1990) estimated that low-level storms that elevate sea level 3 to 6 ft (1 to 2 m) are likely every 25 yr. Larger storms may occur every 50 to 100 yr (Wise and others, 1981). Mathematical modeling of Chukchi storms indicates that the maximum expectable storm-surge elevation is 10 to 12 ft (3 to 3.5 m) above sea level, about the level of the 1973 storm (Kowalik, 1984; oral commun., 1995). In the adjacent Bering Sea, Mason and others (in press) synthesized accounts in the *Nome Nugget* newspaper to infer that storms recur at cycles of 3 to 7 yr, 11 yr, and 18 to 20 yr; the variation of storm intensity over the three cycles may reflect, respectively, forcing by El Niño atmospheric interconnections, solar intensity and variability, and lunar variables. The trajectory of storms at Shishmaref may be partly in phase with

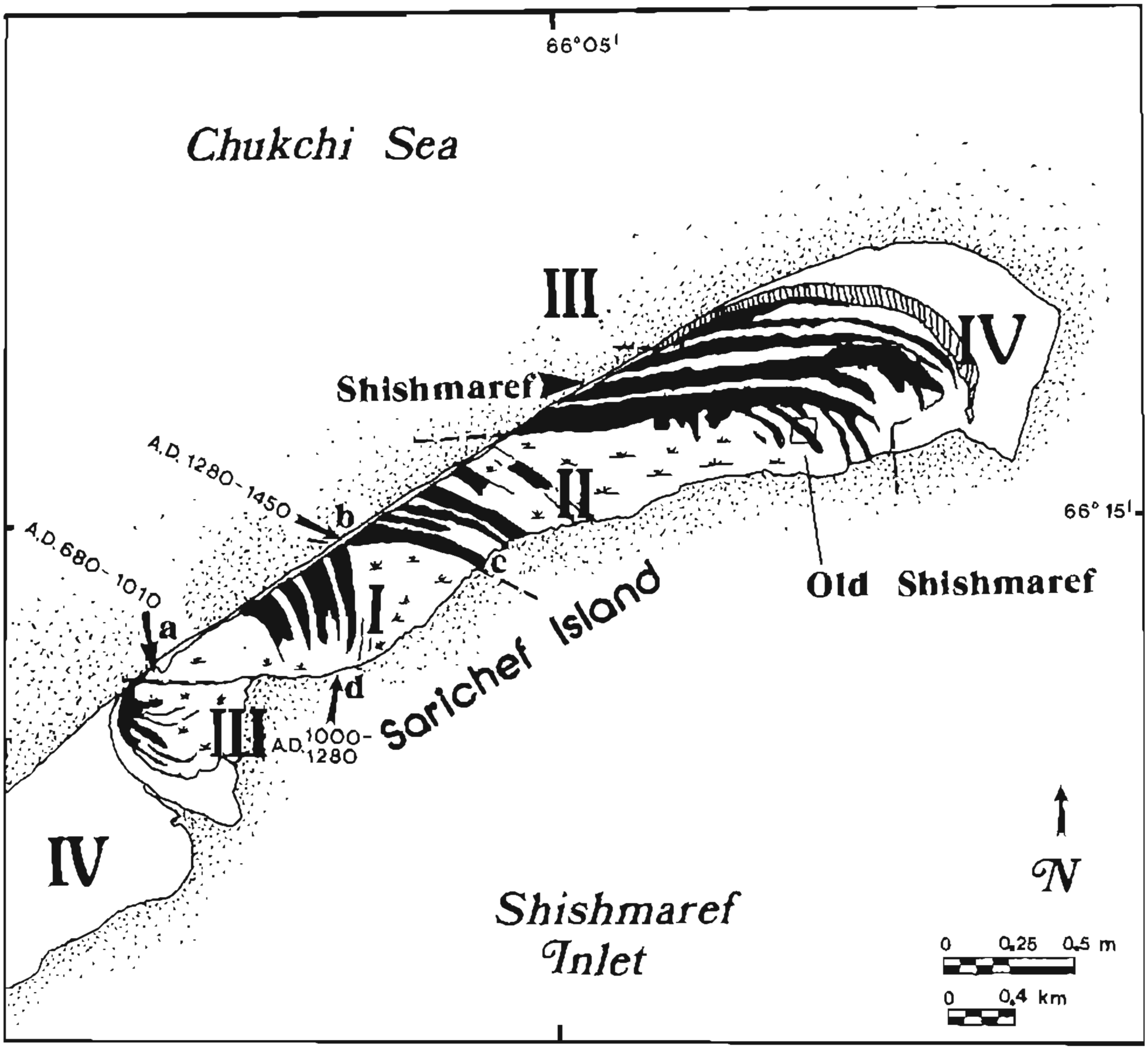

Figure 2. *Surficial-geologic map of Sarichef Island, showing evolution of the island from A.D. 680 to present. The locations of modern and old Shishmaref are indicated. Note the location of the old village away from the eroding shoreline. Stabilized dunes are delineated by black; active dunes are crosshatched. Vegetation symbol indicates marsh; unvegetated tidal flats are unshaded. Depositional units are marked by Roman numerals from oldest (I) to youngest (IV). Selected, calibrated radiocarbon ages are presented as calendar ages for stabilization of dune surfaces. Radiocarbon samples (table 1) were collected from localities a, b, c, and d.*

part, linked in a source-to-sink relationship; erosion from the southwest feeds growth to the northeast. This is due to storm energy from the west and northwest, which produces erosion, and to the prevailing longshore transport direction to the northeast, which favors progradation. However, tidal currents are also strong on the southern margin of the island and have redeposited shoreface material, forming stabilized dunes (unit III) adjacent to a large tidal flat (unit IV).

No geological ages are available to constrain the initiation of unit I (fig. 2). A minimum age for its formation may be inferred from a ^{14}C age on grass from a stabilized surface atop dunes on the remaining portion of unit I (loc. a; table 1, sample Beta-58063). On the basis of this datum, unit I formed before A.D. 700 and probably as early as the first centuries A.D., contemporaneous with progradation of other Shishmaref barrier islands (Jordan, 1990; Jordan and Mason, unpub. data). A ^{14}C age on marsh peat at the contact between units I and II (loc. d; table 1, sample Beta-59588) indicates that the lagoon shore stabilized by A.D. 1000 as storm surges slackened. Unit II formed between A.D. 1000 and A.D. 1200 as a series of marginal dunes built along a decreasingly active surge channel (loc. b; table 1, sample Beta-58062). On the basis of archeological evidence of the maximum age of old Shishmaref (Ray, 1964; Schaaf, oral commun., 1995), another series of dunes expanded west to east to construct unit III parallel to an inlet that was subsequently active from A.D. 1200 to about A.D. 1600. Another series of dunes probably grew contemporaneously along the southern margin of Sarichef Island and is defined here as unit III. The last several centuries of tidal-flat formation are evident in unit IV, which is largely unvegetated.

The cumulative history of inlet fill and adjacent dune growth records storm overwash from variable directions. A north-to-south storm trajectory prevailed from A.D. 800-1200, forming unit II (fig. 2). Storms from west to east prevailed between A.D. 1200 and A.D. 1700, based on a minimum age for old Shishmaref in unit III. A southwest-to-northeast storm trajectory that started after A.D. 1800 has continued to the present. The prehistoric village of old Shishmaref lies on one of the youngest surfaces, which are less than 400 yr old. Significantly, this part of the island is accreting both vertically and horizontally and provides a comparatively stable location.

In summary, the ^{14}C ages from Sarichef Island erosional cutbanks yield the following scenario. The lagoon peat age implies that progradation ceased by A.D. 1000. Dune growth had started earlier, A.D. 700-1000, as erosion of the island intensified. Dune growth was sporadic; at least 3 ft (1 m) of dune accreted by A.D. 1000 and, except for an interruption due to surface stability from A.D. 1200 to A.D. 1400, continued accreting in the centuries afterward. A major shift in island progradation occurred after A.D. 1400, as reflected in the alignment of dune ridges (unit III).

How much has Sarichef Island changed since A.D. 1000? If we apply the erosion rate of 4.1 ft/yr (1.25 m/yr) proposed by Jordan (1988) for the Shishmaref barriers to the south, the active beach during unit I time extended 0.6 to 0.8 mi (1 to 1.25 km) farther seaward. However, this value probably overestimates the true erosion rate of the shoreline at the time, exceeding current rates of landward barrier-island migration. Maximum rates of landward movement on the east coast of the United States were but 160 to 330 ft (50 to 100 m) per century during the early Holocene (7,000 to 4,000 yr ago); they have stabilized since that time (Moslow and Heron, 1979, p. 229). However, barrier islands on the east coast could migrate tens to hundreds of meters in the 21st century if greenhouse warming produces a very rapid sea level rise and storms increase in frequency (Gornitz, 1991; Pilkey and Davis, 1987).

Storm erosion has affected mostly the southwest shore of Sarichef Island. Under the influence of the prevailing northeastward currents, the island has built northeastward. The same process of erosion has affected the next barrier island to the northeast. The tidal channel has grown larger at the expense of this island. Aerial photographs and unpublished ^{14}C ages show that the island responded by eroding and moving landward to the northeast but not quite at the same rate as Sarichef Island.

THE COASTAL EROSION PROBLEM AND COMMUNITY RESPONSE

RECENT HISTORY OF COASTAL EROSION AND PROTECTION AT SHISHMAREF

The present site of Shishmaref had wide beaches in the 1940s, according to local informants (Walter Nayakpok, oral commun., 1992) and historic photographs (Taylor, 1947). By 1965, residents claimed that erosion was 50 ft/yr (15 m/yr) (Sainsbury, 1967a, p. D209). The intensified storms of the 1950s led the community to its first attempts to stabilize the underlying dunes by using 55-gal drums (Clifford Weyiowanna, oral commun., 1992). At this time, the first studies of erosion control and hazard mitigation were undertaken, reportedly by the U.S. Army Corps of Engineers, who advised against hard stabilization (State of Alaska, 1974a). Intense storms in the early 1970s flooded most of Sarichef Island and eroded a considerable area of the most seaward dunes (Peratrovich and Nottingham, 1982).

The catastrophic nature of the 1973-74 storms led residents to seriously contemplate relocation or elaborate

Table 1. *Radiocarbon ages from Sarichef Island*[a]

Laboratory sample	^{14}C yr B.P.	Calibrated calendar age (A.D.)	Material and context (MSL = elevation above mean sea level)	Significance
Beta-58063	1,160 ± 70	680-1010	Detrital grass fragments from lower buried surface, 1.2 m MSL on dune (loc. a)	Provides minimum age of unit I; underlying beach and dune formed before A.D. 680. Same stratigraphic level as sample Beta-67561
Beta-67561	1,050 ± 90	786-1202	Detrital plant fragments from lowest buried surface in dune, 1.8 m MSL (loc. a)	Location within oldest part of unit I provides minimum age for surface formed atop cross-bedded sands. Sample is from the same stratigraphic level as Beta-58063 (A.D.680-1010), suggesting that the dune stabilized during the period of overlap, A.D. 800-1000. The surge channel associated with unit I formed before the dune (before A.D. 800)
Beta-67562	960 ± 60	983-1222	Detrital grass fragments from contact between units I and II (lowest buried surface in dune) on lagoon side of ridge, 1.3 m MSL (loc. c)	This age is older than the age of sample Beta-58062 from loc. b on the ocean side, suggesting that the inlet adjacent to unit II was active before A.D. 1000
Beta-59588	870 ± 80	1000-1280	Fibrous marsh peat from upper level, about 10 cm MSL (loc. d)	Minimum age for stabilization of unit I on the lagoon side; indicates stabilization of the surface and lessening of of overwash after A.D. 1000
Beta-58062	550 ± 70	1280-1450	Detrital grass fragments from lower buried organic surface at contact between unit I and II, where 10 beds of intervening inorganic sand overlie cross-bedded sand, 1.6 m MSL (loc. b)	Records stabilization of dunes filling an inlet formerly at this position. This age may be 400 yr younger than sample Beta-67562, which is also from the lowest buried surface on the same dune. The context and age of this sample imply that stabilization occurred during A.D. 1280-1450 and that the inlet adjacent to unit II formed during or after this time
Beta-67570	390 ± 60	1424-1651	Detrital grass fragments from upper buried surface (loc. a); collected from same location as Beta-67561 (A.D. 786-1202) in unit I	Indicates dune growth after A.D. 1200, stabilization during A.D. 1424-1651, and dune growth after A.D. 1651, which buried this surface. May reflect presence of active beach scarp nearby during A.D. 1424-1651
Beta-67559	220 ± 60	1520-1955	Detrital grass fragments from upper buried surface, 0.7 m MSL (loc. b), at contact between unit I and II; sample is stratigraphically above Beta-58062 (A.D. 1280-1450)	Indicates that dune stabilization occurred after A.D. 1520. Provides a minimum age estimate for unit II

[a] Sample locations shown on figure 2. Samples were collected by O.K. Mason and J.W. Jordan in 1992 and 1993. ^{14}C yr B.P. refers to age calculations based on the amount of radioactive carbon remaining in an organic sample, using the 5,568-yr Libby half life of carbon (Taylor, 1987). Because of fluctuations in the amount of radioactive carbon in the atmosphere, radiocarbon ages were calibrated using tree-ring dating according to procedures described by Stuiver and Reimer, 1993. The result of this calibration is a 2-sigma (2σ) or 95-percent probability range of the true age of the sample.

engineering solutions. Several engineering firms have evaluated protection strategies for Shishmaref and erosion on Sarichef Island (DOWL Engineers, 1975, 1978; Peratrovich and Nottingham, 1982). To estimate erosion rates, Peratrovich and Nottingham (1982) compared 1937 survey notes for the Shishmaref school with a 1973 aerial photo to produce a rate of 5 ft/yr (1.5 m/yr); they implied that 200 ft (60 m) of erosion had occurred. Similar photogrammetric interpretation by Jordan (1988) yields an average rate of 1.6 to 2.0 ft/yr (0.5 to 0.6 m/yr), for the adjacent islands of the Shishmaref barriers. As noted by Peratrovich and Nottingham (1982) erosion varies with storm intensity and position. About 10 ft (3 m) of dune eroded from parts of the dune face between 1963 and 1972, a rate of 1.1 ft/yr (0.34 m/yr). However, an equivalent amount of erosion, 10 ft (3 m), also resulted from a single storm, that of October 1973. The 1973 event led to increased awareness on the part of Shishmaref residents. Sandbags were first placed at the base of the dunes in 1974, before the storm season. The sandbags may have inhibited erosion during the massive November 1974 storms, as noted by Peratrovich and Nottingham (1982, p. 3).

The administrative process involved in relocation and hazard planning is illuminated by a series of minutes and memoranda from the early 1970s from Shishmaref civic leaders and personnel from the State of Alaska Division of Community Planning (archived in the University of Alaska Fairbanks Rasmuson Library). As early as May 1973, Shishmaref city officials decided to relocate to the mainland site of Five Mile (Nunatak in local terminology), 5 mi (8 km) south of Sarichef Island (fig. 1) (State of Alaska 1974a,b). Ten attributes were offered in favor of the location, including adequate water, close proximity to the present site, and apparently well-drained subsurface. However, the area lacked a gravel source, the city noted (State of Alaska, 1974a), and the decision to move was never carried out.

In early 1974, plans were made for a soil survey of the Five Mile site, including the use of a drilling rig to obtain cores. The results of these studies, if any, are unknown. Memoranda indicate plans for a survey by Dr. Sam Rieger of the U.S. Soil Conservation Service (SCS); however, consultations with the present SCS staff did not confirm these plans. Five Mile remains a favored site among many residents who support relocating.

In the early 1980s Shishmaref used two methods of hard stabilization that eventually extended over 1,700 ft (518 m) of seaward dune face. The first, installed in 1982, was a series of gabions laid at the base of the buffs. Gabion units were piled one atop the other and attached by hand. Along the south part of town, the gabions still remain largely intact after more than 10 yr of salt-water corrosion and wave action. Despite the effort, bluff erosion has proceeded landward and most of the gabions now form a submerged breakwater (City of Shishmaref videotape).

In 1984 a cement-brick revetment was emplaced in the hope of stopping bluff retreat (fig. 3a,b). A series of interlocked 25-lb (11.4-kg) cement bricks fastened by wire was placed over a plastic cover resting directly on sand that had been bulldozed onto the beach from sites on the tidal flats. The concrete mat does not appear to extend several meters below sea level, as had been recommended by engineers for a revetment at Prudhoe Bay (Leidersdorf, 1988). Consultants to the City of Shishmaref proposed burial of the revetment at least 5 ft (1.5 m) (Peratrovich and Nottingham, 1982). Less than half of the original structure is intact, and most of that was rebuilt by residents in 1986 and in the 1990s.

The collapse of the Shishmaref revetment began even during the construction effort, but the revetment started to fail during a small storm surge in summer 1984 (*Nome Nugget*, 1984). Waves overtopped the structure despite the specifications of Peratrovich and Nottingham (1982, fig. 5.4), which show the structure at least 3 ft (1 m) above the 50-yr storm elevation (without considering wave height). Sudden and catastrophic collapse of the revetment resulted from the overtopping of the structure by storm waves in the autumn of 1986. The high water forced the supporting sand out seaward, leading to the collapse of the concrete blocks. Ice push at the base may have been a factor in its deterioration. Shishmaref residents continue to rebuild the revetment. Local efforts in 1993 shored up the structure and added a series of 2.5- to 3-ft-high (0.75 to 1 m) gabions on a stretch of its upper part.

Another proposed option for Shishmaref included partial relocation of shorefront property onto higher, more landward parts of the island (DOWL Engineers, 1978, p. 10, 28). DOWL also suggested that low-lying areas south of the dunes could be filled in and raised. Revegetation and dune stabilization were recommended (DOWL Engineers, 1978, p. 4), but not implemented by residents or other agencies. The village remains tightly clustered on a small fraction of the island.

Various engineering firms have presented the people of Shishmaref with alternatives for hard-stabilization of the shore bluffs. The engineering consultants clearly preferred riprap but noted that sandbags were the cheapest method (Peratrovich and Nottingham, 1982, p. 18, 22). Shishmaref residents chose the most expensive method, a concrete mat. Peratrovich and Nottingham (1982, p. 17) noted the need to accurately grade the mat and to anchor it to the bluff. Lack of attention to these two concerns with the concrete mat may have contributed to its eventual failure.

New houses are surrounded with plastic matting to foster beach-grass growth, trap sand, and build dunes as defensive measures. Careful maintenance will be required

to keep protective matting in place. Dune nourishment is an untested alternative for Shishmaref (Pilkey, 1995).

The Shishmaref erosion-control efforts have not been without great cost. The greatest consequence is the end-around erosion resulting from both the gabions and the revetment (Kraus, 1988; Pilkey and Wright, 1988). In fact, the 1984 revetment overlaps this end-around zone and may have contributed to its undercutting by storm waves. Another by-product of the revetment is the loss of beach at Shishmaref and the addition of obstacles that prohibit recreation and even temporary boat moorage (Pilkey and Wright, 1988). Residents may inadvertently contribute to bluff erosion during storms by dumping debris such as truck and snowmachine chassis onto the beach, as portrayed in an October 1995 videotape by the City of Shishmaref. While this is a universally used folk method of erosion abatement (in Micronesia and the Caribbean, for example; Orrin Pilkey, oral commun., 1992) the presence of this debris may accelerate erosion by adding projectiles to the force of the waves; this practice should be discouraged.

PREVIOUSLY PROPOSED HAZARD-MANAGEMENT ALTERNATIVES

Maps prepared by DOWL Engineers (1978) describe residential use and indicate possible expansion areas in relation to the extreme surge limits of the 1973-74 storms. Peratrovich and Nottingham (1982) drafted a hazards map for Shishmaref that placed about 80 percent of the village beyond the wave runup and stormsurge flooding projections for a 100-yr event. However, the safe area leaves little breathing room for the community.

In 1994, the community again began giving serious thought to moving to the mainland. The various locations considered are on the south shore of Shishmaref Inlet and all are underlain by ice-rich silt (fig. 1, sheet 1). These sites would require the emplacement of a thick and sizable gravel pad and the use of pilings to provide cold-air circulation below structures. The cost of moving Shishmaref would considerably exceed the figure of $50 million estimated by DOWL Engineers (1994) for moving Kivalina because Shishmaref's population is at least 25 percent larger. An additional necessity for Shishmaref involves building more than 20 mi (32 km) of road from a rock quarry site near Ear Mountain.

Figure 3. *(Top) Shishmaref revetment, July 1992. The concrete-block structure had collapsed in the mid-1980s following a low-level storm surge that overtopped it and flushed out the underlying sand. Note the eroding dune bluff in the background. (Bottom) Same revetment in September 1993 following a rebuilding effort by residents. the appearance of the revetment in this photograph approximates its original design except that gabions—sand bags enclosed in wire enclosures—are placed at the crest of the strucutre. The rehabilitated revetment has not yet been tested by major storm activity.*

GEOLOGIC MAP OF PARTS OF THE SHISHMAREF A-3, B-3, AND TELLER D-3 QUADRANGLES

The research conducted for this report included aerial-photograph interpretation and limited field reconnaissance as a basis for mapping surficial deposits in areas suggested by Shishmaref representatives. The aerial photographs were obtained from the Geo-Data Center of the University of Alaska Geophysical Institute in Fairbanks. A series of adjoining false-color infrared photos at approximately 1:60,000 scale was used. Geologic units were first delineated by tracing on Mylar photo overlays, then transferred to 1:63,360-scale topographic maps (sheet 1).

Most of the study area is in the northern coastal plain of Seward Peninsula. This plain has a gentle slope, rising south from near sea level to the prominent bedrock knob of Ear Mountain, 2,325 ft (709 m) high. Geologic units follow the designations of Charron (1995) and Patricia Heiser (oral commun., 1995) for the northern part of Seward Peninsula in the Bering Land Bridge National Preserve. The units approximate the soil associations delineated by the U.S. Soil Conservation Service (Van Patten, [n.d.]).

The oldest geologic units noted in the study area are limestones mapped by Sainsbury (1972). No modifications were made to the bedrock units described by Sainsbury on Ear Mountain. The limestone originated during Precambrian time (570 m.y. ago) and has since undergone repeated metamorphism. The bedrock surface is composed of a rubbly array of large clasts (4 to 8 in. or 10 to 20 cm long) produced by intense weathering and frost action. A large proportion of silt and clay is present at shallow depth.

Two considerably younger Quaternary sedimentary units represent most of the remaining land surface on the low coastal plain. The lowlands are largely silty-sand thaw-lake deposits of either young or old age. Both of these units represent Holocene modification of sandsheet and loess sediments preserved as high erosional terraces adjacent to the present drainages.

The origin and history of the sand-sheet deposits in the Shishmaref Quadrangle are not known with any certainty. Unlike the Cape Espenberg maar region to the east (Hopkins, 1988; Charron, 1995; Hoefle and others, 1994), sand-sheet deposits in the Shishmaref Quadrangle do not appear to be tephraceous. They were probably glacial in origin based on the extensive expansion of the early and middle Pleistocene glaciers in the York and Kigluaik Mountains of western Seward Peninsula (Sainsbury, 1967a,b, 1972; Kaufman and Hopkins, 1986). The age of deposition for sand of the Shishmaref B-2 Quadrangle may be older than 125,000 yr B.P. Some of the topography of the study area may reflect original deposition within sand dunes.

However, much of the complex topography of northern Seward Peninsula results from the long-term action of the thaw-lake cycle on fine-grained ice-rich sediments (Hopkins, 1988; Hopkins and Kidd, 1988). Most thaw lakes appear to drain catastrophically into older lake basins before thermal bank erosion reaches the small rivers that cross the plain. The preservation of higher surfaces adjacent to the rivers is a consequence of catastrophic drainage that preserves the retaining margins of the lakes. The landform may represent the cumulative activity of more than 100,000 yr of accretion by wind deposition of sand-sheet or dune deposits.

Sediment and engineering characteristics of the geologic units are summarized in table 2. Information from soil-survey descriptions was used in assembling engineering properties. The soil-survey data are limited to representative sections for each association and should be used with caution.

GEOLOGICAL AND ENGINEERING PROPERTIES OF SUGGESTED RELOCATION SITES

This study involved aerial-photo geologic mapping (sheet 1) and limited field visits to three mainland localities: (a) north slope of Ear Mountain; (b) Tin Creek; and (c) Five Mile bluff.

EAR MOUNTAIN

The limestone bedrock substrate on Ear Mountain is obviously out of the way of storm surge. The area is covered by large clasts of limestone and thin silt. Soil-survey data (Van Patten, [n.d.]) indicate that the organic mat is only 2 in (5 cm) thick, with permafrost generally 3 ft (1 m) below that. The surface is subject to frost-related processes that generate gelifluction lobes, stone stripes, and other forms of patterned ground. Gravel, including large clasts, predominates, although sand and silt are accessory sedimentary components. Conditions may be adequate for foundations, although construction on pilings is advisable to prevent thermokarst settling. Soil-survey personnel advised caution in road construction on steep slopes in this area because of possible slope degradation (Van Patten, [n.d.]).

The Ear Mountain site is more than 20 mi (32 km) from the coast. Besides the added costs of road construction and maintenance, the site offers only limited level ground and may offer occasional weather problems for aviation because of its proximity to the summit of Ear Mountain. However, the area has high potential for quarry rock; this may be useful for other building sites as well.

TIN CREEK

The Tin Creek locality (sheet 1) consists of residual silt hillocks adjacent to a small stream. The hillocks are ice rich, with a series of deep wedges observed on the surface. Although the active layer reached a 1.6-ft (0.5-m) depth in July, permafrost is probably present at depth, thereby providing an uneven and unstable building surface. In addition, space is limited on any one hill. Considerable effort would be involved in rendering the Tin Creek site usable—beginning with an extensive cover of gravel to insulate the frozen substrate.

An equally large concern is that the small stream of Tin Creek would require dredging to improve navigability. The stream is shallow and probably carries enough silt to continually fill any dredged channels. At present, little more than a single skiff can reach the surveyed townsite. Further, navigation along the entire shore of Shishmaref Inlet in this area is restricted to skiffs, mainly at high tide. Without constant dredging, barge traffic probably could not reach the Tin Creek site.

FIVE MILE BLUFF

Five Mile bluff (sheet 1) is composed of very fine to medium sand deposited as dunes adjacent to beach deposits of the last interglacial high stand of sea level, 125,000 yr ago (Sainsbury, 1967b). Parts of the bluff appear comparatively well drained; however, basinal topography atop the bluff indicates that thaw lakes and, presumably, permafrost have formed in the sand within the last 10,000 yr. Thus, some possibility exists that the ground is frozen in places, especially in drained lake basins. Ice wedges and polygonal ground are evident on residual interlake bluffs mapped as Qotlb (sheet 1). The active layer is only 1.3 to 2.0 ft (0.4 to 0.6 m) below the surface in these areas and within former thaw-lake basins. Erosion—although apparently not as severe as on Sarichef Island—appears to be a problem on parts of the bluff, especially in its eastern, better drained portion. Navigation could pose problems at low water along parts of the bluff. Considerable modification would be required to render Five Mile bluff a livable site. For example, gravel would have to be imported by high-cost shipping or by road.

Table 2. *Description and engineering properties of geologic units shown on sheet 1*

Geologic unit	Lithology	Distribution and thickness	Vegetation	Permafrost	Drainage and suitability as water source	Susceptibility to floods	Susceptibility to frost action	Bearing strength and slope stability	Construction considerations
Qmb/Qbr Modern beach deposits and older beach-ridge and dune deposits	Fine to medium sand, thinly bedded. Distinct organic beds in upper eolian facies overlies older marine beach-ridge and overwash deposits (Qbr)	Occupies barrier islands; not subdivided by age. Beach deposits at least several meters thick, possibly up to 20 m. Dunes up to 8 m high	Grass, sedges, low shrubs on older, stable surfaces	Thaw dependent on elevation; generally several meters below dunes, but less than 1 to 2 m in lower areas	Dunes are well drained but swales may be ponded. Fresh water limited in distribution, subject to salt intrusion	High to moderate threat from storm surge depending on elevation of dune and of individual storms	Moderate to low	Bearing strength good if frozen or compacted, susceptible to storm undercutting and thermokarst collapse if frozen dunes subjected to warmer temperatures	Easily excavated when unfrozen
Qe Estuarine deposits	Fine silt to clay with considerable fine to medium sand. Thinly bedded to massive. Represents marine reworking of eroded bluff and alluvial sediments	Forms emergent sand bars and river mouths adjacent to bluffs and within lagoons. Less than 2 m above sea level	Sedges or unvegetated. Locally covered by grasses and low dunes	May lack permafrost but may be aggrading at depth	Saline in subsurface. Completely saturated	Highly susceptible to storm surge; nearly all this unit below maximum surge-tide levels	Highly susceptible at depth. Surface is probably unfrozen	[Not rated, probably flooded for part of most years]	Easily excavated if unfrozen, possible use in beach nourishment, etc.
Qob Late-Pleistocene beach and dune deposits	Medium to fine sand, locally cross-bedded, with occasional organic beds. Represents dune deposits atop beach deposits from last interglacial stand of high sea level.	Forms prominent high bluffs for several km along Shishmaref Inlet. Eolian sand about 15 m overlying several meters of beach deposits below sea level. Thaw lakes form in upper part	Sedges, low shrubs, forbs.	Variable thickness of permafrost; polygons and ice wedges common in more westerly portions, active layer > 0.5 m in July.	Prominent organic bed may impede drainage; local permafrost impedes drainage. Possible source of water at depth. Areas closest to inlet are fully thawed, gullies common on bluffs	Surface is above elevated sea levels due to surges, but margins of bluff are subject to erosion from storms	Low to moderate	Bearing strength good when frozen, poor after thaw	Excavation easy when thawed; requires heavy equipment for frozen excavation. Uneven surface requires stabilization
Qitl Inorganic thermokarst -lake sediments and windblown silt	Fine silt to clay, massive to thinly bedded. Organic concentration varies with genesis of deposit. Lacustrine deposits developed in former eolian deposits (loess or dune)	Forms higher bluffs adjacent to small creeks; represents uneroded portion of older surface (>15,000 yr B.P.). Several tens of meters to 100 m thick	Sedges, low shrubs	Active layer less than 1 m, permafrost permeates this unit. Thick ice wedges and polygons may be developed in upper portions	Poorly drained. Potential for wells at depth uncertain	Most areas are above surge and flooding limits; susceptible to erosion of lower slopes, collapse of marginal areas	Silt: high Sand: moderate to low Presence of high percentages of water presents considerable possibility frost action	Bearing strength may be locally good if silt frozen or compacted. Problems arise from melt associated with increasing active layer	Excavation requires considerable machine power; presence of ice masses create problem areas. Uneven surface topography necessitates modification. Protective layer required
Qotlb Organic-rich thermokarst-lake deposits overlying Qob	Fine silt to clay, thinly bedded with at least 20 percent organics. Deposited from suspension within lakes, subject to reworking at bottom. Organic beds alternate with inorganic sediments	Extends across the surface of most of Qob; forms distinct basins due to thermokarst expansion of lakes. Several meters thick	Sedges, mosses, hydrophilic plants, low shrubs	Polygonal ice in places. Ice underlying this unit is relatively shallow, less than 2 m deep along bluff margin	Generally poorly drained, runoff restricted by development of ice wedges, peat mounds, permafrost at depth. Low potential for water and wells	No threat from storm surge	Silt: moderate to intense Sand: less susceptible	Bearing strength may be locally good if silt frozen or compacted. Problems arise from melt associated with increasing active layer	Excavation requires considerable machine power. Uneven surface topography necessitates modification. Protective layer required
Qdl Deposits of recently drained thaw lakes	Fine silt to clay, thinly bedded with at least 20 percent organics. Deposited from suspension within lakes; subject to reworking at bottom. Organic beds alternate with inorganic sediments	Occupies some lowland areas; recently drained lakes are inset into older thaw-lake sediments. Thickness several meters; underlain by greater thickness of older thaw lakes	Sedges, mosses, hydrophilic plants, low shrubs	Permafrost is rapidly aggrading in this setting, with rapid development of ice wedges and ice-cored mounds	Slightly better than in older lake deposits, drainage may proceed into channels that catastrophically drained this lake. As permafrost increases, drainage decreases. Not likely as water source.	No threat from storm surge; possible inundation during summer rains or from thaw of permafrost	Moderate to intense. Freshly drained lake surfaces in the process of freezing and wedge formation due to high moisture content	Bearing strength low due to considerable thickness of active layer under silty drained lake basins. Slopes especially unstable in areas of ice wedge collapse-thaw	Hazardous for excavations; inadvisable site for any long-term construction due to the rapidity of formation of permafrost features, debris slides, collapses

Continued on page 12

Table 2. *Description and engineering properties of geologic units shown on sheet 1—Continued*

Geologic unit	Lithology	Distribution and thickness	Vegetation	Permafrost	Drainage and suitability as water source	Susceptibility to floods	Susceptibility to frost action	Bearing strength and slope stability	Construction considerations
Qotl Older organic-rich thermokarst-lake deposits	Fine silt to clay with some sand likely; thinly bedded with at least 20 percent organics. Deposited from suspension within lakes and subject to reworking at bottom. Organic beds alternate with inorganic sediments	Extends over most of the lowland areas, but not adjacent to large creeks. Several tens of meters thick	Sedges, mosses, hydrophilic plants, low shrubs	Present underlying this unit is relatively shallow, less than 50 cm	Generally poorly drained, runoff restricted by development of ice wedges, peat mounds, permafrost at depth. Low potential for water and wells	No threat from storm surge; possible temporary inundation during summer rain or thaw of permafrost	Silt: moderate to intense Sand: less susceptible	Bearing strength marginal due to presence of thick organic deposits on surface. Slopes subject to collapse on thawing	Standing water and organic deposits mitigate against use in construction
Qc Colluvium	Silt and very fine to fine sand. Generally crudely bedded and reworked	Several meters thick atop bedrock on lower slopes of Ear Mountain. Adjacent to narrow drainages and intermittent channels	Sedges, low shrubs, forbs	Frost-heaved mounds, gelifluction lobes, stone stripes indicate action of permafrost at shallow depth	Poorly drained in permafrost, surface drainage seasonal. Limited possible water sources	[Not applicable]	Silt: high	Bearing strength good when frozen and level; subject to landsliding and sloughing when thawed and poorly drained	Poor for road foundations and subject to frost heaving. Considerable subsidence expected during excavation or inadvertent thaw during construction
pCl Precambrian limestone	Surface is rubbly with silty loam intermixed. Thinly bedded limestone and rhythmically interbedded dolomitic limestone. Locally intruded by dikes of rhyolite, rhyolitic porphyry, granite, or diabase	Forms middle and upper slopes of Ear Mountain at elevations of 300 to 600 m ASL. Slopes vary from level to 75 percent. Thickness assumed to be several hundred meters	Sedges, low shrubs, forbs, lichen	Permafrost at depths greater than 1 m. Gelifluction lobes, stone stripes, and other cryogenic features indicate operation permafrost at depth	Adequate engineering properties on level areas of rubble fields, if properly engineered. Water unlikely at depth, given presence of permafrost	[Not applicable]	Moderate to high	Bearing strength high, but may settle if active layer increases. Use of pile construction to maintain permafrost	Difficult excavation during frozen conditions due to presence of large clasts; also difficult in unfrozen conditions. Good for foundations and roads if frozen

ANTHROPOLOGICAL AND ECONOMIC CONSIDERATIONS IN RELOCATING SHISHMAREF

SUBSISTENCE PATTERN AND INDUSTRIAL BASE

The consumption of subsistence foods, especially ringed seal and salmon, is an important part of the economy of Shishmaref (Sobelman, 1985). The island location gives residents the requisite proximity to sea mammals. Subsistence also requires gas-and-oil resources and motorized vessels. Boats must have access to water and protection from storms. At present, Shishmaref boats are rendered high and dry daily during part of the tidal cycle. Shishmaref generates power from oil-fired generators; the oil is delivered by barge. In addition, many materials are delivered by barge, although many perishables are transported by air.

SANITARY AND HEALTH PROBLEMS

The need for sufficient water for drinking, laundry, and hygiene is considerable, although no recent studies of water consumption are available for Shishmaref. The Public Health Service installed a 1.3-million-gal (4.9-million-L) reservoir in the early 1980s, at a cost of $2.9 million (Farmwald and Crum, 1986). Using a recommended (Martini 1995, p. 1033) water-consumption figure of 38.4 oz/day (1.2 L/day), Shishmaref residents (about 500) require 54,750 gal/yr (207,000 L/yr); this excludes laundry, sanitary, and emergency (fire) needs. Assuming even a minimal 5 gal/week (19 L/week) per person for hygienic requirements (130,000 gal/yr or 492,000 L/yr total), water consumption in Shishmaref may easily approach 150,000-200,000 gal/yr (570,000-760,000 L/yr). Water needs (including emergencies) are probably several times higher. In its first year (1984-85) of operation, about 1 million gal (3.8 million L) water was used at the laundromat for laundry and showers, or roughly one-third of the total water (snow) that is annually impounded by snow fences installed by the Public Health Service (Farmwald and Crum, 1986).

The increased population of Shishmaref presently requires residents to obtain water from off the island (James J.K. Simon, University of Alaska Department of Anthropology, oral commun., 1995). Summer water collection requires a substantial trip up the Serpentine River, a task that can be accommodated during the course of other subsistence activities. During winter, water is obtained from pack ice or by collecting and melting snow. Water-collection sources on the island are limited; coring in the 1970s revealed only saline water at depth (Farmwald and Crum, 1986). The present source is a holding pond excavated into the dunes northeast of the old airport. This water is used solely for laundry; heavy chlorination renders it unpalatable for some residents. In addition, the water-collection reservoir constructed by the Public Health Service removes part of the island from habitation. Water is collected by using a 1,200-ft-long (370 m) 8-ft-high (2.4 m) snow fence. The reservoir-collection area and the fence extend over a watershed area of 13 acres (5.3 ha). Although the collection watershed, as mapped by Farmwald and Crum (1986, fig. 2) occupies less than 25 percent of the northeastern part of the island, many residents cautiously believe that the entire part of the island east of the airport must be avoided. Further hydrological studies may show that some land could be opened for construction. Water from another source could transform settlement dynamics on the island by making more land available.

BUILDINGS AND STRUCTURES

A year after the major storm of 1973 (State of Alaska, 1974b), the City of Shishmaref inventoried the structures in town. Of the 134 structures standing at that time, more than half were nonresidential. Nearly all structures in 1974 were wood frame. Storage sheds and warehouses comprised nearly 42 percent of the structures, whereas residences accounted for only 45 percent of the total. Of the residences standing in 1974, about half were over 15 yr old at that time. A building boom occurred during the early 1970s. Much of the housing standing in 1974 is still in use today, but is now more than 30 yr old; nearly all of the older housing stock survived the storm surges of the 1970s.

ALTERNATIVES

Three different strategies might be used to maintain the subsistence economy of Shishmaref residents and relieve the community of major storm-erosion problems: (a) living with the island; (b) relocating (in a generation) to another island; or (c) moving to one of three mainland sites.

OPTION 1: LIVING WITH THE 'MOBILE' SARICHEF ISLAND

Living with—and accepting—the future transformation of the island may be difficult. Options for living with the island were discussed by DOWL Engineers more than 20 yr ago. One option included partial relocation of shorefront property onto higher, more landward parts of the island (DOWL Engineers, 1978, p. 10, 28). Other proposals were to add artificial fill to the low-lying areas south of the dunes to increase elevation to about surge level. Revegetation and dune stabilization were also suggested by DOWL Engineers (1978, p. 4), but not implemented by residents. The village remains tightly clustered on a small fraction of the island.

If residents elect to stay on Sarichef Island, the first priority should be to set back the most landward and exposed houses from the actively eroding dunes. This would involve moving 5 to 10 structures to another part of the island. Residents should develop a contingency plan for relocating each threatened residence as the eroding bank encroaches. Alternatively, it may be practicable to lift houses onto supports about 3 ft (1 m) above dune level, adding a cushion of safety.

Usable space is extremely limited on the island. However, the usable land area could be increased by 50 percent if the water-collection facilities on the northern part of the island are replaced. Use of desalination equipment would probably be cheaper than moving the entire town.

Beach nourishment and dune building are expensive alternatives that might buy some additional time in maintaining the present configuration of Sarichef Island. Adding sand to the seaward shore of the island would provide a buffer and simulate non-stormy conditions that build the beach. Beach nourishment requires constant attention and annual monitoring (Pilkey, 1988, 1995). On the positive side it would provide jobs. A rigorous program of grass planting and pedestrian avoidance might produce a comparatively high dune over the period of a generation. However, this program would require discipline from all residents.

Engineers should be consulted to determine if the existing revetment is doing more harm than good (Kraus, 1988; Pilkey and Wright, 1988). It may be causing erosion on unprotected parts of the island because of the edge-around effect.

OPTION 2: MOVING TO ANOTHER BARRIER ISLAND

To some residents, moving to another barrier island may seem risky, but it does offer several advantages. That the location of Shishmaref is related to subsistence pursuits is obvious. However, these pursuits may be transferable to another island. Given the assumed erosion rate of 3 ft (1 m) per yr, the present configuration of Sarichef Island may be livable for 20 yr, providing that storm frequencies remain similar to present levels. If so, this may buy residents some time in making a decision. Keeping in mind that the other islands of the Shishmaref barriers are also moving landward, it may be possible to relocate to another island in a generation. Several islands about 30 mi (50 km) north have high dunes on the seaward side. Residents could also select an island and foster a suitable topography by beginning a concerted effort of dune building now. This could be accomplished by emplacing a network of fences and by planting and stabilizing grasses.

OPTION 3: RELOCATING TO THE MAINLAND

Proponents of this solution should consider what defines the community of Shishmaref and how far it can be moved from the sea before these values are irretrievably lost. The experience of King Islanders who moved to Nome may be useful in guiding these relocation efforts (Deanna Kingston, University of Alaska Department of Anthropology, oral commun., 1995). No one has estimated the cost of moving Shishmaref since a $4.7 to $8.1 million estimate in the 1970s (DOWL Engineers, 1975). The costs, in the 1990s, would probably exceed the $35 million to $50 million estimated for moving Kivalina (DOWL Engineers, 1994), considering the 25 percent higher population and the requirements for gravel, a 20-mi-long (32-km) road, and road maintenance.

In addition to Five Mile bluff, Tin Creek, and Ear Mountain, two sites are considered here that are outside the map area of sheet 1. These are Serpentine River delta and Singeak (fig. 1).

FIVE MILE BLUFF (NUNATAK)

This location (fig. 1) is attractive to some residents and has been considered as an alternative village site since 1973 (State of Alaska 1974b; DOWL Engineers, 1975). Erosion is a problem on the better-drained eastern part of the high bluff. Photointerpretative studies should be used to quantify the anecdotal accounts of several tens of meters of erosion in the last 20 yr. In addition, the development of thaw lakes atop this sandy features implies that permafrost may be present at shallow depth. Detailed soils and engineering studies are recommended to determine feasibility of the site. The area would require substantial gravel for foundations and for a new airport. Gravel would doubtless have to be secured from Ear Mountain, which would require construction of an extensive road. Boating to the site now depends on the tide; dredging would be required to facilitate both the use of skiffs and barge deliveries.

TIN CREEK

The Tin Creek locality offers very little. First, usable space is limited atop the low terraces above the creek. Second, the surface is likely underlain by a considerable thickness of ice-rich permafrost; the surface is irregular and would probably require a bed of gravel for insulation prior to construction. A further complication arises from the limited depth of Tin Creek; dredging would be required to improve navigability, and the approach to the creek would require modification and continual dredging.

EAR MOUNTAIN

The Ear Mountain site, more than 20 mi (32 km) from the coast, is certainly beyond the reach of storms. The rubbly surface offers some promise for foundations and building sites. Level space is limited on the north slope and space may be insufficient for both a town and an airport. However, the site's greatest disadvantage is the total reorientation that residents would face. The largest risk is that some people would still wish to retain houses at the old town site, which would create two villages in place of one, further multiplying current logistical problems.

SERPENTINE RIVER DELTA

Many residents maintain seasonal fish camps along the banks of the Serpentine River delta (Sobelman, 1985). Many of these cabins are probably on low-lying river banks. Flooding, both from upriver and storm surge, could be a hazard but probably would not be as severe or as frequent as on Sarichef Island. However, water in the adjacent inlet is very shallow. Most residents are familiar with the region but it could prove divisive to isolate a townsite because of existing Native allotments on the best parcels.

SINGEAK

The Singeak location is at the farthest north extent of Cowpack Lagoon and lies within the Bering Land Bridge National Preserve. Singeak supported a small community during the 19th century (Ray, 1964; Schaaf, 1988); this precedent lends it credibility as a possible relocation site. Singeak is less than 1.3 mi (2 km) from the major, stable inlet on the northern part of the barriers. On the basis of a 1986 archaeological survey, the late prehistoric site consists of six house depressions on a low dune (<6 ft or 2 m above sea level) below the mainland bluff. Cabins from the 1920s are situated atop the low bluff (Schaaf, 1988).

Singeak's mainland location offers security from storm surges. The site also offers access to a wide range of resources; this may account for its previous use and for the community interest in the site today.

The Singeak locale is probably underlain by ice-rich tephraceous sand and silt (Charron, 1995) and would require substantial modification. In addition, the lagoon is shallow and would require dredging to improve navigation. The Singeak location is far from sources of gravel required for a village foundation. Relocation to Singeak would also force a reorientation in subsistence pursuits because some residents may be less knowledgeable about this part of the peninsula (Sobelman, 1985). Travel time to familiar and well-used areas such as the Serpentine River would also be complicated, especially during the critical summer months, when the shallow Cowpack lagoon may not be navigable.

SUMMARY AND RECOMMENDATIONS

Storm erosion and flooding during the past 20 yr along the Chukchi Sea coast has raised concerns among residents of Shishmaref and Kivalina for the future of their communities. Residents witness their islands visibly constricting. Long-term erosion rates are not well documented, although each storm may produce several meters of bluff collapse. However, scientists have no firm idea of the rapidity of sea-level rise in the Chukchi Sea or the long-term frequency of large storms.

Shishmaref is at the crossroads between continuing as a barrier-island community and relocating to the mainland. Geological information alone will not provide a path; a solid consensus among the residents will be necessary. In considering alternatives, residents might reflect on the time scales operating on the barrier-island system. The short-term (10- to 20-yr) perspective might allow island life to continue with accommodations. In the long term (50- to 100-yr) perspective, the present configuration of the island will change beyond recognition. If catastrophist theories of global change are correct, a worldwide sea level rise of 3 ft (1 m) may occur within 100 yr (Gornitz, 1992; Wigley and Raper, 1992). Anticipating this possible sea-level rise, the entire barrier-island chain might be extinguished or transformed beyond habitation during the 21st century. Residents should reflect on which time scale has greater importance: the safety of retreating from the long-term threat of the sea or the needs of the present generations. In facing the possible threat of greenhouse warming and sea-level rise, the residents of Shishmaref are not alone; a large proportion of the earth's residents live along threatened shores.

In the meantime, engineering solutions exist that could stave off the immediate threat. Building remediation using high pilings, beach nourishment, and dune building are untested but promising possibilities for the arctic. In the long run (over several generations), retreat probably would prove to be the best engineering solution but not necessarily the best cultural solution. Given the present fiscal climate, the state of Alaska or the Federal government may not be able to provide the funds to move 500 people several miles at a cost that may exceed $100 million. Before making a decision, residents of Shishmaref should view the geological information presented in this report through the prism of their cultural priorities.

COMMUNITY SURVEYS AND STUDIES

Community-based studies would assist in the decision-making process by isolating economic problems with the various alternatives. A combination of anthropological, economic, and sociological perspectives may be useful. Anthropological studies could reveal household consumption patterns, community values, and other social factors. Economic studies could isolate the costs and benefits associated with various alternatives.

A series of public meetings could focus the will of the community and resolve any lingering doubts about moving or remaining on the island. Any mandate for change should be unequivocal to avoid the possibility of creating two communities, one on the mainland and one that remains on the barrier island, still saddled with the threat from storms.

WATER CONSUMPTION AND WATER RESOURCES

Use of the northern part of Sarichef Island for water storage and collection is one of the largest obstacles to maximizing and successfully living on the island. Water may prove a similar problem at any mainland site. Recommended surveys include water consumption of residents, sources of water, and potential desalination of sea water. Desalination could prove more cost beneficial than obtaining water from mainland sources.

GEOTECHNICAL STUDIES

Any site chosen for relocation will require considerable investigation to determine its engineering properties. A detailed program of coring will establish sediment characteristics such as ice content and grain-size variation with depth. With basic data, engineers will be able to assess the ability of the ground to serve as a community site and recommend specific building designs. Private contractors are available to conduct this research; a consortium of geologists and engineers is recommended.

Coastal engineers should be consulted to determine the dredging requirements for maintaining barge transport to any of the mainland sites. Dredging will be a long-term responsibility and should be factored into any cost study. The community should consult with the U.S. Army Corps of Engineers and other recognized experts in coastal processes to obtain qualified dredging consultants.

Geotechnical studies on Sarichef Island could also prove beneficial in the decision-making process. Coastal consultants could establish the feasibility of removing the failed revetment and instituting geomorphic management techniques such as beach nourishment or artificial dune growth.

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