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# ENGINEERING GEOLOGY BEARING ON HARBOR SITE SELECTION ALONG THE NORTHWEST COAST OF ALASKA FROM NOME TO POINT BARROW*

By

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# ENGINEERING GEOLOGY BEARING ON HARBOR SITE SELECTION ALONG THE NORTHWEST COAST OF ALASKA FROM NOME TO POINT BARROW

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## ABSTRACT

This report describes geologic and oceanographic factors relevant to the selection of a site in northwestern Alaska, at which an experimental harbor can be created by the explosion of a nuclear device. Part I describes the results of a preliminary survey of the entire coastal and offshore region between Nome and Point Barrow: Part II consists of a more detailed evaluation of the Cape Thompson-Cape Seppings area; and Part III is a theoretical consideration of the effect of the ocean upon the temperature and distribution of permafrost. The report is based entirely upon the study of published and unpublished reports, field notes, and maps, interviews with the few geologists who have visited the region, and the interpretation of aerial photographs. Field investigations, recommended in this report, were begun during the summer of 1958 in the Cape Thompson-Cape Seppings area; the results will be presented in another report.

The northwest coast of Alaska is remote and thinly populated. The climate is characterized by long, cold winters; short, cool summers; and light but frequent precipitation. Sea ice closes the coast to navigation during periods ranging from 7 months per year at Nome to 10 or 11 months per year at Point Barrow. The almost universal presence of permafrost and the general intensity of seasonal frost action pose serious engineering problems.

Mountainous land areas, hilly uplands, plateaus, and lowlands of diversified geologic structure adjoin different parts of the northwest coast.

For the purposes of this report, different segments of the coast are assigned to one of the following broad engineering-geology units: (1) hard, dense, crystalline rock underlying mountainous areas; (2) soft, friable, less resistant sedimentary rock underlying hilly areas; (3) hard, crystalline rocks covered by 10 to 150 feet of frozen silt, sand, and gravel underlying lowland areas; (4) soft sedimentary rocks covered by 10 to 150 feet of frozen silt, sand, and gravel underlying lowland and plateau areas; (5) frozen silt, sand, and gravel more than 150 feet thick underlying lowland areas; (6) frozen volcanic pumice more than 150 feet thick underlying low hills; and (7) frozen silt, sand, and gravel of unknown thickness interstratified with basaltic lava flows and underlying low hills. The terrain of units (1) and (2), though generally rugged, includes a few low areas near the coast in which a harbor having steep, stable subaqueous slopes can be built and in which satisfactory sites for land installations are abundant. The remaining units offer much less favorable conditions for the construction of an artificial harbor and associated facilities.

An approach channel will be required to connect an artificial harbor with deep water off shore. Most of the coast of northwest Alaska is adjoined by very shallow water; deep water close inshore is most likely to be found in areas adjoining steep bedrock cliffs. Sediment is transported to the shore and along the shore by waves, currents, and sea ice at unknown rates and in unknown volumes and directions. An accurate estimate of the amounts, rates, and volumes of sediment transport will be required in order to estimate the amount of annual dredging that will be required to keep an approach channel open.

The Cape Thompson-Cape Seppings area, tentatively selected as the general area in which to create the artificial harbor, contains three sites that merit further consideration. Site 1 in the valley of Ogotoruk Creek and

Site 2 in the valley of Kisimulowk Creek offer opportunities to create a relatively steep-sided conical crater in bedrock; good foundation conditions for shore installations are widely distributed in both sites. Site 3, near Cape Seppings, offers an opportunity to create a wide, shallow crater, but field investigations may indicate that the subaqueous side slopes could not be stabilized at steep angles; good foundation conditions are less widely distributed but are by no means lacking. The character of the offshore topography and bottom deposits--as yet unknown--probably will prove to be the ruling factor governing a choice among the three potential sites in the Cape Thompson-Cape Seppings area.

In high latitudes the mean temperature of near-shore bottom sediments is appreciably greater than that of the adjacent land surface, and as a consequence, permafrost thins rapidly or disappears as the shoreline is approached. The configuration of the bottom of permafrost near a shoreline can be estimated by theoretical means from climatic and oceanographic data. In the Cape Thompson area of northwestern Alaska subfreezing bottom sediment temperatures are not expected farther from shore than about 100 feet although a considerable thickness of frozen material could occur beneath the shoreline and near it on the landward side.

## INTRODUCTION

The immense explosive energy concentrated in modern nuclear devices is capable of creating a crater that, properly situated, could be used as a deep-water harbor; it appears likely that an artificial harbor could be constructed at much less expense by this means than by means of conventional explosives and earth-moving equipment. The obvious potential value of cheaply constructed harbors for many undeveloped coastal regions and the equally obvious practical problems associated with constructing the harbor have led to a proposal that an experimental harbor be created as a part of Project Plowshare. Because of its remoteness from centers of population and its almost complete lack of natural harbors, the coast of northwestern Alaskan between Nome and Point Barrow was selected as an appropriate region in which to conduct the experiment.

The U. S. Geological Survey was asked to undertake on behalf of San Francisco Operations Office, U. S. Atomic Energy Commission, a study of the geologic and oceanographic factors relevant to the selection of a site for the experiment within the region between Nome and Point Barrow (pl.1). Later, the area between Cape Thompson and Cape Seppings was tentatively selected as the optimum site for the experiment, and we were asked to prepare a more detailed evaluation of this 20-mile strip of coast. Special interest was expressed regarding the probable presence or absence of permafrost in marine sediments beneath shallow water adjoining the coast. Finally, we were asked to outline a program of geologic and oceanographic field studies needed in the vicinity of the proposed site before and after the proposed harbor is created.

This report describes the results of the preliminary investigation of the entire coastal and offshore region between Nome and Point Barrow (Part I); the more detailed evaluation of the Cape Thompson-Cape Seppings area (Part II); and the results of a theoretical consideration of the effect of the ocean on the temperature and distribution of permafrost (Part III). The report is based entirely upon an examination of published reports and unpublished manuscripts, field notes, and maps in the files of the Geological Survey, interviews with the few geologists who have visited the region, and the geologic interpretation of aerial photographs.

Detailed field investigations are essential to confirm the tentative conclusions reached in this office study and to fill the many vital gaps in the presently available information. The field studies should include: (1) a detailed examination of the three possible sites in the Cape Thompson-Cape Seppings area; (2) studies of the mechanism, rate, and volume of sediment transport along beaches and streams in the Cape Thompson-Cape Seppings area; (3) temperature measurements in several carefully located drill holes in order to establish the normal geothermal regime; (4) a submarine geologic and topographic survey of the sea bottom shoreward from the 60-foot depth contour in the Cape Thompson-Cape Seppings area; and (5) a concurrent reconnaissance examination of other seemingly suitable coastal areas in order that an alternative site may be chosen in the event that the Cape Thompson-Cape Seppings area should prove unsuitable. The geologic and oceanographic investigations should be supplemented by exploration of the subsurface and submarine geology by means of shallow drill holes.

## PART I. GENERAL ENGINEERING AND MARINE GEOLOGY OF THE NORTHWEST COAST OF ALASKA FROM NOME TO POINT BARROW

by Troy L. Péwé

### Introduction

#### Preliminary statement

The northwest coast of Alaska is relatively unknown geologically. Nevertheless some information of varying quality and dependability is available from a variety of published and unpublished sources. The area considered comprises a strip of land about 1,600 miles long, which lies in several different physiographic divisions of the Territory (pl. 1). The far northern part lies in the Arctic Slope region, the center part in the Brooks Range region, and the southern part in what might be termed the Interior region. Most of the southern part is in a province, the Seward Peninsula, which contains its own prominent physiographic subdivisions.

The linear area under consideration includes coastal plains, rolling mountain topography, prominent cliffed headlands, broad delta areas, and prominent spits and bars.

## Climate

The climate of northwestern Alaska is characterized by long cold winters, short cool summers, and light precipitation. North of Kotzebue the region is exposed to the cold air from the ice and cold water of the Arctic Ocean and has a distinctively polar climate. This results in climate domination by the Arctic anti-cyclone, except when a low pressure area penetrates the region, usually during the summer season. The Seward Peninsula has somewhat less severe winter temperatures. The mean annual temperatures at sea level range from 10°F. at Barrow to 26°F. at Nome.

Precipitation is light and 35 to 65 percent of the average annual precipitation falls as snow. The average annual precipitation ranges from 4 inches at Barrow to 18 inches at Nome. The ground is snow free about 3 months in the north and 4 months on Seward Peninsula.

The coast is windy with an average annual wind velocity at Barrow of 12 m.p.h., Kotzebue 13 m.p.h., and 10 m.p.h. at Nome. Winds of 100 m.p.h. have been recorded along the northwest coast. Prevailing winds are from the northeast except during summer periods when low pressure areas develop in northern Alaska causing winds from the south. The coast is generally cloudy, ranging from 35 percent cover in February to 95 percent cover in August and September.

The weather along the coast during the summer is generally bad and changeable. Much cloudy, foggy, and some rainy weather can be expected and the sea is frozen for the greater part of the year. In most years the ice breaks up at Nome by early June, but it may vary a few weeks either way. Farther north at Point Hope the waters are normally not navigable for ocean-going vessels before late June and at Point Barrow not before late July or early August. At Nome the sea normally freezes over in late October or November and at Point Barrow in September or early October. Even during the normally ice-free period at Point Barrow an onshore wind can bring the ice pack in to shore.

## Population

Several villages, one town, and a few military installations dot the coast from Nome to Barrow. Locations of population centers are noted on plate 2, and the populations are listed below:

| | |
|---|---|
| Barrow | 986 |
| Wainwright | 180 |
| Pt. Lay | 63 |
| Pt. Hope | 304 |
| Kivalena | 104 |
| Kotzebue | 606 |
| Noorvik | 246 |
| Kinalik | 10 (?) |
| Deering | 159 |
| Shishmaref | 166 |
| Wales | 135 |
| Teller Mission | 64 |
| Teller | 75 |
| Nome | 1600 |
| Solomon | 79 |

Distant Early Warning (DEW) line stations, other radar stations, and other military installations, including airstrips, are present along this 1,600-mile stretch of coast.

## Permafrost and frost action

Engineering structures in high latitudes are in many places deformed and sometimes destroyed by thawing of the underlying perennially frozen ground. The formation of a layer of frozen ground which does not completely thaw in summer is perhaps the most common result of the long cold winters and short summers in high latitudes. This perennially frozen ground, or permafrost, is more widespread and extends to greater depths in the far north than in the southern part of the permafrost region. The region underlain by permafrost can be divided arbitrarily into three generalized zones, the continuous, discontinuous, and sporadic permafrost zones. As shown in plate 3, the northwest coast of Alaska lies mostly in the continuous permafrost zone of the far north where permafrost is nearly everywhere present and may extend to depths of 1,000 feet or more. In this area the temperature of permafrost at a depth of 50 to 75 feet is less than -5°C. (50 to 75 feet is the maximum depth to which appreciable annual temperature fluctuations affect the ground.) Southward in the discontinuous permafrost zone the thickness of permafrost decreases, and nonfrozen areas are more and more abundant. Here the temperature of the permafrost at a depth of 50 to 75 feet may be between -0.5°C. and -5°C. In the sporadic permafrost zone to the south the perennially frozen ground is confined to local areas and the mean annual ground temperature is generally between -1°C. and 0°C.

Permafrost forms when more heat leaves the ground than enters, and a temperature below 0°C. is maintained continuously for several years. Inasmuch as permafrost is defined on the basis of temperature alone, any material, whether it is silt, sand, gravel, peat, refuse piles, or bedrock, as long as it has been below freezing continuously for a few years, is termed permafrost. Most permafrost is cemented by ice; permafrost with no ice or free water is termed "dry permafrost." Ground with saline or brackish soil moisture may be colder than 0°C. for several years, but would contain no ice and would not be firmly cemented; nevertheless such ground would be classified as permafrost.

The type, amount, and distribution of the ice content of permafrost is the most important feature of the perennially frozen ground. If the ice content of the ground is greater than the available pore space in the sediments there will be a subsidence of buildings, roads, airfields, and other engineering structures as the perennially frozen ground thaws. Heated buildings especially cause the permafrost to thaw. Most perennially frozen sand or gravel contains little ice, and structures built on these materials are not deformed; however, silt and clay generally contain much ground ice and form poor foundations for engineering structures.

Blasting operations in perennially frozen bedrock would perhaps be little different than in unfrozen rock because of small ice content; however, blasting in a considerable thickness of frozen (ice-cemented) silt, sand, and gravel would result in a different distribution of energy than if the material were not frozen. No quantitative data are available to evaluate this difference.

The seasonal freezing and thawing of ground and its effect on engineering structures is commonly termed frost action. This process is common in the northern United States, but in the far north the process becomes intense and is a serious problem in all poorly drained areas of fine-grained sediment. Ice grows in the ground upon freezing and forces up the ground surface, deforming and sometimes destroying engineering structures. In the spring and summer the ice melts, reducing the bearing strength of the ground and permitting roads, buildings, and air strips to settle or sink and be deformed.

A thorough study of the frozen ground should be part of the planning of any engineering project in the North. It is generally best to attempt to disturb the permafrost as little as possible in order to maintain a stable foundation for engineering structures.

## Geology

### Preliminary statement

The 1,600-mile strip of coast may be divided into broad geologic units. There are areas of hard crystalline rocks such as granite, limestone, or schist as well as areas of soft rocks such as sandstone and shale. Along most of the coast the rocks are blanketed by silt, sand, or gravel from 10 to more than 150 feet thick.

### Areal geology

(1) Unit 1 on plate 2 includes areas of hard, dense, highly resistant crystalline rock such as granite, limestone, schist, or gneiss locally with a veneer of silt, sand, or gravel as much as 10 feet thick. Such rocks occur in the vicinity of Cape Lisburne and Cape Thompson in the central part of the coastal strip, and also on the northern and southern coasts of Seward Peninsula. Rocks of this type produce prominent uplands that are several hundred feet above the water, although the uplands are breached by streams draining to the seas. The area delineated as unit 1 is well drained.

The hard rocks below the surface have a temperature lower than 0°C. but the ice content is extremely small, existing only in small cracks and joints in the rock. Frost action on the bedrock is absent and the bedrock areas form excellent foundations for engineering structures. These rocks would react to blasting as a relatively homogeneous unit.

(2) Soft, friable, less resistant sedimentary rocks such as sandstone, shale, and conglomerate comprise unit 2 (pl. 2); they occur in the Brooks Range physiographic region. At the surface they have no appreciable blanket of overlying unconsolidated silt, sand, and gravel, although as much as 10 feet of sediments may cover them locally. These rocks form less prominent mountain areas than the crystalline rocks. The area mapped as unit 2 is well drained, and the ice content is low in this type of bedrock. Frost action is mild. The sandstone and conglomerate constitute excellent foundation materials, and the shale moderately good foundation material.

(3) Areas of hard crystalline bedrock overlain with a blanket of frozen silt, sand, and gravel 10 to 150 feet thick are mapped as unit 3 (pl. 2). These areas flank the north side of Kotzebue Sound and also occur on the southwest coast of Seward Peninsula. In most of these areas the unconsolidated materials are sediments deposited by glaciers in the geologic past and consist of a rather heterogeneous cover of silt, sand, and gravel. In the vicinity of Kivalina the cover may be in large part wind-blown silt, much of which has been retransported by slope wash. In all places the cover of sediments is frozen and the fine-grained material (silt) contains considerable ground-ice. The areas are fairly well drained except for broad river valleys directly north of Kotzebue. Frost action is intense in the fine-grained sediments but moderate to mild in the coarser material. The gravel and sand areas are satisfactory for construction but areas with a blanket of frozen ice-rich silt provide many foundation problems in engineering construction.

A sharp discontinuity exists between the hard crystalline bedrock and the overlying unconsolidated sediments, and they would react quite differently to a blasting operation. A blast in the unconsolidated material probably would result in a wide shallow crater which would extend only down to bedrock.

Harbor walls consisting of frozen silt, sand and gravel would soon thaw, and the fine- to medium-grained material would slough into the water because of its very low angle of repose.

(4) Areas of soft, friable, less resistant sedimentary bedrock overlain with a blanket of frozen silt, sand, and gravel 10 to 150 feet thick are mapped as unit 4 (pl. 2). Except for a very small area in Kotzebue Sound and near Cape Seppings this unit is confined to the northern slope of Alaska. The unconsolidated material in the two small areas is comprised of wind-blown silt with some river deposits. In the north the sediments are mainly marine in origin and consist of lenses and layers of silt, sand, and gravel with some clay. In much of the northern areas the upper 1 to 30 feet is mostly silt with lenses and layers of peat. All of the sediments are frozen and the fine-grained material contains much ice. The upper 30 feet of the frozen ground contains many masses of relatively pure ice. These ice masses are 1 to 50 feet long and 1 to 30 feet wide; they lie within 1 to 5 feet of the ground surface, and generally produce polygonal soil and microrelief patterns on the ground surface.

In this northern slope region the overlying unconsolidated sediments should not react too differently to a blasting operation than the underlying soft sedimentary bedrock, although a discontinuity is present between the two types of material.

Near Cape Seppings and on the south side of Kotzebue Sound are low rolling hills, but north of Cape Beaufort a flat poorly drained coastal plain extends to Point Barrow. Frost action is intense in much of this area; this process, plus the existence of large masses of ice in the perennially frozen ground, give rise to many foundation construction problems. Harbor walls of fine-grained high ice-content sediment will slide and collapse upon thawing.

(5) Unit 5 (pl. 2) comprises frozen silt, sand, and gravel that is more than 150 feet thick. Depth to bedrock is unknown. This unit includes bars and spits of sand and gravel such as at Point Hope, Point Spencer, Kotzebue, and many offshore bars on the northwest coast of Seward Peninsula. Also in this unit is the broad delta of the Kobuk River and the glacial deposits that form most of the Baldwin Peninsula (Kotzebue is on the northern tip of the Baldwin Peninsula). The coastal plain of northwestern Seward Peninsula forms a large area of this map unit.

Between Cape Krusenstern and Kivalina is a thick deposit of unconsolidated material thought to be of glacial origin.

Most of unit 5 is poorly drained lowland with many lakes and streams. Frost action is intense in all of this area except the sandy and gravelly beaches, spits, and bars. Intense frost action plus the ice-rich permafrost pose serious engineering problems, including foundation problems and maintenance of harbor walls in frozen ice-rich sediments.

(6) Unit 6 (pl. 2) is an area on the north coast of Seward Peninsula that is composed of frozen pumice, a light, porous, coarse volcanic ash, more than 150 feet thick overlain locally by a veneer of silt as much as 10 feet thick. The volcanic material is well drained and has little or no ice content, and is relatively unconsolidated except for some cementation by ice. Except for some compaction upon loading, the pumice would provide satisfactory foundation conditions for engineering structures, but probably would not be entirely stable as harbor walls.

(7) Unit 7 (pl. 2), on the north coast of Seward Peninsula, is an area composed of frozen silt, sand, and gravel interstratified with hard basaltic lava flows. The low rolling hills are well drained except near the coast where

the hills give way to a poorly drained lowland. Frost action is intense in the fine-grained sediments but moderate to mild in the coarser material. The gravel, sand, and bedrock areas are satisfactory for construction but areas with a blanket of frozen ice-rich silt provide many foundation problems in engineering construction. This material would cause problems in blasting because of the great contrast of physical properties between layers of hard rocks and soft sediments.

## Offshore features

### Preliminary statement

A review of the offshore geologic processes and sediment distribution is necessary in any consideration of engineering geology problems concerned with harbor installation and maintenance. Features to consider are bottom sediments, submarine topography, and sediment transport. Such offshore phenomena are generally not as well known as the areal geology; therefore, in a relatively unknown area geologically, such as northwest Alaska, information about offshore features is scarce. Only a few oceanographic studies have been made in this part of Alaska.

### Bottom sediments

Very little information is available concerning the bottom sediments of the Bering Sea, the Chukchi Sea, and the Arctic Ocean. The United States Navy Electronics Laboratory collected widely spaced samples far offshore during oceanographic expeditions in the late 1940's; detailed Coast and Geodetic Survey harbor charts record the character of the bottom in shallow water in the vicinity of Nome and Point Barrow, in Port Clarence, and in scattered localities from

Point Lay to Point Barrow; and scientists associated with the Arctic Research Laboratory at Point Barrow have conducted additional studies of the bottom sediments near Point Barrow. Plate 3 shows the general distribution of sea bottom sediments inferred from these sources of information.

Little information is available near shore; however, at least some general conclusions can be drawn. The surficial sediments in Kotzebue Sound are fine-grained, -- consisting of mud in the inner part of the Sound and sandy mud toward the open Chukchi Sea. Port Clarence is reported to have a predominantly mud bottom. Areas of sand, areas of mud, and local areas in which boulders are scattered over the sea floor are reported in the offshore area near Nome. Muddy bottom predominates from Point Lay to Point Barrow.

Another method of obtaining information concerning the geology of near-shore bottom sediments is by inference from the onshore geology. For example, in the Kotzebue area glaciers moved down the Kobuk and Noatak valleys in the geologic past and deposited an arcuate glacial end moraine consisting of a jumble of silt, sand, and gravel. Part of this glacier pushed into the sea and therefore part of this end moraine may be assumed to lie beneath the muddy bottom of Kotzebue Sound. In general, in areas of mountains or highlands, short steep-gradient streams occur and coarse material is deposited in the sea. In areas of large sluggish streams, deltas of fine-grained to medium-grained sediments extend into the sea.

## Submarine topography

The offshore sea bottom configuration is of primary importance in installation and maintenance of harbor facilities. Deep sea shipping demands 40 to 50 feet of water. Only general information is available for most of the northwest coast of Alaska; however, more detailed soundings have been taken in the vicinity of Port Safety, Port Clarence, Point Barrow, Bering Strait, and along the coast from Kasegaluk Lagoon north to Barrow.

In general the northwest Alaska coast has shoal waters, and deep sea shipping entails coast lighterage everywhere in this area. Freight is lightered to shore in barges that draw less than 8 feet of water. Practically all of Kotzebue Sound is shallower than 60 feet and the 60-foot submarine contour is 10 to 50 miles from land nearly everywhere else (pl. 3). The 30-foot submarine contour is at least 5 miles from shore throughout most of the coast and only at a few places, such as near steep-cliffed bedrock areas, is it closer to the shore.

In general it can be stated that a harbor installation anywhere on the coast will require a dug channel at least 500 to 3000 yards long to provide 45 to 50 feet of water depth between deep water and the harbor. It will be necessary to map the submarine topography of the area near the projected harbor installation to learn the nature and magnitude of the channel cutting job as well as to learn the existence of natural channels along which sediment transportation is taking place.

## Sediment transportation

The sediments brought to the sea by rivers are subject to transport by ocean currents. Near-shore transport and deposition of such sediments are of great interest and importance to harbor installation and maintenance. The two main methods or directions of sediment transport that are of interest in this study are of long-shore drift, and transportation and deposition of sediments by waves and currents coming directly into the coast. Harbor installations in high latitudes also must consider sediment transport by ice push.

General directions of long-shore drift in northwest Alaska are indicated n plate 3. Sediments are carried along and deposited in slack water, building bars that enclose lagoons, protected bays, and spits. Deposits of sediments along the coast deflect many streams flowing into the sea. A study of stream deflection, spit formation, and direction of bar construction as revealed on aerial photographs and maps enables the geologist roughly to determine the direction of the long-shore drift. No field studies have yet been made of sediment transport by long-shore drift in this area, and the data presented in plate 3 are tentative. Only a few isolated studies of ocean currents in this area have been conducted (Bloom, 1956).

No critical quantitative data are available concerning amount of sediment carried and deposited; however, the large size of major bars and spits along the coast indicate that considerable material is thus transported. At Barrow, garbage thrown overboard from ships is quickly carried north along the coast to Point Barrow and farther north. A small eastward-trending artificial cut about 20 or 30 feet wide excavated between Elson Lagoon and the ocean (pl. 3) is annually closed by deposition of fine gravel and sand carried northward along the coast. Any natural or artificial opening or channel from the sea to a lagoon, harbor, or bay is subject to filling by sediment.

When the base of a wave strikes a shoal shore it stirs up the sediment and tends to carry it forward a short distance to build a ridge. When this ridge is finally built up to and above the water surface it forms an offshore bar, separated from the coast by a sheltered lagoon. Such offshore bars are widespread and well developed in northwest Alaska (pl. 3). Sediments are constantly being added to the bar, especially in times of storms. Little quantitative data are available but rapid shoaling can occur. A harbor 8 feet deep is maintained in the mouth of the Snake River at Nome by the Corps of Engineers (U.S. Army); all material consigned to Nome is transferred from ocean-going vessels standing offshore to barges and tugs capable of entering the harbor.

Constant dredging is required to maintain the 8-foot depth in the harbor; rapid shoaling during southerly storms temporarily reduces the depth from 8 to 5, or even 3 feet within a few days.

Sea ice is present many months of the year along the northwest coast of Alaska. The ice, which is blown onto the land during spring and summer breakup, pushes up sediment from the shallow sea bottom and adds it to the offshore bar or to the mainland coast. No quantitative data are available for this phenomenon, but it is felt that such sediment transport could be of such a magnitude as to be detrimental to harbor installations in northwest Alaska.

Any plans for a harbor installation should include careful study of near-shore sediment transportation and deposition. Information should be obtained in the field concerning the direction and amount of sediment transport; from this information calculations could be made to show how rapidly the opening from the harbor to the sea and the channel in the shoal water area would be filled.

## Summary and conclusions

The northwest coast of Alaska from Nome to Point Barrow consists of a 1,600 mile strip of land which includes a wide range of land forms ranging from mountains to plains and an equally wide range of rock types ranging from hard, crystalline rocks to ice-rich unconsolidated sediments. Seven broad engineering geology units have been delineated on plate 2, and the engineering geology characteristics of the rocks pertaining to: (1) creation of a harbor by nuclear detonation, and (2) establishment of engineering structures, have been considered.

Map unit 1 (hard, dense, highly resistant crystalline rock) and map unit 2 (soft, friable, less resistant sedimentary rock) are favorable for a Plowshare experiment because the rocks are close to the surface, would react relatively homogeneously to blasting, and the crater walls would be stable. Although sites suitable for construction from an engineering geological standpoint are abundant, there are relatively few areas in these map units where the coast is low enough to be considered as a site to create a harbor.

Unit 3 consists of frozen silt, sand, and gravel less than 150 feet thick overlying hard crystalline rocks. A blast crater in the unconsolidated sediments probably would be wide, shallow, and extend down only to bedrock. In many places the frozen sediments will thaw and not maintain steep harbor walls. Sites suitable for construction are only moderately abundant.

In rocks of map unit 4 (frozen silt, sand, and gravel overlying soft sedimentary rocks), a blast in the unconsolidated sediments that lie in the areas south of Kasegaluk Lagoon, would result in a wide shallow crater and extend down only to bedrock. North of Kasegaluk Lagoon, the soft sedimentary rocks and the overlying unconsolidated sediments may act as a unit. In many places the ice-rich sediments will thaw and not maintain steep walls in a harbor. Sites suitable for construction from an engineering geological standpoint are scarce in this map unit.

Frozen silt, sand, and gravel more than 150 feet thick comprise map unit 5; a blast excavation in this material would yield a crater whose walls in most localities would not be stable. Sites suitable for construction are relatively scarce.

In rocks of map unit 6 (frozen pumice more than 150 feet thick) a blast would probably form a fairly deep crater and the stability of the crater walls would be fair to good. Sites for construction would be moderately abundant.

In unit 7 (frozen silt, sand, and gravel interstratified with basaltic lava flows) the contrast of hard rock and soft sediments would cause the material to react to blasting as a non-homogeneous unit. The crater size and shape would be difficult to predict. The frozen fine-grained material will thaw and not maintain steep walls. Sites suitable for construction from an engineering geological standpoint are scarce.

From an engineering geological point of view map units 1, 2, 3, and 4 outline the areas in which the establishment of a harbor by nuclear detonation would be most favorable. Sites suitable for engineering construction are abundant in units 1 and 2, and scarce to moderately abundant in units 3 and 4.

# PART II. POSSIBLE HARBOR SITES IN THE CAPE THOMPSON-CAPE SEPPINGS AREA, ALASKA

by David M. Hopkins

## Introduction

The coast of Chukchi Sea between Cape Thompson and Cape Seppings, Alaska (pl. 1) has been tentatively selected as an area in which to attempt to create an artificial harbor by experimental methods. This report describes aspects of the geology bearing upon the feasibility of the experiment. Three sites within the Cape Thompson-Cape Seppings area (sites 1, 2, and 3 on pls. 4 and 5) merit continued consideration as possible sites for the experiment.

The Cape Thompson-Cape Seppings area is largely unexplored, geologically; only the area immediately adjoining Cape Thompson has been visited by geologists. This report is based chiefly upon a study of air photos and large-scale topographic maps, upon a manuscript report describing the bedrock geology of the area immediately adjoining Cape Thompson, and upon inferences drawn from reports describing nearby regions with similar geology (Collier, 1906; Sable and Chapman, 1956).

A photogeologic study such as the study described here can provide only a limited amount of information, and many fundamental questions having an important bearing upon the feasibility of the proposed experiment cannot be answered without additional ground studies at each of the three suggested sites. All three sites should be examined during the summer of 1958, and a final choice should be deferred until the ground studies have been substantially completed.

## Location and population

The Cape Thompson-Cape Seppings area comprises the south coast of the Lisburne Peninsula, a western projection of the northern Alaskan mainland into the Chukchi Sea (pl. 1). Cape Seppings, at Lat. 67°58'N. and Cape Thompson, at Lat. 68°09'N. lie more than 100 miles north of the Arctic Circle.

The Cape Thompson-Cape Seppings area contains no year-round habitations, and is relatively remote from centers of population. The village of Point Hope lies about 24 miles northwest of Cape Thompson, and the village of Kivalina is about 24 miles southeast of Cape Seppings. The town of Kotzebue, which serves as a commercial center for this part of Alaska, lies about 125 miles to the southeast. Facilities at Kotzebue include an airfield capable of accomodating DC-3 aircraft, several stores, and a small hotel. Light aircraft are available for charter at Kotzebue, and two companies there are engaged in lighterage service and coastwise marine transport.

## Land topography

The Cape Thompson-Cape Seppings area consists chiefly of an area of low ridges having summit altitudes ranging from 700 to 800 feet near Cape Thompson and from 200 to 300 feet near Cape Seppings. Rocky cliffs rise abruptly from the sea to altitudes of several hundred feet between Cape Thompson and Ogotoruk Creek (pl. 4). Southeastward from Ogotoruk Creek, the ridges terminate in an

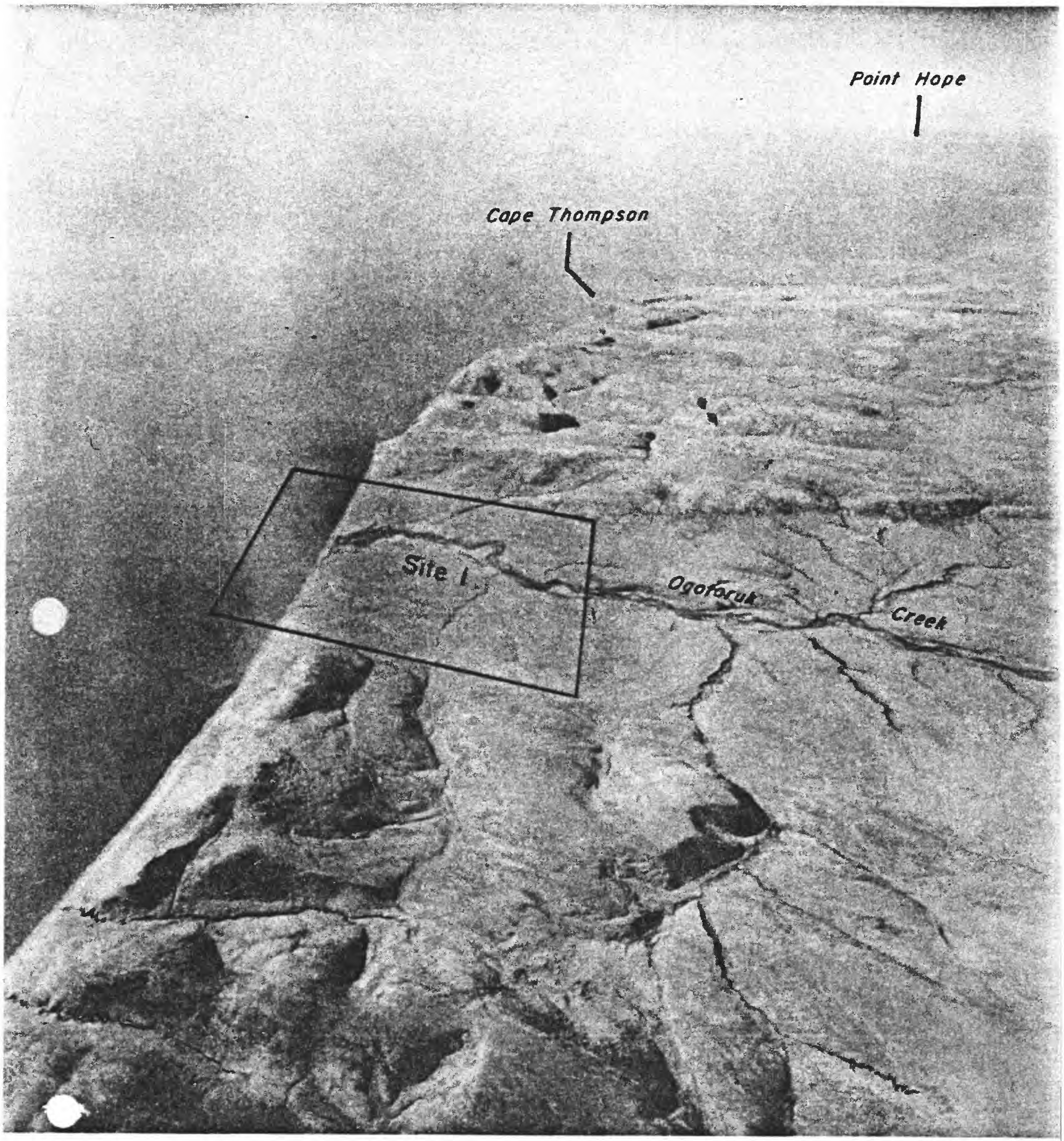


PLATE 4 - AERIAL VIEW WESTWARD TOWARD CAPE THOMPSON

ancient wave-cut cliff separated from the present strand line by a narrow coastal plain lying less than 100 feet above sea level. The coastal plain is merely a sloping shelf less than 0.2 mile wide between Ogotoruk Creek and Kisimulowk Creek. Southeastward from Kisimulowk Creek the coastal plain widens, reaching a maximum of about one mile at Cape Seppings (pl. 5).

The Cape Thompson-Cape Seppings area is drained by a series of short streams that head in a drainage divide only a few miles inland; areas farther north are drained by tributaries of the westward-flowing Kukpuk River, which enters the Chukchi Sea north of Point Hope. Ogotoruk Creek (11 miles long), Kisimulowk Creek (97 miles long) and the Singoalik River (20 miles long) are the largest streams in the area. The broad valleys of Ogotoruk Creek and Kisimulowk Creek constitute the only large areas of low-lying topography in the western half of the Cape Thompson-Cape Seppings area.

## Submarine topography

No reliable data are available to the author concerning the offshore topography in the Cape Thompson-Cape Seppings area. It appears that no detailed bathymetric surveys have ever been undertaken.

Coast and Geodetic Surveys Chart 9400 (scale 1:1,587,870 edition of 1947) shows 11 soundings within about 10 miles of the coast between Cape Thompson and Cape Seppings[1/]. These scanty data suggest that a shoal area less than 18 feet deep extends several miles south of Cape Thompson and eastward beyond the mouth of Ogotoruk Creek. The 50-foot depth contour may lie as much as 4 miles offshore throughout the Cape Thompson-Cape Seppings area.

[1/] The 18-, 30-, and 60-foot depth contours shown on the Noatak (1951) and Point Hope (1952) 1:250,000 quadrangle maps of the U. S. Geological Survey Alaska Reconnaissance Series are based upon these 11 soundings and consequently must be considered entirely unreliable.

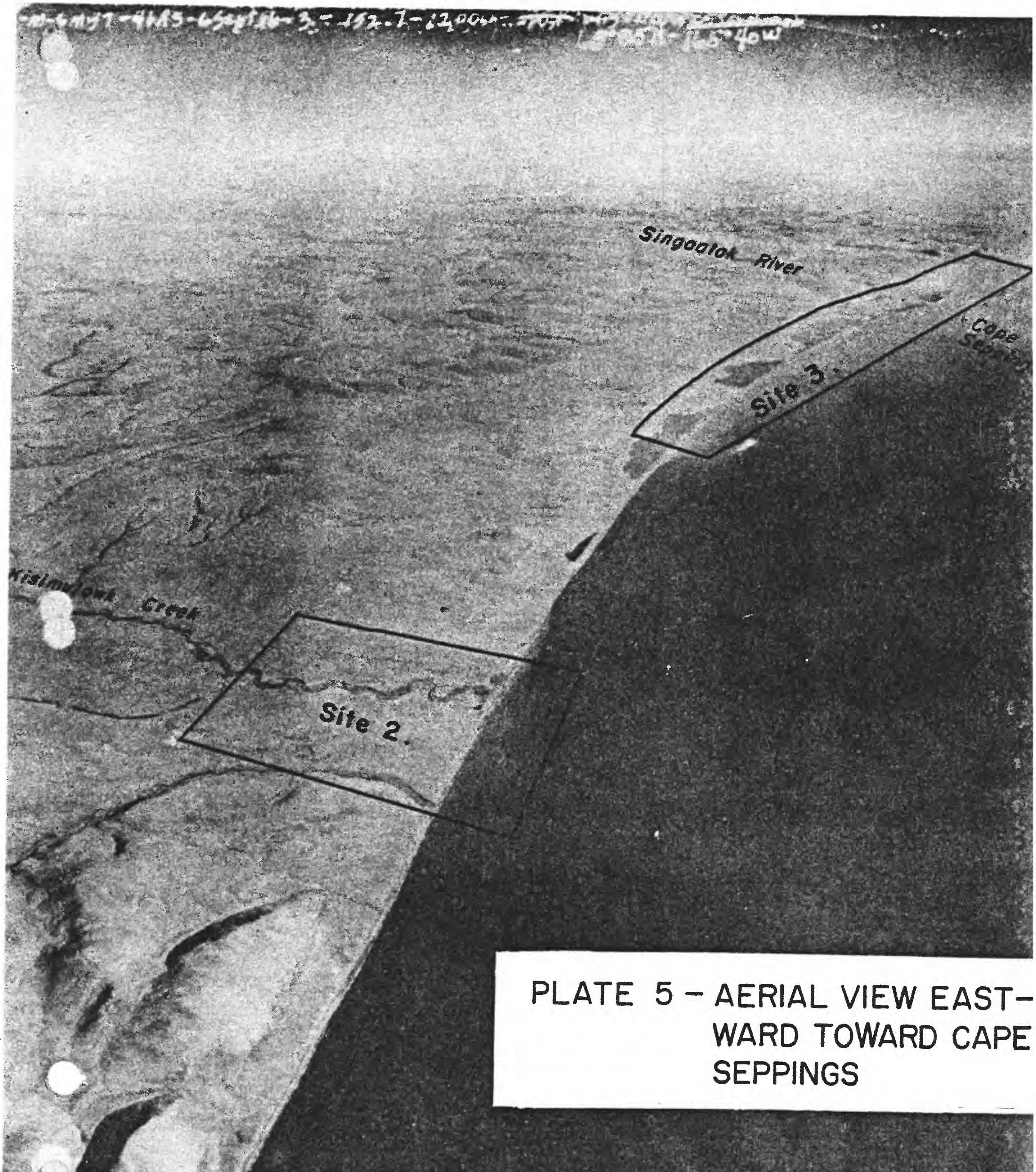


PLATE 5 - AERIAL VIEW EASTWARD TOWARD CAPE SEPPINGS

It is of vital importance to the proper planning of the proposed experiment to obtain detailed bottom topography out to the 50-foot depth contour between Cape Seppings and Cape Thompson during the summer of 1958. Distance to deep water may well prove to be the ruling factor governing the choice of any particular site for the proposed experiment.

## Bedrock geology

The Cape Thompson-Cape Seppings area is underlain by limestone, chert, sandstone, and shale ranging in age from Devonian to Cretaceous. Carbonate rocks and minor chert and shale predominate in the areas west of Ogotoruk Creek and east of Cape Seppings, and shale and silty sandstone predominate at the surface in the area between Ogotoruk Creek and Cape Seppings. Frozen silt, sand, and gravel ranging in thickness from a few feet to about 100 feet form a discontinuous mantle covering bedrock throughout more than half of the area.

### Stratigraphy

The oldest rocks exposed on the Lisburne Peninsula consist of thick-bedded sandstone with interbedded calcareous slate; the total thickness is unknown. These rocks are not exposed at the surface in the Cape Thompson-Cape Seppings area but they are probably present throughout the area at depths of several thousand feet.

Mississippian rocks about 2,500 feet thick are exposed in the ridges west of Ogotoruk Creek and probably in the ridges east of the Singoalik River (pl. 6); the Mississippian sequence probably is also present at a depth of several thousand feet throughout the intervening area. The Mississippian rocks consist chiefly of limestone and dolomite, but they include minor amounts of sandstone and shale near the base of the sequence and interbeds of black chert near the top.

The Mississippian rocks are overlain by a sequence several hundred feet thick of silty argillite and chert of probable Permian age, and these beds are overlain in turn by 100 or 200 feet of chert, limestone, and shale of Triassio age. The Permian(?) and Triassic rocks are exposed in the ridges west of Ogotoruk Creek and probably also in the hills east of the Singoalik River; they probably are present at depth throughout the intervening area.

The youngest consolidated rocks in the region consist of an enormous thickness of fine-grained sandstone, siltstone, shale, and possibly coal of probable Jurassic age and of Cretaceous age. Rocks of this type are at the surface in the area between Ogotoruk Creek and the Singoalik River. The Mississippian, Permian(?), and Triassic rocks comprising the hills west of Ogotoruk Creek have been thrust eastward over the younger rocks, which there are probably less than 1,000 feet below sea level. The Jurassic(?) and Cretaceous rocks have not been studied in the Cape Thompson-Cape Seppings area; similar rocks, however, attain a thickness exceeding 15,000 feet along the north coast of the Lisburne Peninsula (Sable and Chapman, 1956).

## Structure

The Cape Thompson-Cape Seppings area lies in a zone where two orogenic belts (major arcuate belts of folded and faulted rocks) converge. The limestone, shale, and chert of Mississippian, Permian(?), and Triassic age exposed in the ridges west of Ogotoruk Creek are part of an orogenic belt trending north-northwestward to Cape Lisburne; a continuation of this orogenic belt reappears above sea level far to the northwest on Wrangell Island, north of the coast of eastern Siberia. Older rocks in the Cape Thompson-Cape Lisburne-Wrangell Island orogenic belt have been thrust eastward and northward over younger rocks. The total displacement near Cape Thompson may be as little as one or two miles, but it may be as much as several tens of miles.

The rocks exposed east of the Singoalik River are part of an orogenic belt trending northeastward and comprising the Brooks Range of northern Alaska. No studies have been made of the structural geology in the vicinity of Cape Seppings, but elsewhere in the Brooks Range, older rocks have been thrust westward and northward over younger rocks.

The sandstone, siltstone, and shale of Jurassic (?) and Cretaceous age exposed between Ogotoruk Creek and the Singoalik River thus occupies a deep structural trough that has been tightly compressed between two zones of strong, deep-seated lateral movement. The bedrock in all three possible harbor sites is folded and probably faulted. Individual beds may be expected to dip at angles of 30° to 60°. The valleys of Ogotoruk Creek and of the Singoalik River may lie along zones where the Jurassic (?) and Cretaceous rocks have been intensely crushed and sheared as a consequence of the overriding by the older rocks. If crushing and shearing has taken place, it would modify considerably the response of the sandstone, siltstone, and shale to a large-scale explosion.

## Surficial character of bedrock

Solid, sound bedrock is rarely exposed at the surface in areas at the latitude of Cape Thompson and Cape Seppings. In areas that are not mantled by Pleistocene or Recent sediments, bedrock near the ground surface generally has been reduced to a mass of angular rock fragments in a matrix of sandy silt as a result of long-continued frost action. Brecciation by frost action generally extends to depths of at least 10 feet and may extend to depths of several tens of feet. A zone of frost-brecciated rock is also likely to be present in many places beneath the mantle of Pleistocene and Recent sediments.

Engineering and chemical characteristics of bedrock

The author has no information concerning the elasticity, porosity, or brittleness of the bedrock in the Cape Thompson-Cape Seppings areas; studies of the physical characteristics of these rocks should constitute an important part of the field investigations during the summer of 1958.

The sediments of Mississippian, Permian(?) and Triassic age consist largely of carbonates, but rocks composed mostly of silica and clay minerals (various aluminum silicates) are interstratified in zones ranging from a few feet to several hundred feet in thickness. The rocks of Jurassic(?) and Cretaceous age consist mostly of silica and clay minerals.

The rock within a few feet of the surface that has been shattered by frost action is subject to considerable frost heaving during annual cycles of freezing and thawing. Foundations for buildings in bedrock areas should be placed in sound bedrock below the surficial zone of frost-brecciated material. Some types of frost-brecciated bedrock may prove to be satisfactory sources of fill for roads or airfields.

The carbonate rocks underlying the ridges west of Ogotoruk Creek and east of the Singoalik River may contain appreciable ground-water supplies in porous, unfrozen zones. Ground water is not obtainable in the other bedrock types of the Cape Thompson-Cape Seppings area because of their original impermeability and because they are everywhere perennially frozen (the occurrence of ground water in permafrost areas in general is discussed in Hopkins, Karlstrom, and others, 1955).

The subaqueous angle of repose for unbroken limestone and sandstone probably ranges from 30° to 90°. Shale, a prominent constituent of the sediment of Jurassic(?) and Cretaceous age, is much less competent, and is likely to slump to angles of 10° to 30°. If the rocks underlying the valleys of Ogotoruk Creek and the Singoalik River are intensely crushed and sheared, they are likely to slump on subaqueous slopes to angles of about 10°.

## Description and engineering geology of surficial deposits

Sediments of Pleistocene and Recent age mantle bedrock throughout about half of the Cape Thompson-Cape Seppings area (pl. 6). In general, the Pleistocene and Recent sediments grow thinner and less extensive as one proceeds across the rolling ridges from Cape Seppings toward Cape Thompson. However, the narrow coastal plain extending from Cape Seppings to Ogotoruk Creek bears an almost continuous mantle of Pleistocene and Recent sediments from 50 to 100 feet thick.

### Colluvium and wind-blown silt

Wind-blown silt and colluvium (silt, sand, and gravel that have been moved down slopes by slow soil movements and by minor streams) constitute the most widely distributed sediments of Pleistocene and Recent age in the Cape Thompson-Cape Seppings area. The original source of the wind-blown silt lay in glaciated valleys several tens of miles to the east; easterly winds picked up silt on the broad, vegetation-free flood plains of glacial streams and deposited it over ridge tops, slopes, and valley bottoms in a westward-thinning blanket. Much of the silt that was deposited on the summits and upper slopes has subsequently been moved downslope and has become incorporated in the local colluvium. Because of the regional westward thinning of the wind-blown silt, the local colluvial deposits become richer in gravel and poorer in silt from east to west. The wind-blown silt and colluvium probably are less than 10 feet thick on upland surfaces and in the flatter areas of the valley bottoms. Thicknesses as great as 50 feet may exist in fan-shaped accumulations on the valley walls and along the base of the ancient sea cliff extending southeastward from Ogotoruk Creek.

The colluvium and wind-blown silt are perennially frozen throughout the Cape Thompson-Cape Seppings area; summer thawing penetrates only 1 to 3 feet. Clear ice comprises a large part of the colluvium and silt; locally it may constitute as much as 50 percent of the total volume. The colluvium and silt are thus subject to intense frost heaving and to appreciable subsidence and loss of strength upon thawing.

The colluvium and wind-blown silt are generally unsatisfactory for building sites and should be avoided or removed wherever possible. They do not constitute a satisfactory construction material except in a few places in the western part of the area where the mantle is believed to consist mostly of colluvium containing relatively little silt. They are not a potential source of ground water.

A stable subaqueous slope will be very difficult to establish in the colluvium and silt because of their small grain size and high ice content. Frozen colluvium and silt will thaw rapidly upon contact with standing or flowing water, and the material will slump to form slopes as low as 1° or 2°.

## Alluvial sand and gravel

Stratified sand and gravel largely free of silt underlies the flood plains of the larger streams in the Cape Thompson-Cape Seppings area. The alluvium consists chiefly of cobble gravel in the upper reaches of the streams and of sandy pebble gravel in the lower reaches near their mouths. The alluvium probably ranges in thickness from 10 feet beneath the smaller streams and beneath the headwater portions of the larger streams to nearly 100 feet beneath the larger streams near their mouths.

Alluvial sand and gravel a few tens of feet thick also probably underlies colluvium and wind-blown silt in terraces near the Ogotoruk Creek

(Section A-A', pl. 7) and alluvial fans along the base of the ancient wave-cut cliff extending southeastward from Ogotoruk Creek (Section D-D', pl. 7).

The alluvial sand and gravel probably is perennially frozen below depths of 10 or 20 feet, and at shallower depths in areas where it is covered by colluvium and silt. Seasonal frost may penetrate 5 to 10 feet into gravel and sand exposed in the creek bars. The alluvial sand and gravel is relatively non-susceptible to intense frost heaving and does not subside or lose strength upon thawing. Most of the areas of alluvial sand and gravel in the Cape Thompson-Cape Seppings area are subject to flooding during the spring snow melt and occasionally during the late summer rainy season.

Areas of alluvial sand and gravel contain easily obtainable fill material. They also offer the most stable foundation conditions to be found in the Cape Thompson-Cape Seppings area, but in all such areas streams must be diverted in order to prevent flooding. The surface flow of most streams diminishes sharply during winter, but the larger streams, such as Ogotoruk Creek, Kisimulowk Creek, and the Singoalik River can be expected to maintain an appreciable underflow in their alluvial sand and gravel beds; the alluvial sand and gravel associated with the larger streams offers the only dependable year-round water supply in the Cape Thompson-Cape Seppings area.

Alluvial sand and gravel will stand in relatively steep subaqueous slopes (probably $5^{\circ}$ to $10^{\circ}$), but areas of alluvial sand and gravel in the Cape Thompson-Cape Seppings area represent sites where sediment is being actively moved by streams. A crater intersecting one of the larger areas mapped on pl. 6 as alluvial sand and gravel is likely to be filled within one or two decades unless the stream is permanently diverted.

## Estuarine and deltaic sediments

Estuarine and deltaic sediments consist of sandy and peaty silt deposited by brackish water in the delta of the Singoalik River. Similar material underlies the small lagoons southeast of Kisimulowk Creek. The estuarine and deltaic sediments probably range in thickness from 10 to 20 feet beneath the lagoon and from 50 to 100 feet in the Singoalik delta.

The delta of the Singoalik River lies only a few feet above sea level, and about half of the surface consists of small lakes and distributary channels. The entire delta probably is occasionally flooded.

Permafrost is present at depths of 1 or 2 feet in the older part of the Singoalik delta and at depths of 10 or 20 feet beneath the younger part of the delta and beneath the lagoons. The ice content of the frozen sandy silt is moderately high, and considerable subsidence can be expected when the material is allowed to thaw. The sandy and peaty silt are subject to intense frost heaving wherever they are exposed to annual freezing and thawing.

The estuarine and deltaic sediments are unsatisfactory building sites because of poor drainage, intense frost susceptibility, and the low initial strength of the sediments. The sandy and peaty silt are not suitable for use as a construction material.

A year-round ground-water supply possibly could be developed in lenses of gravel within the delta of the Singoalik River.

The estuarine and deltaic sediments have a relatively low subaqueous angle of repose, probably on the order of $1^\circ$ to $5^\circ$ depending upon the initial ice content. The Singoalik delta is the site of active and rapid sedimentation. A crater intersecting the delta area probably would be filled with sediment within a few decades. Relatively little silting would be expected, however, on the site of one of the lagoons away from the delta.

## Beach sand and gravel

Well sorted sand and gravel, entirely free of silt, comprises the narrow beach that lines the coast throughout the Cape Thompson-Cape Seppings area. The beach sediments consist of pebble-cobble gravel near the rocky headlands at Cape Thompson, and elsewhere they consist of sand and pebble gravel. The beach sediments probably extend to depths of only 20 or 30 feet. Much driftwood is likely to be scattered over the surface.

Buried beach sediments may cover bedrock at the base of the ancient wave-cut cliff extending southeastward from Ogotoruk Creek.

Beach sediments in this latitude are perennially frozen at depths ranging from 10 to 20 feet, but the frozen beach sediments contain relatively little ice. Seasonal frost penetrates to depths of 5 or 10 feet. Extreme storm waves sweep the entire width of the beaches in the Cape Thompson-Cape Seppings area, and sea ice is occasionally thrust across the beaches during winter. Consequently, permanent structures cannot be maintained upon the beaches.

The beach sediments are an excellent source of sand and gravel for construction purposes.

Light aircraft can be landed upon the beaches in areas where driftwood is scarce, and areas can be cleared easily of driftwood to provide a landing strip. Tracked vehicles, and possibly wheeled vehicles can move freely along the beaches between streams. If the streams can be forded, the beaches afford a highway for travel along the entire coast of the Cape Thompson-Cape Seppings area.

The beaches are sites of active sediment transport. The material making up the beaches in derived from several sources: (1) material scoured by waves from the ocean bottom a short distance offshore; (2) material scraped from the bottom by partially grounded sea ice that is subsequently thrust ashore; (3) material eroded by waves from rocky headlands such as Cape Thompson and from the low bluffs of gravel, sand, and silt that line the beach southeastward from Cape Thompson; and (4) material carried to the beach from inland areas by the larger streams. Waves striking the coast obliquely transport material from all of these sources laterally along the coast. The net effect of the processes that move material from offshore to the beach and laterally along the beach is a tendency to mend rather rapidly any break, such as a stream mouth or an artificial entrance to a harbor, in the continuity of the beach.

A careful quantitative study of sediment transport to and along the beach is required to permit the selection of the optimum design and location of the proposed harbor entrance. Examination of aerial photographs suggests that the dominant longshore drift is southeastward in the Cape Thompson-Cape Seppings area. However, nothing is known concerning the quantity and rate at which material is being furnished to the beach and transported southeastward. The relative importance of the several sources of beach sediment is not known.

## Marine sand, silt, and gravel

Marine sediments of unknown character underlie the ocean bottom and probably are present at depth throughout much of the coastal plain southeast of Kisimulowk Creek. The marine sediments probably consist largely of gravelly sand near the present coast, and they probably grade seaward into sandy silt. The possible presence of permafrost in the marine sediments is discussed in Part III of this report.

Few inferences can be made concerning the physical character and thickness of the marine sediments. The sediments offshore should be carefully investigated by several methods, including drilling through the ice, during the summer and winter of 1958.

## Description of individual sites

Three places within the Cape Thompson-Cape Seppings area merit continued consideration as possible sites for the experimental creation of an artificial harbor: the lower valley of Ogotoruk Creek (site 1); the lowland adjoining Kisimulowk Creek (site 2); and the coastal plain extending several miles northwest and southeast of Cape Seppings (site 3). High bedrock ridges rising to altitudes of several hundred feet within less than a mile of the shore render the remainder of the Cape Thompson-Cape Seppings coast topographically unsuitable for the creation of an artificial harbor.

Marine and beach processes at all three sites will tend to close the approach channel and harbor entrance. Quantitative studies of marine and beach sedimentation are required at each site in order to plan proper design and control measures.

### Site 1.--Ogotoruk Creek

Site 1 consists of an area about 1 3/4 miles wide parallel to the coast and extending about 1 1/2 miles inland in the lower valley of Ogotoruk Creek. The site lies almost entirely below the 150 foot contour. Ogotoruk Creek, a large stream 14 miles long that transports considerable quantities of gravel, flows through the central part of the area. To the east and west lie gently undulating surfaces mantled by a thin, discontinuous blanket of frozen colluvium and silt, beneath which lies shale and sandstone of Jurassic(?) and Cretaceous age (section A-A', pl.7). Study of aerial photographs suggests the presence of a gravel terrace mantled by frozen silt and colluvium on the east bank of Ogotoruk Creek near its mouth.

The detailed character of the bedrock is unknown, but the low topography and the proximity to the thrust fault at the base of the hills to the east suggests that the bedrock is shale whose competence has been greatly reduced as a result of shearing and crushing.

Nothing is known of the offshore geology in the vicinity of site 1. Several scraps of evidence give rise to conflicting hypotheses that have an important bearing upon planning an approach to the proposed harbor; the conflict can be resolved only by investigations on the ground and on the sea bottom. The conflicting evidence is as follows: (1) structural features visible on aerial photographs in bedrock areas between Ogotoruk Creek and Kisimulowk Creek suggest that the coast in this area lies approximately upon the site of a large normal fault and that the land area has been uplifted relative to the sea in fairly recent geologic time; (2) the sparse soundings given on Coast and Geodetic Survey Chart 9400 (ed. of 1947) suggest that an extensive shoal area lies seaward of Cape Thompson, extending southeast as far as the mouth of Ogotoruk Creek; (3) the limestone and shale of Mississippian, Permian(?) and Triassic age that underlie the ridges west of Ogotoruk Creek include exceptionally competent rocks that trend generally southward into the shoal area.

If the coast in the vicinity of Ogotoruk Creek has been uplifted relative to the sea fairly recently, a submerged bedrock cliff buried beneath marine sand, silt, and gravel probably lies a few thousand feet offshore, and the shoal area probably consists of debris several hundred feet thick that has been eroded from the rocky headlands between Cape Thompson and Ogotoruk Creek and carried seaward by marine currents (see lower bedrock profile on section B-B', pl. 7). If no coastal fault is present, however, the shoal probably represents a submerged bedrock ridge composed largely of limestone and bearing a veneer of marine sediments only a few tens of feet thick (see upper bedrock profile on section B-B', pl. 7).

A crater of adequate depth at site 1 would lie entirely within shale and sandstone bedrock, but the competency of the bedrock may have been greatly reduced by crushing and shearing. Subaqueous angles of repose in this material may be as low as $10^{\circ}$. A large amount of bedrock may have to be removed in the creation of an approach channel through the shoal water offshore. Satisfactory building sites are abundantly available at and near site 1. Underflow in the alluvial sand and gravel beneath Ogotoruk Creek offers a dependable year-round water supply, but the creek itself poses a serious problem in the creation of a permanent harbor. Study of aerial photographs leaves little doubt that Ogotoruk Creek is carrying gravel in quantities and at rates that could fill the proposed harbor very quickly. The proposed harbor should either be placed away from the bed of the creek, or the creek should be permanently diverted around the harbor. The ridges adjoining site 1 should afford some protection from easterly and westerly winds to vessels anchored in an artificial harbor there.

Site 2.--Kisimulowk Creek

Site 2 consists of an area of low hills about 1 $\frac{1}{2}$ miles wide parallel to the beach and extending about 1 $\frac{1}{2}$ miles inland in the vicinity of Kisimulowk Creek. A hill west of Kisimulowk Creek has a summit altitude of 185 feet within the site, and two hills east of Kisimulowk Creek and within the site have summits enclosed respectively by the 150 and 200-foot contours.

Kisimulowk Creek, a stream about 7 miles long, flows in a narrow flood plain underlain by alluvial gravel and sand; smaller streams, 6 and 1 miles long respectively, follow the western and eastern margins of the site. The low hills within the site bear a thin, discontinuous mantle of frozen colluvium and silt, beneath which lies shale and sandstone of Jurassic(?) and Cretaceous age (section C-C', pl. 7). The detailed character of the bedrock is unknown, but the low topography suggests that shale predominates.

Almost nothing is known concerning the offshore geology in the vicinity of Kisimulowk Creek. The bedrock offshore probably consists of shale and sandstone of Jurassic(?) and Cretaceous age, and it probably is mantled by several tens of feet of marine sediments. If the coast between Kisimulowk Creek and Ogotoruk Creek is controlled by a large normal fault, a submerged and buried cliff may lie a few thousand feet offshore, and the marine sediments seaward of the cliff may be several hundred feet thick.

A crater of adequate depth at site 2 would lie entirely within shale and sandstone bedrock. An offshore approach channel probably would lie entirely within marine sediments. Building sites are abundant in and near site 2. A small year-round water supply probably can be developed in the alluvial gravel underlying Kisimulowk Creek and in the slightly smaller creek flowing along the western margin of the site. Either creek would deposit gravel in the harbor if the harbor lay across its course. Ridges east, west, and north of site 2 should afford protection from all easterly, westerly, and northerly winds to vessels anchored in an artificial harbor there.

The hills within site 2 at Kisimulowk Creek are considerably higher than those within site 1 at Ogotoruk Creek, and therefore a device of larger yield presumably would be required to create a harbor at site 2. However, field examination may indicate that bedrock in site 2 is much more competent and capable of standing at a considerably steeper angle on a subaqueous slope than the bedrock in site 1. The 50-foot depth contour also may prove to lie closer inshore at site 2 than at site 1; if so, less effort would be required to prepare and maintain an approach channel at site 2. The year-round water supply available at site 2 is smaller than at site 1; however, it probably is adequate. Kisimulowk Creek and the smaller stream along the west edge of the site would deposit gravel in an artificial harbor at a slower rate than Ogotoruk Creek; nevertheless, sedimentation by these streams would limit the life of the harbor unless the streams were diverted or the harbor placed away from their courses.

Site 3.--Cape Seppings Coastal Plain

Site 3 consists of a low-lying area extending about 12 miles along the coast in the vicinity of Cape Seppings; the inner edge of the site lies 1/2 to 1 mile inland along the base of an ancient wave-cut cliff. The 50-foot contour is arbitrarily selected as the inland boundary of the site; most of the area lies below the 25-foot contour. Brackish-water lagoons occupy about one-third of the surface area.

Cape Seppings is a low-lying convexity in the coast created by sediments dumped at the mouth of the Singoalik River. The river deposits include, from southeast to northwest, an ancient fan of alluvial sand and gravel mantled by colluvium and silt more than 10 feet thick; an ancient delta composed of sandy and peaty silt; and an area of alluvial sand and fine gravel along the present meander belt of the river. Elsewhere in site 3, the land area consists chiefly of a series of coalescing fans of alluvial gravel mantled in their older portions by colluvium and silt more than 10 feet thick. The lagoons are underlain by sandy silt. A sheet of marine gravel may underlie the surficial deposits throughout most of site 3.

The total thickness of the unconsolidated deposits probably ranges from 50 to 100 feet. The deposits are perennially frozen in most places at depths below 1 to 10 feet.

The bedrock surface beneath the unconsolidated deposits probably consists of a smooth, featureless plain sloping seaward at a gradient of several tens of feet per mile. The rocks consist of sandstone and shale of Jurassic(?)and

Cretaceous age northwest of Cape Seppings, and probably of limestone and shale of Mississippian, Permian(?) and Triassic age southeast of Cape Seppings.

Nothing is known concerning the offshore geology. Presumably the smooth bedrock surface believed to underlie the coastal plain extends seaward for many miles beneath a mantle of marine sediments several tens of feet thick.

Site 3 seems to offer the possibility of creating a very wide crater of shallow but adequate depth by placing the explosive device in frozen unconsolidated sediments in a position where much of the shock energy will be reflected upward off a smooth bedrock surface. Alternately, the device can be placed in bedrock more than 100 feet beneath the surface in order to achieve a more steeply conical crater. If the device were placed beneath a lagoon, the water might provide a beneficial damping effect during the explosion.

The nature of the unconsolidated materials in site 3 is not known in sufficient detail to permit accurate prediction concerning the steepness and stability of the walls that would result from the creation of an artificial harbor. If frozen silt with a large ice content extends far below sea level, the crater walls would be difficult to stabilize; the silt would thaw rapidly and flow into the deeper parts of the crater. After several years, the margins of the artificial harbor might have subaqueous slopes as low as 1° or 2°, and the harbor might have become too shallow to be useful. However, if the portion of the crater walls below sea level should consist chiefly of sand and gravel, they would stabilize much more rapidly in relatively steep subaqueous slopes, and the harbor depth probably would not be seriously impaired. Geological field work and considerable test drilling would be required to establish the nature and distribution of the unconsolidated materials in site 3.

An offshore approach channel to site 3 probably would lie entirely within marine sediments. Building sites are much less abundant in site 3 than in sites 1 and 2; however, satisfactory foundation conditions are found locally on the alluvial fans. A large year-round supply of ground water can be developed in the alluvium of Singoalik River, and smaller supplies may be available in some of the alluvial fans.

The Singoalik River is a major sediment source and should not be allowed to enter the artificial harbor. The other streams entering site 3 are small and constitute only minor sources of sediment.

A harbor in site 3 would be less protected from easterly and westerly winds than a harbor in sites 1 and 2.

## Conclusions

The character of the offshore topography and bottom deposits is likely to prove to be the ruling factor governing choice of a site in the Cape Thompson-Cape Seppings area for the proposed experiment to create an artificial harbor. Consequently, a study of the offshore geology and topography should receive top priority among the investigations to be conducted during 1958. A concurrent study of marine and beach sedimentational processes is essential to the proper planning of the offshore approach channel and to evaluate the amount of maintenance that is going to be required to keep the approach and entrance open. The proposal to conduct the experiment during the summer of 1959 seems to require that all three potential harbor sites be carefully examined during 1958.

If offshore conditions prove to be about the same throughout the Cape Thompson-Cape Seppings area, a choice can be made on the basis of the merits of the individual sites after field investigations have been conducted. Sites 1 and 2 offer an opportunity to create a relatively steep conical crater in bedrock. Site 3 offers an opportunity to create a wide, shallow crater in unconsolidated material, but field investigations may show that the walls of a crater could not be stabilized in site 3. The existence of large lagoons beneath which the device could be placed may be a factor favoring site 3; the other two sites contain no enclosed bodies of water.

The surface topography is low in site 3 and consequently a relatively small volume of material must be removed to create an artificial harbor. The surface topography is higher in site 1, and much higher in site 2. However, field investigations may indicate that the rocks underlying site 2 will stand in much steeper subaqueous slopes than the rocks underlying site 1.

If site 1 is chosen, careful attention must be given to either diverting Ogotoruk Creek or to locating the harbor so that it will not intersect the present course of the creek. The streams crossing site 2 are smaller and presumably easier to divert. Site 3 contains many places where a harbor can be created that will not be entered by any large stream.

Sites 1 and 2 are located in terrain that affords protection from winds from the east, north, and west; the hills behind site 3 afford protection only from winds in the northern quadrant.

Sites 1 and 2 contain an abundance of building sites and a dependable year-round water supply. Building sites are less abundant, though by no means lacking, in site 3; a dependable year-round water supply would be available to facilities within a mile of the Singoalik River, but ground water may prove difficult to find elsewhere in site 3.

Shallow drilling will be required at any of the three sites in order to establish the character of the rocks and unconsolidated sediments at depth. Drilling also will be required offshore--presumably through the ice--in order to establish the character of the marine sediments to depths of at least 50 feet below the water surface.

## PART III. EFFECT OF THE OCEAN ON EARTH TEMPERATURE

by Arthur H. Lachenbruch

In high latitudes large bodies of water that do not freeze to bottom in winter can have a profound effect upon the temperature and distribution of permafrost. This effect arises from the fact that the mean annual temperature of the bottom sediments must be greater than the freezing temperature of the water, and the mean annual temperature of the emergent land surface may be many degrees lower. The sites of bodies of water are thus relatively warm regions of the surface, and they give rise to anomalous conditions of heat flow in the underlying ground.

With the aid of an idealized mathematical model we can estimate the temperature distribution under the ocean's edge from a knowledge of the mean annual temperatures of the sea bottom and adjacent land surface, and an assumption regarding shoreline history. The problem has been discussed at some length in a published paper (Lachenbruch, 1957b) and the reader is referred to this work for details. In plate 8 the conditions of the idealized problem are presented, and plate 9 illustrates the general behavior of the geothermal disturbance due to the ocean. For a shoreline that has been stationary for many thousands of years in a stable climatic regime, the thermal disturbance due to the ocean reduces to

$$A \ \frac{1}{2} + \frac{1}{\ } \tan^{-1}(x/z)$$

Here A represents the amount by which the mean annual temperature of the sea bottom exceeds that of the adjacent land surface. The use of x and z is as indicated in plate 8.

To calculate the ocean disturbance we need the value of A, i.e., the mean temperatures of land and sea bottom. To calculate the earth temperature as a function of depth at any point in the vicinity of the shoreline we need, in addition, the undisturbed temperature of the land as a function of depth, since it is upon this that we superimpose the ocean disturbance. In the Cape Thompson area of northwestern Alaska the mean annual temperature of the land surface is probably close to -5°C., and the mean annual temperature of the sea bottom near shore is probably at or slightly greater than 0°C. A value of the undisturbed geothermal gradient consistent with typical outward earth heat flow in rocks of the Cape Thompson area is about 1°C. per 100 feet. Using these values, the configuration of the 0°C. isotherm would be approximately as indicated in plate 10. These results are quite sensitive to the assumed value for the mean ocean bottom temperature. At Barrow its value is about $-\frac{1}{2}$°C. and this leads to a somewhat different configuration (Lachenbruch, 1957b, see fig. 4). Periodic annual deviation of the sea-bottom temperature from the mean will result in a somewhat greater penetration of the bottom sediments by superfreezing temperatures. This is illustrated schematically by the dashed line in plate 10. The case illustrated should not be considered as a precise description of conditions at Cape Thompson because of the sizeable uncertainty introduced with the choice of parameters and the possible error in the assumptions regarding stability of shoreline and climate. However, if temperature data were obtained to depths of several hundred feet in one or two boreholes on land in the area, much of the uncertainty could be eliminated.

Sea bottom sediments at temperatures below 0°C. do not necessarily contain ice, for if they are coarse grained and permeable the interstitial water is probably saline. Ice cannot coexist in thermodynamic equilibrium with normal sea water unless the temperature is below about -1.8°C. Calculations show that of the near-shore bottom sediments whose temperature is below $0^{o}C.$, a large portion is not colder than $-1.8^{o}C$. The physical state of this material will thus depend upon the salinity of the interstitial fluid. Fine-grained impermeable bottom sediments can probably contain a large percentage of fresh-water ice at temperatures close to $0^{o}C$. If such sediments are exposed to the sea water by excavation, however, they can be expected to thaw to depths of several feet each summer due to the warming and wind-mixing of sea water during the ice-free period. Thus considerable slumping should be anticipated on sloping surfaces excavated in material of this kind.

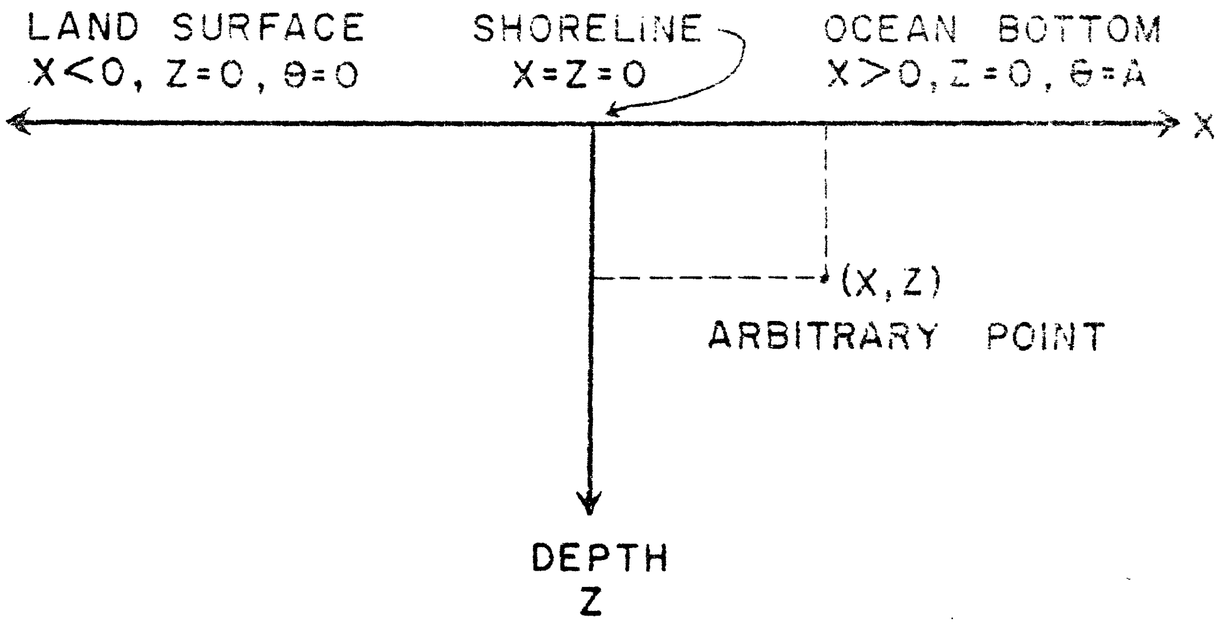


PLATE 3. CONDITIONS OF THE IDEALIZED PROBLEM

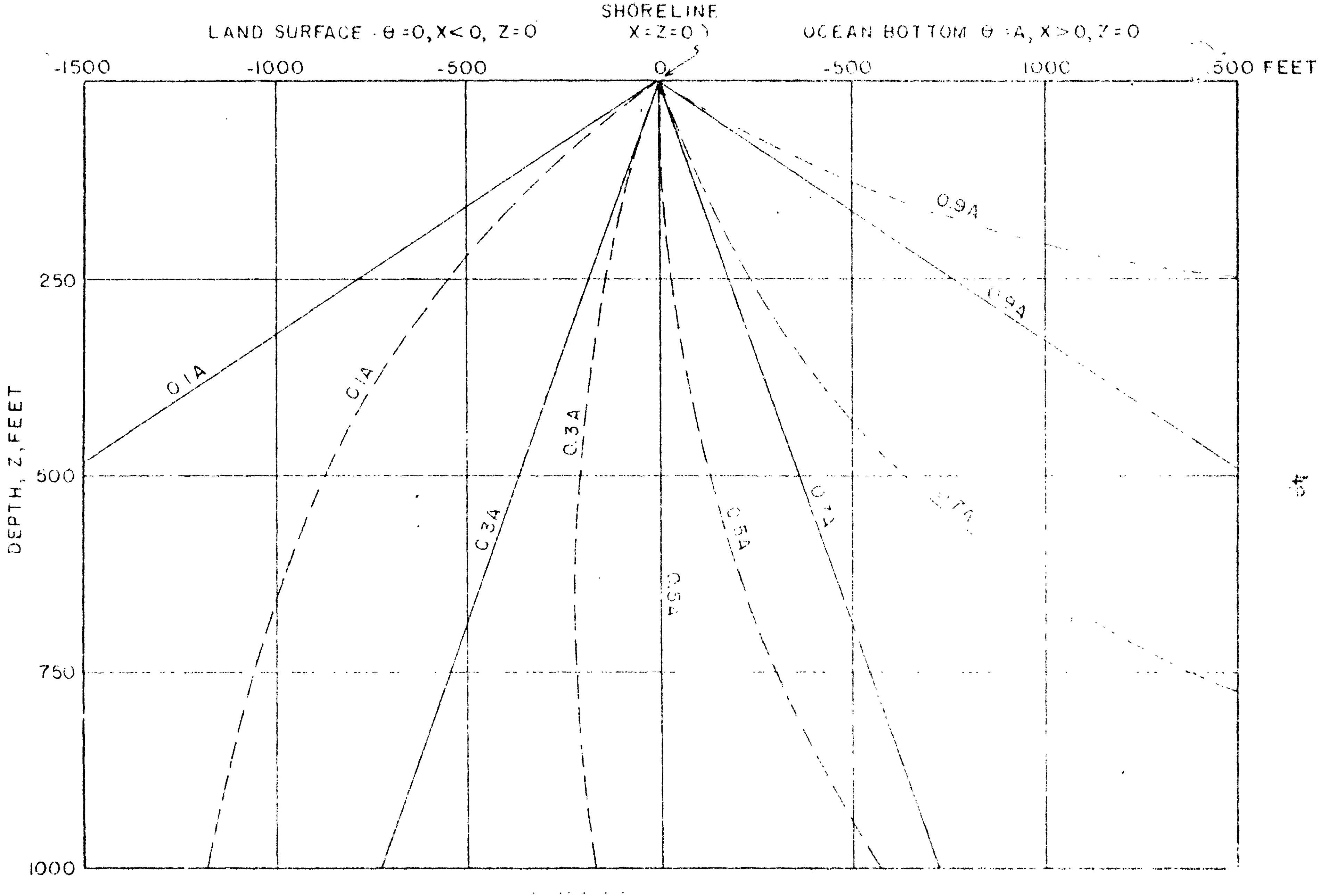


PLATE 6. LINES OF EQUAL OCEAN DISTURBANCE

Solid lines represent steady state; broken lines, about 10,000 years after a rapid transgression (for $\alpha = 0.01$ $cm^2$/sec.)

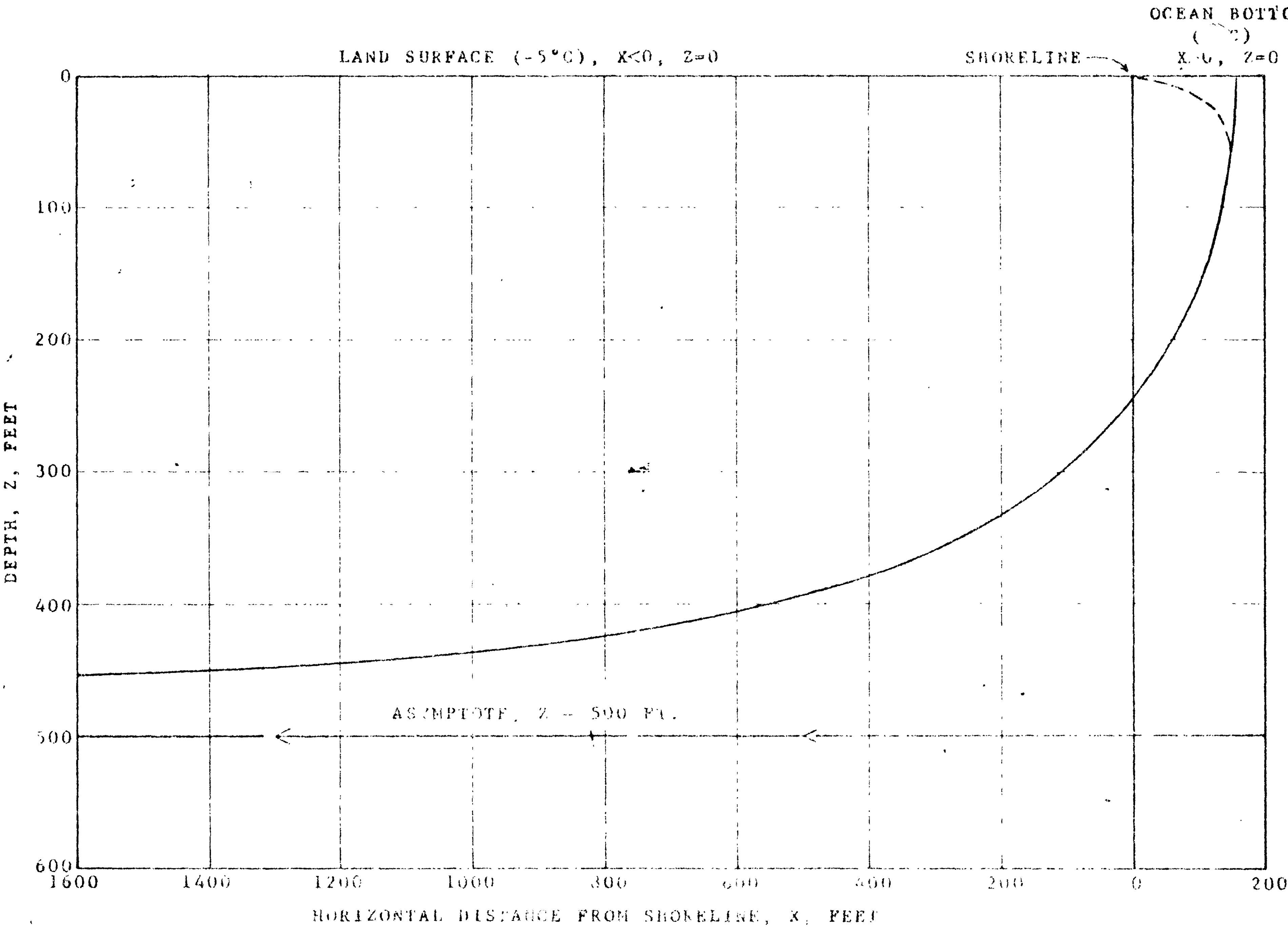


PLATE 10. CALCULATED DISTRIBUTION OF PERMAFROST IN THE VICINITY OF THE SHORE LINE FOR THE SPECIAL CASE OUTLINED IN TEXT.

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