The Alaska Earthquake

March 27, 1964

Effects on Communities

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Homer

GEOLOGICAL SURVEY PROFESSIONAL PAPER 542-D

This page intentionally left blank

THE ALASKA EARTHQUAKE, MARCH 27, 1964:
EFFECTS ON COMMUNITIES

Effects of the Earthquake Of March 27, 1964 In the Homer Area, Alaska

By ROGER M. WALLER

With a Section on

BEACH CHANGES ON HOMER SPIT

By KIRK W. STANLEY

A description of the damage caused by landmass subsidence, earthflows, landslides, seiche waves, and submarine landslides resulting from the earthquake in the Homer area, Alaska

GEOLOGICAL SURVEY PROFESSIONAL PAPER 542-D

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 65 cents (paper cover)

THE
ALASKA EARTHQUAKE
SERIES

The U.S. Geological Survey is publishing the results of investigations of the Alaska earthquake of March 27, 1964, in a series of six professional papers. Professional Paper 542 describes the effects of the earthquake on communities: Anchorage (542–A), Whittier (542–B), Valdez (542–C), Homer (542–D); other chapters are in preparation on Seward, Kodiak, and several smaller communities. Succeeding professional papers will describe the regional effects of the earthquake; the effects on the hydrologic regimen; the effects on transportation, communications, and utilities; and the history of the field investigations and reconstruction effort.

CONTENTS

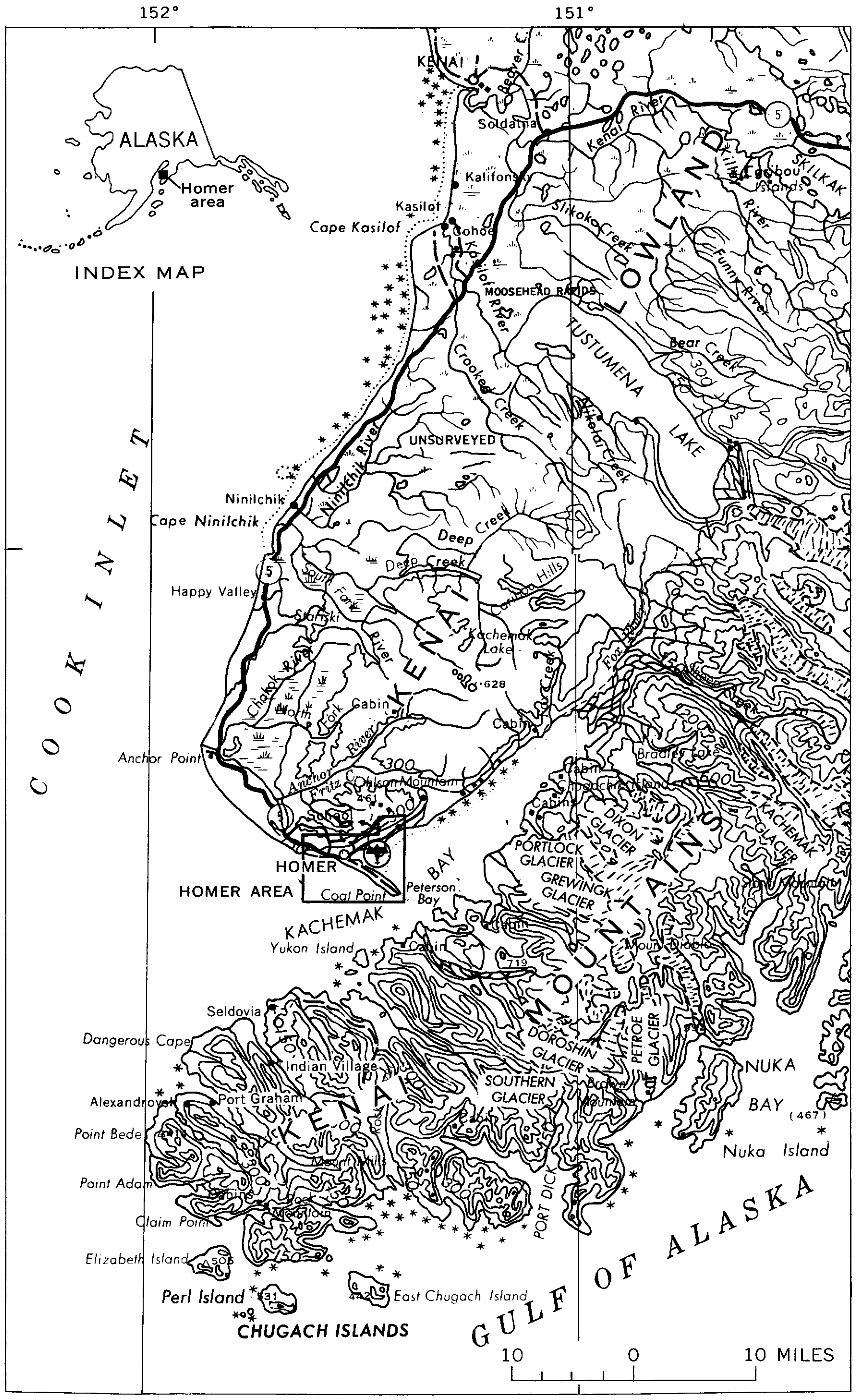
ILLUSTRATIONS

PLATE

FIGURES

TABLES

797-974 O—66——2



Base map from U.S. Army Map Service,
1:1 000,000 series; Anchorage, 1951–53
and Kodiak, 1952

1.—Maps of Alaska showing Homer area.

EFFECTS OF THE EARTHQUAKE OF MARCH 27, 1964, IN THE HOMER AREA, ALASKA

By Roger M. Waller

ABSTRACT

The March 27, 1964, earthquake shook the Homer area for about 3 minutes. Land effects consisted of a 2- to 6-foot subsidence of the mainland and Homer Spit, one earthflow at the mouth of a canyon, several landslides on the Homer escarpment and along the sea bluffs, and minor fissuring of the ground, principally at the edges of bluffs and on Homer Spit. Hydrologic effects consisted of at least one and possibly two submarine landslides at the end of the spit, seiche waves in Kachemak Bay, ice breakage on Beluga Lake, sanding of wells, and a temporary loss of water in some wells.

Seismic damage to the community was light in comparison with that of other communities closer to the epicenter. One submarine landslide, however, took out most of the harbor breakwater. The greatest damage was due to the subsidence of the spit, both tectonically (2–3 ft) and by differential compaction or lateral spreading (an additional 1–4 ft). Higher tides now flood much of the spit. The harbor and dock had to be replaced, and buildings on the end of the spit had to be elevated. Protection works for other buildings and the highway were needed. These works included application of fill to raise the highway and parts of the spit above high tides. Reconstruction costs and disaster loans totaled about $2½ million, but this amount includes added improvement costs over preexisting values.

Homer Spit in particular and the Homer area in general rank as areas where precautions must be taken in selecting building sites. The hazards of landslides, earthflows, compaction and submarine slumping—all of which might be triggered by an earthquake—should be considered in site selection.

In plan, Homer Spit resembles a scimitar with its curving blade pointed seaward. It is about 4 miles long and as much as 1,500 feet wide. The spit is composed largely of gravel intermixed with some sand.

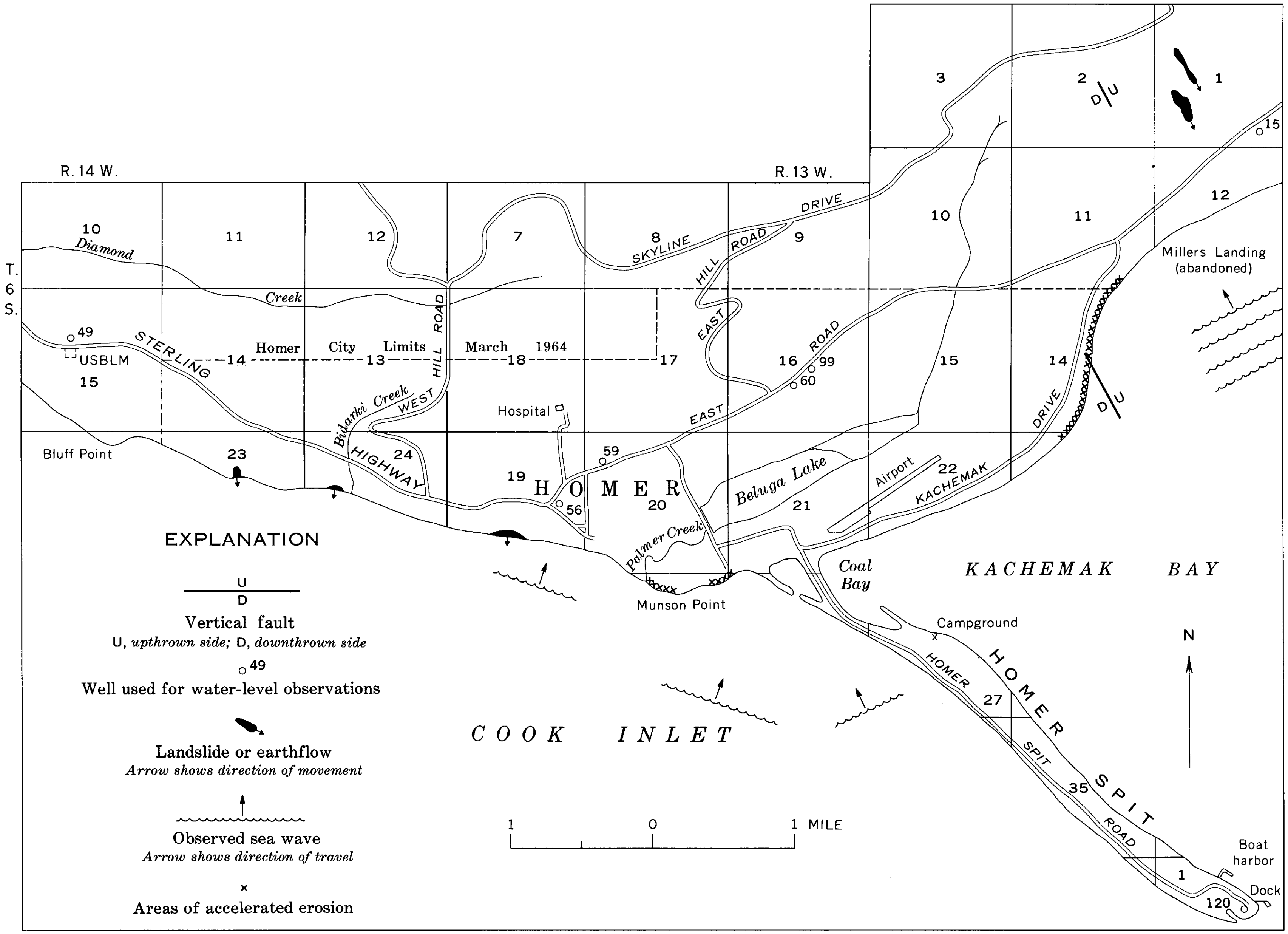
After the earthquake and the resulting tectonic subsidence and compaction, much of the spit was below high-tide levels and consequently flooded periodically. The entire beach face has retreated. Much of the material eroded from the beach has been redeposited to form a new storm or frontal berm, locally migrating around buildings and covering roads. Beach recession of 10–15 feet is probably the overall average; maximum recession 1 year after the earthquake was 56 feet along one limited section of the distal end of the spit.

Subsidence of the mainland has caused accelerated erosion of the beaches and headlands that have been—and are—source areas for the material deposited on Homer Spit. The resulting increased supply of gravel and sand probably will cause the spit to widen gradually on the Cook Inlet side. Similarly, the new frontal berm will probably grow to a height sufficient to prevent overtopping by all but the larger storm swashes. The nature of shore processes on the spit has not been materially altered by subsidence, but the rates of erosion and deposition have been accelerated. The lasting effect of subsidence (excluding flooding) will be enlargement of the beach on the Cook Inlet side and gradual wasting of the beach on the bay side of the spit.

INTRODUCTION

Homer is located at the southern tip of the lowland part of the Kenai Peninsula in south-central Alaska (fig. 1). The lowland lies west of the Kenai Mountains and east of Cook Inlet. This paper deals with the earthquake effects in the general area along the shore of Kachemak Bay from Diamond Creek on the west to Fritz Creek, about 6 miles east of Homer. Homer is about 160 miles southwest of the epicenter of the earthquake of March 1964.

Immediate field observations were limited because the writer's primary assignment was to Anchorage. Early observations in the Homer area were made by U.S. Geological Survey colleagues Reuben Kachadoorian and George Plafker. Special thanks are due to the numerous people at Homer who provided their observations of the earthquake and to Mr. Al Billings, project engineer, U.S. Army Corps of Engineers, Homer, who helped make the offshore fathometer traverses.



2.—Map of the Homer area showing slide areas, beach erosion points, and locations of wells.

PERSONAL OBSERVATIONS

Most of the residents of the small town of Homer were settling down for the evening meal at 5:36 p.m. (Alaska standard time) on Good Friday, March 27, 1964. Several people were still out at the end of the Homer Spit which extends 4 miles into Kachemak Bay (fig. 2). The weather was mild; there was an overcast and near-freezing temperatures and light snow was falling. A thin snow cover lay over most of the land. A high tide of 19.4 feet was ebbing to a low which would occur at about 7:30 p.m.

To some people the first indication of something happening was the loss of electric power, but most persons realized that there was an earthquake when they felt the initial shock at about 5:37 p.m. As the shock waves continued, they realized this was an exceptionally severe earthquake. Estimates of the length of time of earth movement ranged from 1 to 5 minutes. Mr. Ralph Cowles, the mayor of Homer, stated (Grantz and others, 1964, p. 24) "that the total time of the tremor was from 2 to 2½ minutes and that its motion was 'wavy' and east-west." Mr. Paul Gardiner reported 2- to 3-foot ground waves moving east-west near the airport, and Mr. and Mrs. D. P. Lowcock sensed east-west motion on Munson Point. Many people stated, however, that the principal direction of movement was north-south and that the movement was so violent that standing unsupported was impossible. Mr. and Mrs. Albert Greer reported ground waves coming two at a time downhill from north to south. In general, the ground movement was reported to be a gradual buildup of a rolling motion to a peak intensity, then a lull, and then another buildup to a peak before suddenly stopping. Mrs. Leo Rhodes, Mr. and Mrs. Vic Nelson, and Mrs. Gus Weber remarked on the great silence that prevailed during lulls in the earthquake, in contrast with the rumbling, cracking, and popping noises reported by Mr. Karl Baier, Mrs. Rhodes, the Nelsons, and others as prevalent during the violent-motion phases of the quake.

The violence of earth movement was noted by several witnesses. Mr. Tex Sharp, in his apartment when the quake occurred and the power failed, tried to cross the 10 feet from his apartment door to his place of business, the Waterfront Bar and Dining Establishment. He was unable to cross for about 4 minutes. When the shaking stopped, he entered the bar, in his bare feet, and found his stock of bottled goods and glassware almost totally destroyed. On East Road near Fritz Creek, Mr. Karl Baier was thrown to the ground and was unable to rise for some time. Near the airport, Mrs. Leo Rhodes and Mrs. Vic Nelson were unable to walk without support during the violent phases of the quake; Mr. and Mrs. D. P. Lowcock reported that they and their dog were thrown to the ground by the force of the motion on Munson Point.

Animals, too, were affected. Dogs, sheep, and geese were thrown to the ground. Mrs. Gus Weber reported that two moose ran from the woods into a clearing where they "jumped, bucked up and down like horses, reared up on their hind legs and ran back and forth as the earth moved in all directions." These experiences suggest that the quake had an intensity of between VII and VIII on the Modified Mercalli scale.

At the height of the quake, earth fissures formed and closed in many parts of Homer and the vicinity. Near the airport, according to Mrs. Vic Nelson, the ground and snow cover "cracked like lightning," opening and closing. Mr. and Mrs. Albert Greer reported that fissures formed in the ground "with a cracking noise." Mr. Karl Baier saw a field crack in a checkerboard pattern and a 6-inch fissure traverse the ground and split a spruce tree. On Homer Spit, Mr. Glen Sewell (Grantz and others, 1964, p. 24) watched a fissure form on the oceanside of the spit and travel toward him. The ground split under his truck and between his legs, opening up to about 12 inches and allowing gravel to roll in. The fissure extended, splitting the concrete floor of the Porpoise Room. Paved roads were fissured in various places throughout the Homer area, but significant patterns and extensions of fissures into adjacent unpaved areas have not been recorded.

Exceptional sea waves, both in Cook Inlet and in Kachemak Bay, were seen by various observers. Inasmuch as the waves were observed within 5–10 minutes after the quake, the waves clearly did not originate near the epicenter, 160 miles distant. On the other hand, some reported waves apparently came in from the open ocean; hence it cannot be assumed that all of the waves were seiches although waves that traveled approximately at right angles to the shores of Cook Inlet may have been seiches. Submarine slumping occurred off the tip of Homer Spit. The possibility of larger

797-974 O—66——3

scale slumping or landsliding, or both, in uninhabited parts of Cook Inlet cannot be disregarded; however, there is no direct evidence that such sliding and slumping occurred to cause the sea waves. In short, the origin of the waves remains unexplained. The reported wave patterns are shown diagrammatically on figure 2.

Eyewitnesses reported that wave heights and patterns were markedly different in Cook Inlet and in Kachemak Bay. For example, while returning to Homer from the spit, shortly after the earthquake, Mr. Glen Sewell noticed a wave "rolling in from the ocean" about a mile offshore. Mr. and Mrs. D. P. Lowcock also saw a wave which probably was the same one seen by Mr. Sewell. After the ground motion stopped, the Lowcocks looked offshore and saw a wave "rolling in from Seldovia." It was perhaps a mile long, cresting, and alined approximately northwest to southeast. They also observed another wave coming directly northwestward toward them. It was shorter and did not appear as high, but it was cresting also. The two waves gave the appearance of an "inverted V," but they were not joined (fig. 2).

The wave coming from the ocean was probably the same one observed also from downtown Homer. It reportedly (Mr. Velton Cason, oral commun., 1964) came in as a 9-foot swell about 5 minutes after the beginning of the earthquake motion, and there was a withdrawal of water on the beach before it struck.

Within Kachemak Bay, wave action developed also. Mrs. Fitzgerald, on East Road, reported that it looked as if "the land was being shoved under the bay" because of the curious breaking and surging of the waves on the tidal flats. Her family had counted seven waves rolling in when their attention was diverted due to a "harder part of the shock." She reported that others counted 14 waves in the bay.

The U.S. Coast and Geodetic Survey (1964a, p. 82) reported from news excerpts that "Ten-foot waves at 2-minute intervals occurred at about the same time the ground shock was felt." This report agrees with Stanley's (1965) statement that the waves immediately after the earthquake were 9 feet high in Cook Inlet and 4 feet high in Kachemak Bay.

Evidently a series of waves was immediately generated in the bay. All except one of the observed waves were parallel to the north shore. Probably the same waves were noted by J. M. Moss (written commun., 1964) on the south shore at Peterson Bay (fig. 1) as the "Tide came and went for at least 15 hrs."

Kachadoorian (unpub. data, Apr. 1, 1964) recorded a fisherman's report of an estimated 50-foot wave seen after dark off the south tip of Kenai Peninsula (lat. 59°07′, long. 151°35′); the wave appeared to emit geysers or smoke. A 28-foot wave hit Perl Island, 35 miles south of Seldovia (fig. 1) at 8:40 p.m. (H. D. Hess, written commun., 1964). Wave action in the general area was also recorded by Jim Reardon, Alaska Department of Fish and Game at Homer, in his radio log (written commun., 1964) as follows: At 10:25 p.m. March 27 Seldovia radio reported the "tide slowly coming in." This rise was 3 hours before the high tide was due at 1:39 a.m. At the same time the radio station at Kasitsna Bay (first bay east of Seldovia, fig. 1) reported that water came in at 40 miles per hour. At 10:28 p.m. Seldovia radio reported "tide coming in fast," and at 10:37 p.m. "water going back out." At 11:15 p.m. Seldovia radio reported "harbor damaged," and at 11:17 p.m. "water coming up fast, estimate 18 feet, going to higher ground." At 11:21 p.m. Seldovia radio said "Water receding" and at 11:55 p.m., "Water down to 12 feet, starting up." Meanwhile Perl Island radio reported a second wave (30 feet) at 11:40 p.m. At 1:40 a.m. March 28 Seldovia radio noted the "tide reached normal high, receding normally." Perl Island radio reported a third wave (30 feet) at 2:30 a.m. At 2:48 a.m. Seldovia radio again reported "water up to 25 feet and receding."

These records of wave action suggest that a tsunami could have arrived about 10:30 p.m. at Seldovia, a second at 11:18 p.m. before the normal high tide arrived, and a third at 2:48 a.m. after the high tide. Halibut Cove (wide bay almost due east of the end of Homer Spit, fig. 1) also reported a tide of 24 feet at 11:35 p.m. which could have been the same one that hit Seldovia at 11:18 p.m. If these waves were tsunamis, Homer would have been hit by them also.

There is some evidence that Homer did indeed experience tsunamis. A. G. Green reported (written commun., 1964) that a 20-foot wave arrived about 9:30 p.m. at Homer. Mr. Jim Reardon reported (H. S. Thompson, oral commun., 1964) overwash at the base of the spit in the late evening. The Inlet Courier [Homer] (Mar. 30, 1964) also reported that at the end of the Homer Spit "Water rose in surges beyond the normal tide heights and covered the floor in the new Porpoise Room. It rose to a height of 4 feet in the Salty Dawg * * * and also covered the floor * * *" of the Land's End Hotel.

The long single wave that was seen to approach Homer from the southwest on the oceanside of the spit may have originated from submarine slumping, possibly along the coastline near Seldovia; it may have been an oscillatory wave (seiche); or it may have been the response of the ocean to sudden lowering of the Kenai Peninsula and the floor of Kachemak Bay.

The complex pattern of smaller waves seen in Kachemak Bay perhaps had no relation to tsunamis. More probably these waves were generated by horizontal and vertical movement of the land during the earthquake. Tectonic subsidence also doubtless contributed to the development of the waves in the bay. Alternatively—or additionally—submarine landslides may have contributed to the Kachemak Bay waves. Slumping along the front of the delta lying off Grewingk Glacier (fig. 1) is a likely source of energy for these waves. Tectonic movement probably was the cause of many or even all of the wave phenomena observed at Homer. Furthermore, the larger waves that appeared at intervals probably resulted when the oscillating waves reinforced one another, as is known to happen. It is noteworthy also that most waves became visible only when they traversed the shoals that extend far out from the north shore of Kachemak Bay and Cook Inlet. But the alternative possibilities must be considered as well.

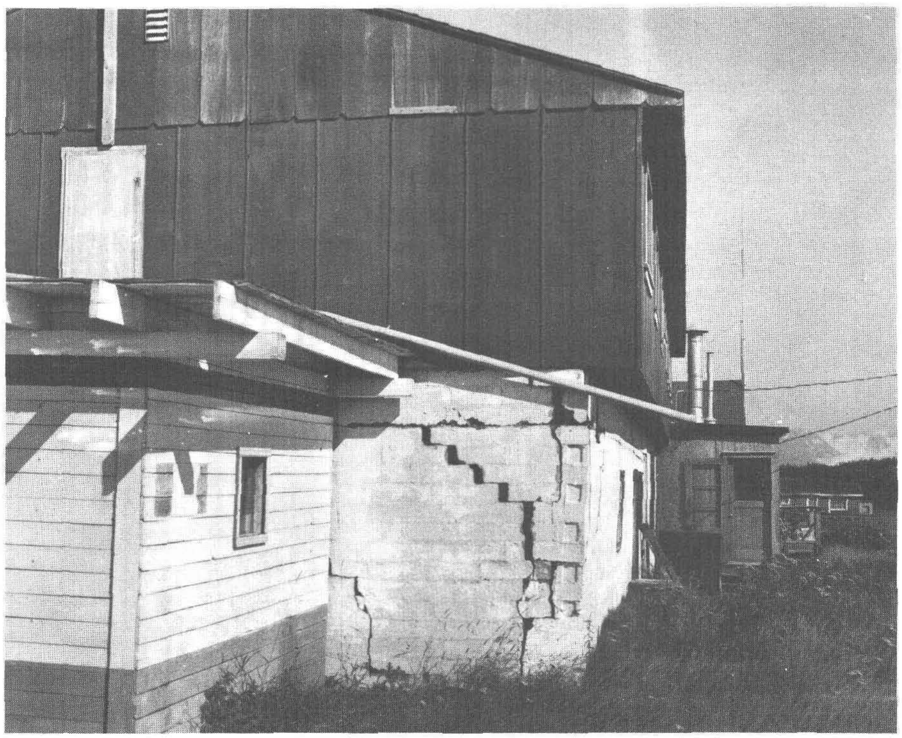
In any event, damage from waves was negligible at Homer for two reasons: (1) the incident waves were small, and (2) the larger waves impinged on the land when the tide was low and an 18-foot tidal freeboard protected the town. If larger waves occur when the tide is high during an earthquake in the future, the damage may be appreciable—especially on Homer Spit.

EFFECTS OF THE EARTHQUAKE

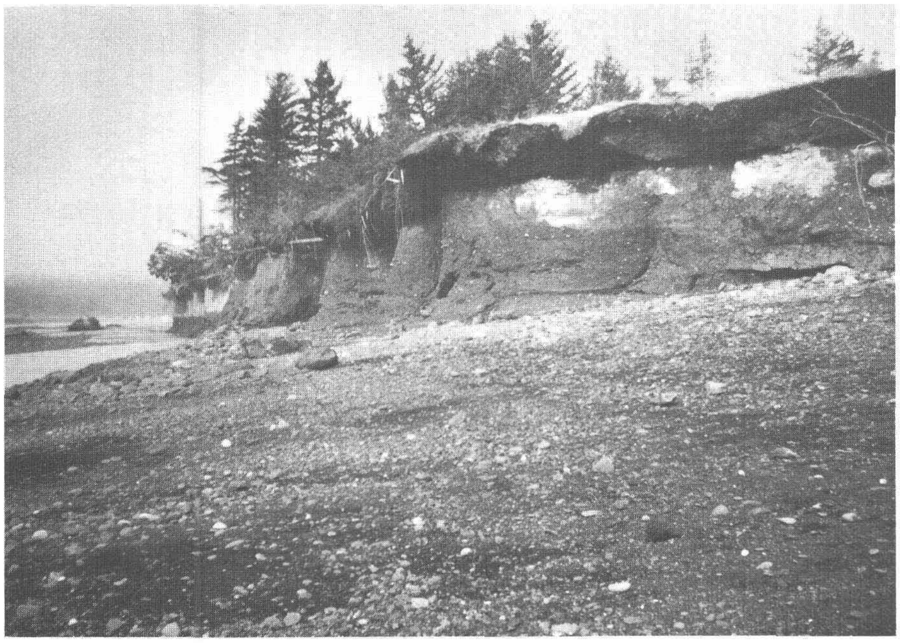
The effects of the earthquake in the Homer area were light compared to the catastrophic effects experienced elsewhere in Alaska. These effects will be considered in four classes: (1) general effects and damage to structures, (2) geologic effects on the mainland, (3) effects on Homer Spit, and (4) hydrologic effects. There is necessarily some overlap and repetition in the discussion.

GENERAL EFFECTS AND DAMAGES

One of the first effects of the shock noticed in Homer was loss of electric power. It was, however, restored in 17 minutes when a standby diesel plant went into operation. Long-distance telephone service was temporarily disrupted, but local service continued. The U.S. Federal Aviation Agency communications cable under Beluga Lake (fig. 2) was broken. Buildings throughout the area were severely shaken but survived, in general, with no damage or only minor damage. At least five chimneys were knocked down, a few plate-glass windows were broken, and several foundations (fig. 3) and concrete-slab floors were cracked or fissured. Dishes and glassware were broken in many homes and business estab-



3.—Damage to foundation walls of the Inlet Inn Hotel. Unreinforced concrete-block construction.



4.—Postearthquake erosion at Munson Point as of April 13, 1964. About 5 feet of the overhanging vegetal mat attests to recent erosion of the underlying glacial till as a result of higher water levels relative to land.

lishments. The most severe damage, however, was to the small-boat harbor near the end of Homer Spit. There the outer seawall largely disappeared as a submarine slide removed its foundations. A few small buildings at the distal end of the spit were overturned by falling into another slumped area. Private individuals experienced property losses of about $1,040,000, the sum of 40 applications for Small Business Administration disaster loans (Inlet Courier, June 19, 1964). Total reconstruction costs for Homer are about $2½ million. That sum, however, includes improvement of facilities—especially the small-boat harbor—and is not a reflection of actual damage alone.

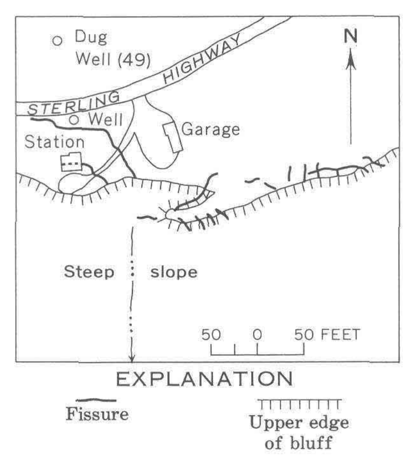
Potential suffering and losses that might have resulted from food shortages because of destruction of highway bridges between Anchorage and Homer were averted by airlifts. In particular, airlifted fodder tided over the needs of cattlemen caught by the earthquake with a short supply of feed for their animals.

GEOLOGIC EFFECTS ON THE MAINLAND

Changes brought about by the earthquake on the mainland at Homer are of interest principally because they illustrate the types of disruption that under other circumstances have been damaging in other areas. The most far-reaching effect was tectonic subsidence that lowered most of the Kenai Peninsula a few feet relative to sea level (Grantz and others, 1964, fig. 3). This subsidence proved to be most damaging on Homer Spit (p. D7) but had little effect on the mainland other than to expose fresh areas to wave erosion along sea cliffs in the Homer area (fig. 4).

Only one landslide and one earthflow of any consequence occurred near Homer, both in sec. 1, T. 6 S., R. 13 W. (fig. 2). This fact is surprising in view of the incompetent nature of the bedrock and of the thin layer of soil that overlies the rock. The bedrock is described by Barnes and Cobb (1959, p. 224) as "* * * moderately indurated sand, silt and clay in generally thin and intergraded beds and lenses * * *," material that might readily yield to gravity when disturbed by seismic shocks.

The landslide (easternmost in sec. 1, fig. 2) debris covers an area about 600 feet long and 100 feet wide. The material that slid stood previously as a promontory along a bluff eroded into the Kenai Formation. The slide area is near a fault in sec. 2 mapped by Barnes and Cobb (1959, pl. 18), but there is no evidence that this fault moved in 1964. Landslide hazards exist in comparable situations near Homer—and indeed anywhere that promontories extend out from precipitous bluffs and cliffs. Bluff Point, north of Homer (fig. 2) is an example. A field station of the U.S. Bureau of Land Management is situated about 50 feet from the edge of a 700-foot bluff. Numerous fissures (fig. 5) developed during the



5.—Sketch map of the ground-fissure pattern at the U.S. Bureau of Land Management field station near Homer. Traced from field compilation on aerial photograph by K. A. Roddy, U.S. Bureau of Land Management, May 1, 1964.

earthquake on the surface above the bluff, some of them several inches wide. A few could be traced about 20 feet down the bluff face. One earth fissure extended across the area of a field-station building and cracked the basement floor of the structure. Areas above and close below promontories where earthslides might occur must remain suspect as sites for any building.

An earthflow occurred in the first canyon southwest of the landslide (fig. 2); it created a jumbled mass of uprooted trees, mudflows, rafts of soil and vegetation, and collapsed ground. The area of disturbed ground is about 1,000 feet long and has a maximum width of about 400 feet. Horizontal displacement of material within the flow, however, probably did not exceed 200 feet. The material involved consists mainly of silt, some fine sand, and occasional layers of flat pebbles. The head of the flow is near the apex of an alluvial fan at the mouth of a small canyon occupied by an intermittent stream. Water was seeping from both disturbed and undisturbed material on June 21, 1964, and may have contributed to causing the flow.

Two large landslides in the Anchor River valley north of Homer (fig. 1) were seen from the air, and other fresh-looking scars appear on aerial photographs of the north shore of Kachemak Bay, taken after the quake. But whether the slides that caused these features were the result of the earthquake is not known.

The entire Homer area appears to be one where steep slopes, the fine texture and weak consolidation of the rocks of the Kenai Formation, and the common condition of saturation with water favor landslides and earthflows. These hazards should be considered when locating sites for building, especially because the shaking incidental to earthquakes tends to weaken the cohesion of the rock materials and to cause them to move under the influence of gravity.

Ground fissuring occurred in the Homer area, but as in most other parts of south-central Alaska it was probably not caused by deep bedrock faulting. In general, the fissuring was of minor importance in the Homer area, except for the fissures occurring at the U.S. Bureau of Land Management station and on Homer Spit. Most of the fissures formed on the spit probably were caused by the submarine landslides or compaction. Other fissures were reported at the mouth of Thurston Canyon just west of Fritz Creek in the northeast corner of the study area, but were not checked in the field. These fissures were reportedly so large that a Shetland pony fell into one several days after the earthquake and could not get out.

No fissures formed on the mudflats of the Palmer Creek tidal area near Munson Point (fig. 2) although elsewhere in south-central Alaska such sites were characterized by extensive fissuring. Perhaps the depth of alluvium, estimated at about 200 feet, was not sufficient or the distance from the epicenter was too great for fissuring to develop during the earthquake. Fissuring of unconsolidated material from a seismic wave is a function of distance, topography, and geologic conditions, but thickness of the material probably is important also.

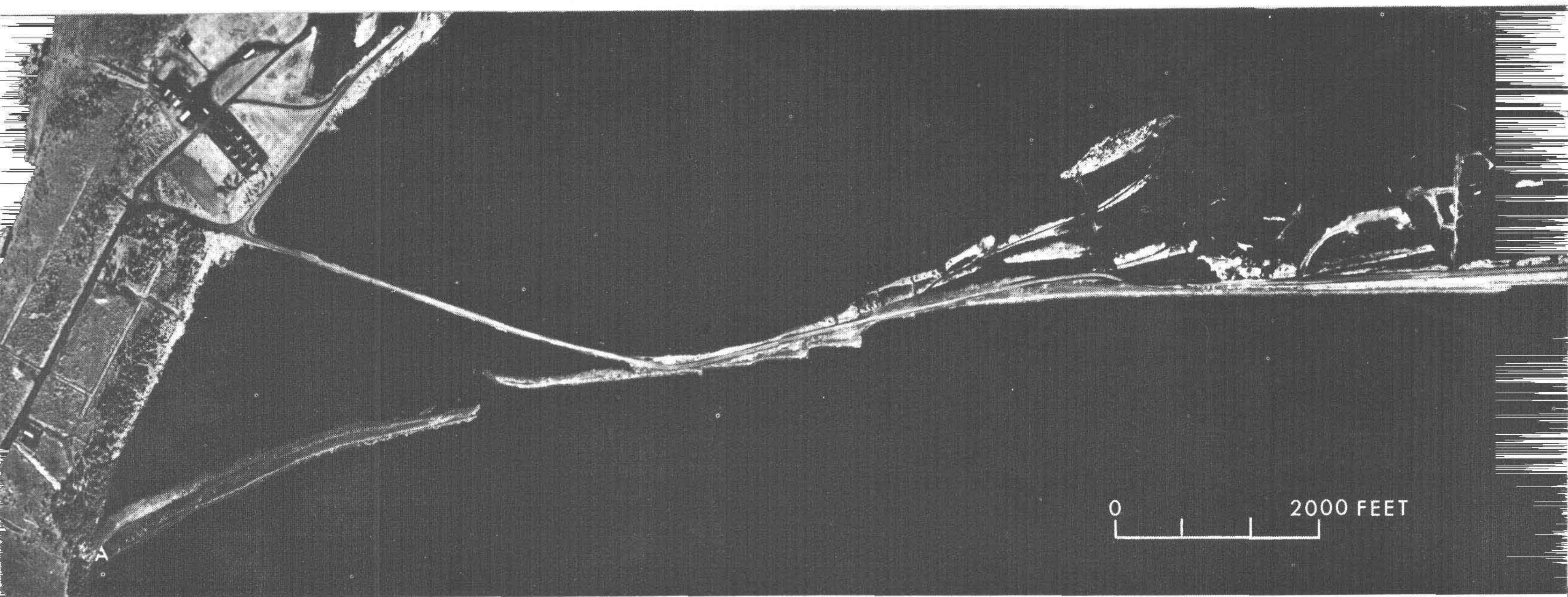
EFFECTS ON HOMER SPIT

The commercial and industrial center of the community is on Homer Spit. The port for both large vessels and small boats is there, and the spit is occupied by a hotel, food-processing plants, restaurants and bars, and other places of business. The entire spit subsided as a result of the earthquake. Part of the subsidence was tectonic and part—especially at the seaward end—was probably the result of compaction of the unconsolidated gravel that makes up most of the spit. Total subsidence at the end of the spit by June 1965 is reported by the U.S. Coast and Geodetic Survey (oral commun., 1965) to be 5.9 feet. In addition to extensive damage by flooding caused by subsidence, a submarine slide removed most of the seaward side of the small-boat harbor. The heaviest financial losses at Homer, therefore, occurred as a result of earthquake effects on the spit.

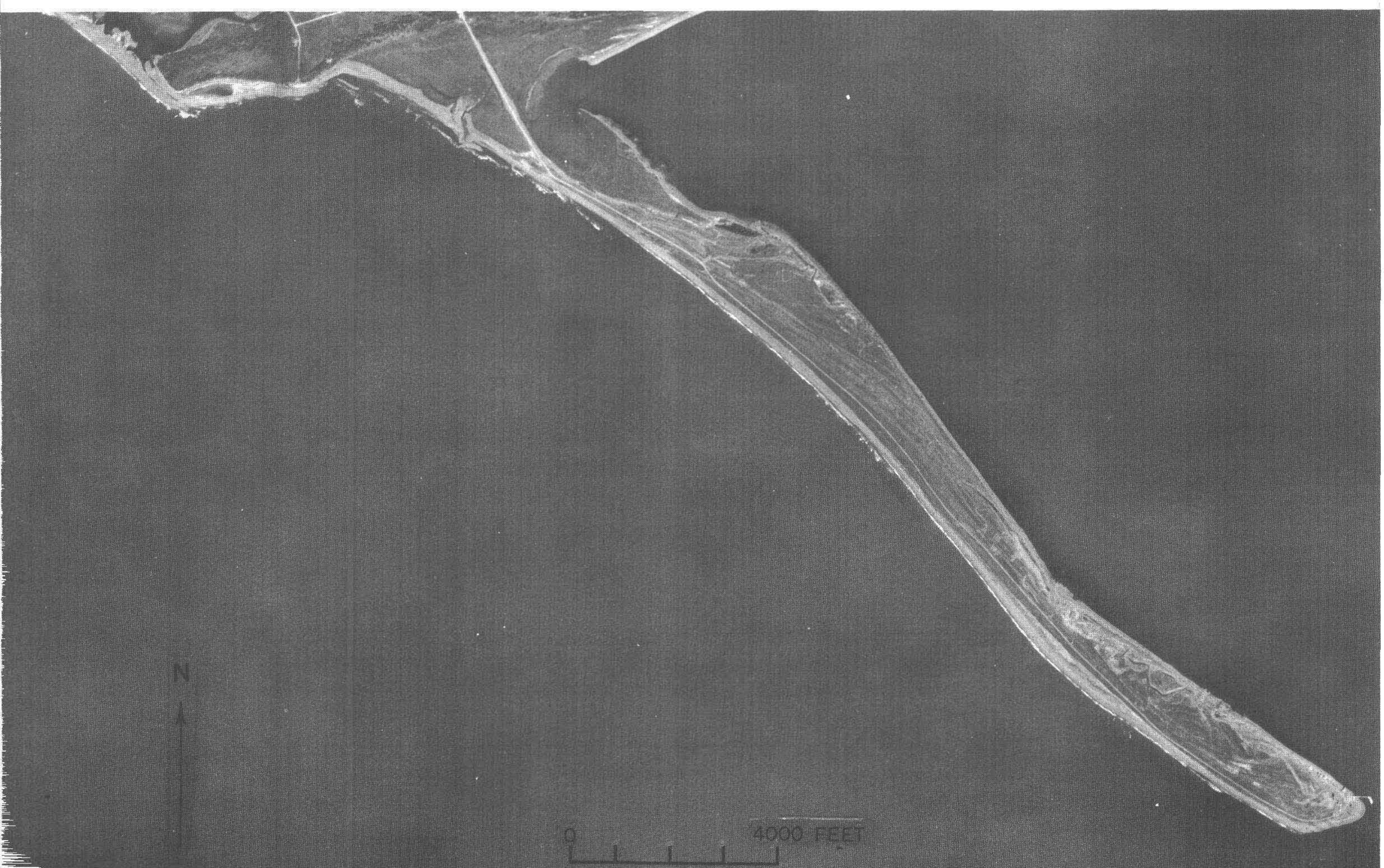
In addition to damage to manmade structures, the subsidence caused a change in the physical relations between the spit and the water surrounding it. As a result, the shape of the spit changed and beach stability was disrupted. The phenomena relating to beach changes on Homer Spit are the subject of the section by K. M. Stanley (p. D20). The extent of high-tide flooding of the spit is shown by Stanley (see fig. 15) in a pair of maps that contrast dry-land exposure on the spit before and after the earthquake. The devastating flooding on the spit immediately after the quake is further illustrated by figures 6 and 7 (on next page), aerial photographs of the spit taken before and after the earthquake.

Some of the specific damage to structures caused by the flooding may be seen in figure 8 (on next page), which shows the Land's End Hotel elevated on jacks to raise it above the postearthquake high-tide level. Figure 9 (p. D10) shows other scenes of the effects of the high tides. During the high tide of about 19 feet that occurred the night following the earth-

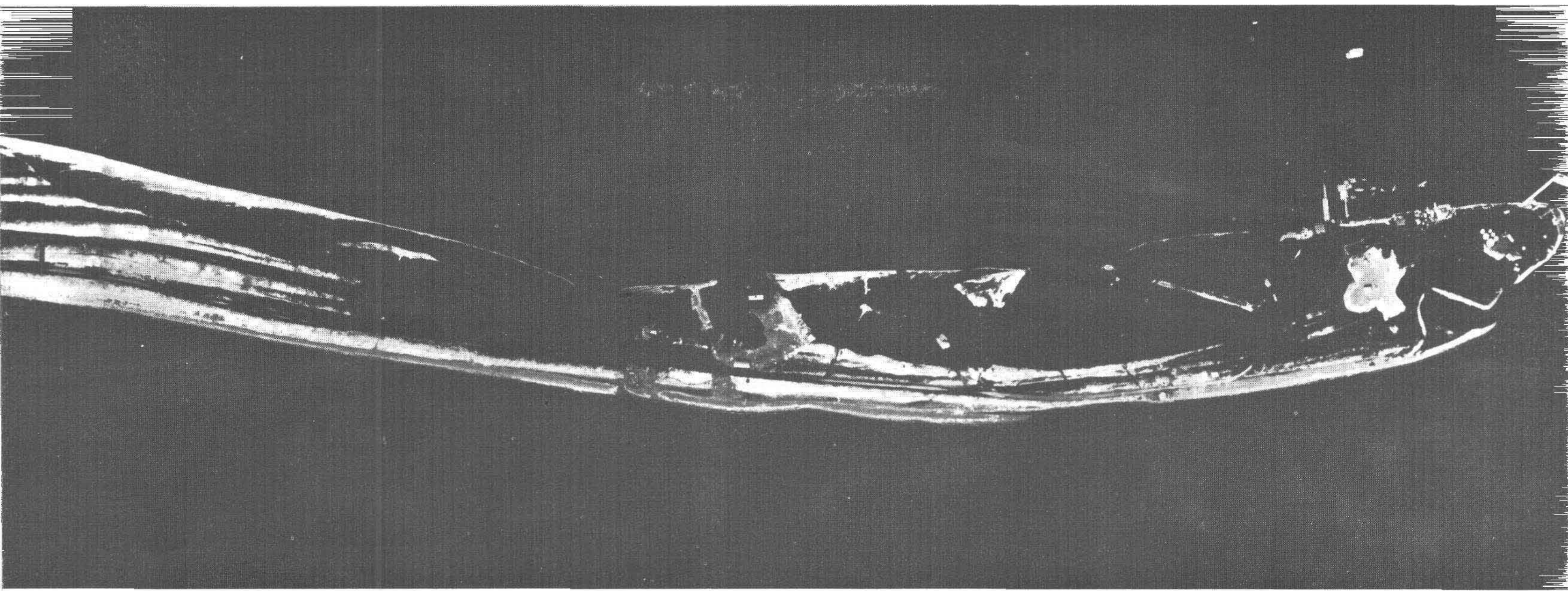
797-974 O - 66 - 4



6—Photomosaic of Homer Spit at high tide on August 8,



7.—Preearthquake aerial photograph of Homer Spit.

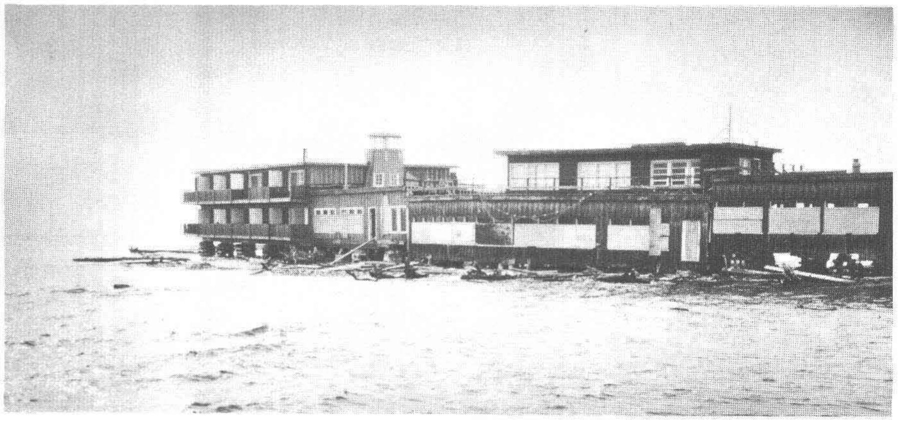


ared photographs by U.S. Bureau of Land Management.

quake, material salt-water damage was done to the hotel, to the Porpoise Room, the Salty Dawg Saloon, two seafood-processing plants, and the Standard Oil Co. tank farm.

Fortunately the mid-April high tides were not accompanied by strong winds, and most of the facilities survived the first onslaught with only salt-water damage. Some structures that could not be raised on jacks were protected against further flooding by hurriedly built embankments. The only land not inundated at the end of the spit was the storm berm around the perimeter of the spit, older storm berms of the beach, and the spoil pile from the original dredging of the small-boat harbor (fig. 6). The asphalt-covered highway was eroded away near the base of the spit by normal wave action at high tide. The dock had only about 1 foot of freeboard, the oil tanks were in water as much as 6 feet deep, water flowed through the windows of the Salty Dawg, one small warehouse building broke up, and the oil-tank farm warehouse tilted; all this indicated differential subsidence.

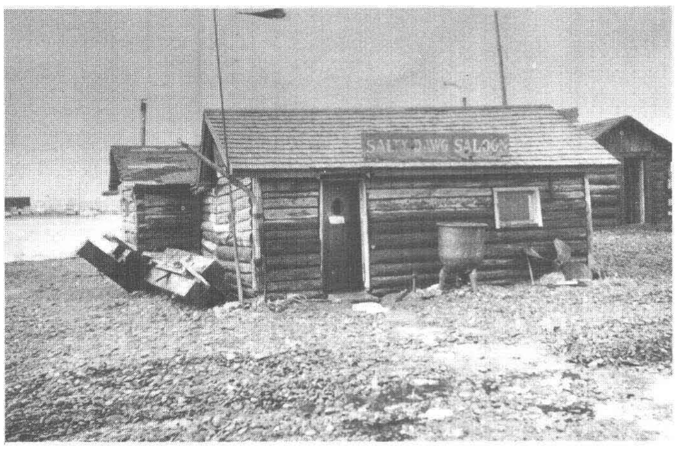
It was apparent that, in addition to repairs, remedial measures were needed to avoid future storm-wave damage as well as damage from normal high tides. Such measures were started immediately by some concerns, whereas others awaited aid from the Government, through the Federal Disaster Act, authorized under Public Law 81–875. As of August 30, 1964, the Office of Emergency Planning had authorized reconstruction projects totaling $1,565,000 to replace or rehabilitate public facilities damaged by the earthquake and tides (Federal Reconstruction and Development Planning Commission for Alaska, 1964, p. 80). The replacement of the Homer dock ($195,000) and a small-boat harbor ($964,200), with more than double the capacity of the old 80-boat harbor, were the principal costs, and construction of both was underway by November 1964. Adverse wind and tide conditions did not occur until late 1964, when wind-driven ice "* * * knocked out part of the new pier now under construction and did further damage to the * * * old pier * * *."



8.—Land's End Hotel jacked up 8 feet to avoid inundation by high tides. View from Homer dock looking west. View during first 20-foot tide. Middle part of hotel not yet raised.

A

B



C

D

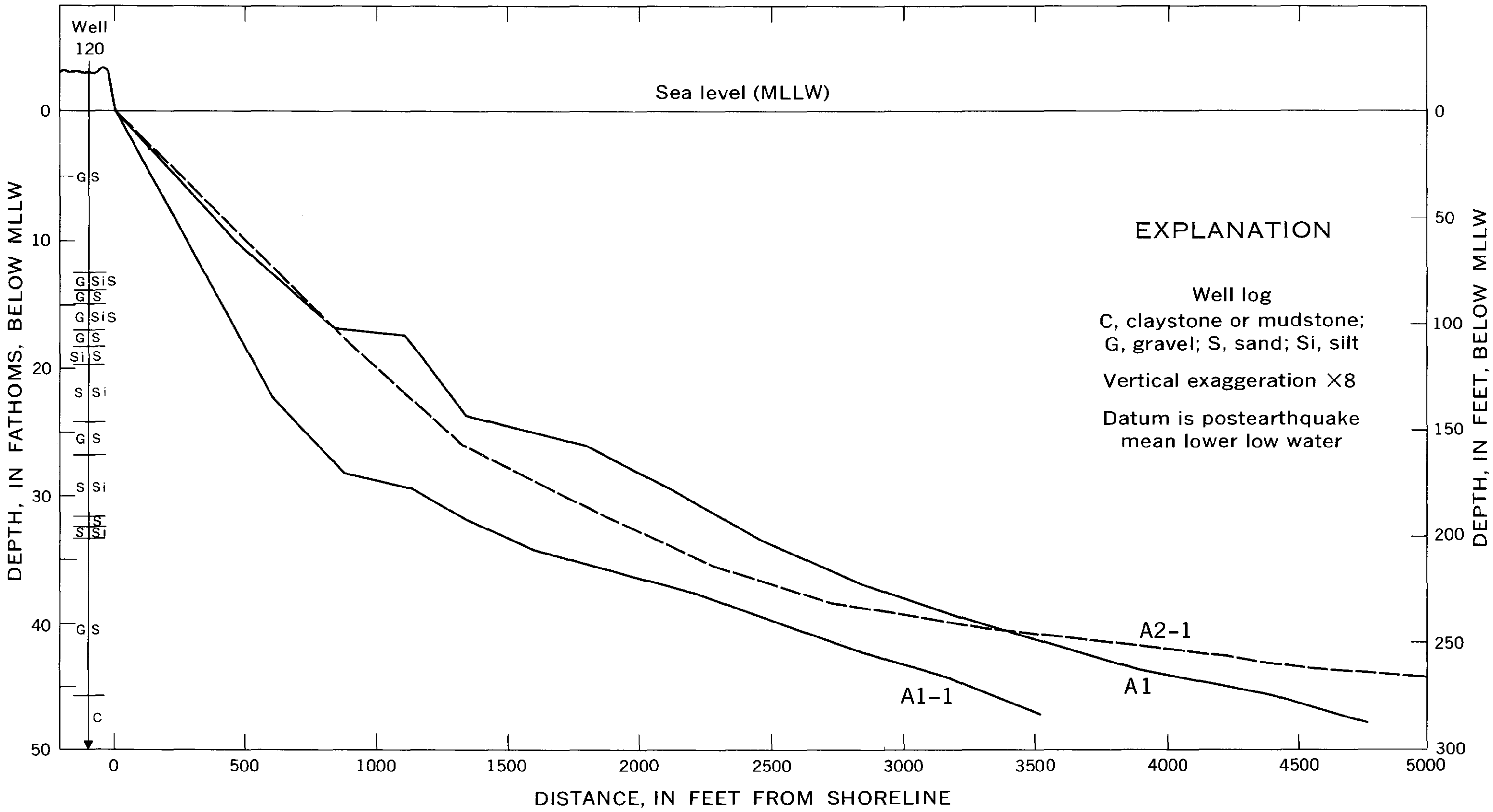
9.—Effects of the high tides submerging the end of Homer Spit on April 12, 1964. *A*, **Standard Oil Co. tank farm awash in as as much as 6 feet of water.** *B*, **Lands End Hotel raised on jacks.** *C*, **Water rose high enough to flow through the windows of the Salty Dawg Saloon.** *D*, **New storm berm encroaching on spit southwest of the Land's End Hotel.**

(Anchorage Daily Times, Jan. 2, 1965). A subsequent storm with winds of as much as 50 knots from the southwest created heavy surf which churned under Land's End Hotel, but the only damage reported was to the road (Anchorage Daily Times, Feb. 16, 1965). By June 1965 the berm at the end of the spit had migrated about 80 feet.

SUBMARINE LANDSLIDE

Available evidence indicates that one and possibly two submarine landslides occurred at the distal end of Homer Spit. The loss of the small-boat harbor breakwater was, of course, obvious, but whether only the breakwater slid or whether substantial material from the spit slid with it was not immediately apparent. Indications of another slide were contained in a report that "The area on the shore west of the Salty Dawg collapsed approximately 10 feet." (The Inlet Courier, Mar. 30, 1964, p. 1). An accompanying picture showed this "collapse" and several buildings slumped into it. The area was covered in a matter of days by a new berm (fig. 9*D*) that prevented observation.

The writer noticed fissures in the area at the end of the spit on April 12, 1964, during observation of one of the first tidal inundations. The sound of air escaping from the ground was heard and bubbles were seen as the tidewaters overran the spit. The air bubbles occurred in linear patterns near the dock (pl. 1). After the tide receded close examinations of the surface showed three large fissures southwest of Land's End Hotel.



10.—Offshore profiles showing the slope off the end of the Homer Spit. Lines of profiles plotted on plate 1. Data from U.S. Army Corps of Engineers. Profile A1 is the easternmost of the two shown on plate 1.

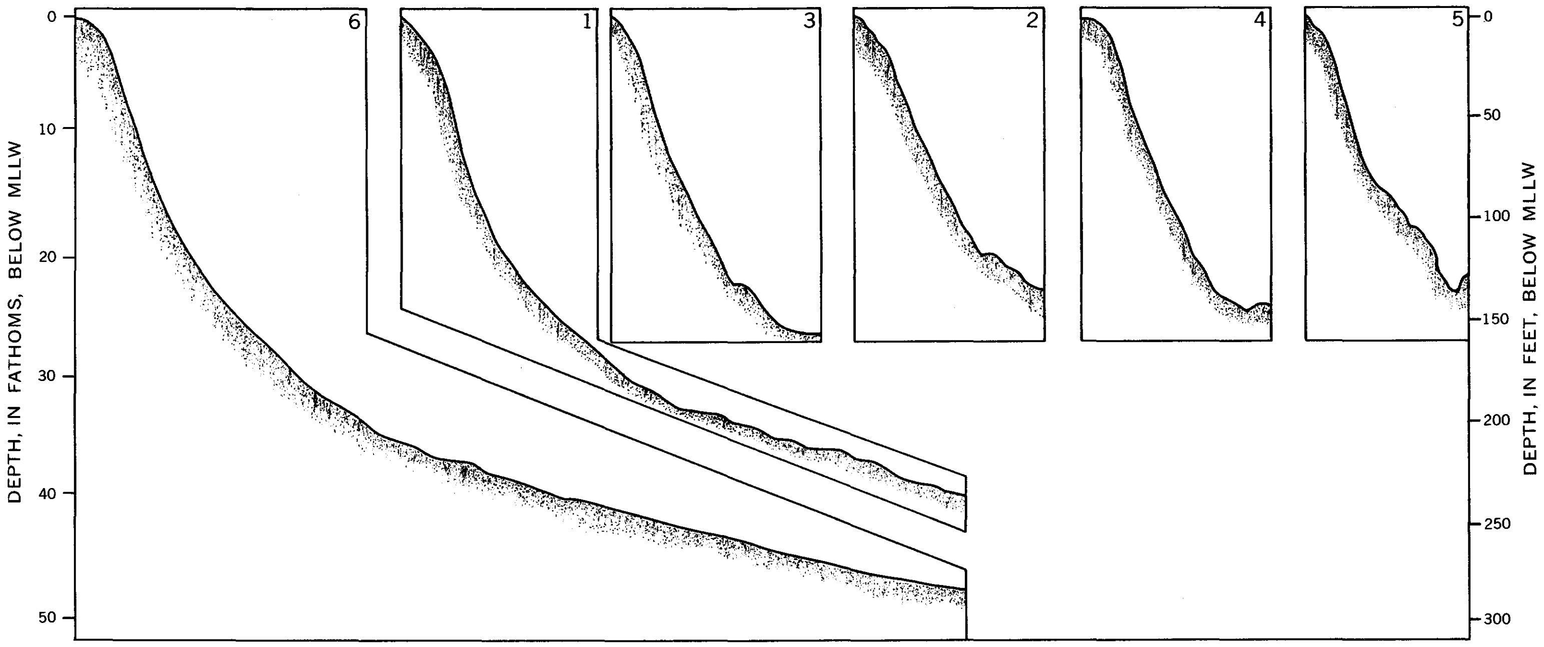
Other fissures were noted near the Alaskan Seafood plant, along the road, and near the west shore.

The fissures on Homer Spit were plotted (pl. 1) in their approximate locations. Many fissures were somewhat obscured by repeated inundation but, surprisingly, those in vegetated (dune grass) areas were still noticeable several months later. Grantz and others (1964, p. 24) reported that "Many of the fractures had vertical displacement, some as much as 8 inches, with the downdropped side toward the coast," presumably meaning both the bay and the ocean shoreline; hence the material was displaced downward between the fissures and the closest shoreline, a fact which suggests lateral spreading.

The fissures at the end of the spit were possibly related to the known slip of the breakwater and the collapse of land west of the Salty Dawg Saloon. Offshore bathymetry that might indicate slides also became available. The U.S. Army Corps of Engineers made a bathymetric survey in July 1964 at and adjacent to the small-boat harbor to determine the bottom topography and the displacement of the breakwater remains. The bathymetry (pl. 1) does not extend far enough seaward to show the full extent of the slide nor far enough around the end of the spit to show the supposed second slide. It does, however, show the position of some of the remains of the breakwater. In addition, four lines (pl. 1) were run offshore, each about 5,000 feet long. Three of these profiles are shown on figure 10. The log of test well 120 is also shown (fig. 10) to indicate the seeming coincidence of silty zones beneath the spit with offshore bulges or plateaus on the bathymetric profiles.

Rehabilitation of the Land's End Hotel and other facilities by the expenditure of Federal funds required that the Scientific and Engineering Task Force, established by the Federal Reconstruction and Development Planning Commission, evaluate the risk involved in reconstruction on the spit. The writer supplied data (Federal Reconstruction and Development Planning Commission for Alaska, 1964, p. 53) for the task force on earthquake effects at Homer and pointed out the potential slide danger. Further study of this hazard was requested. Extension of the Corps of Engineers'

797-974 O - 66 - 5



11.—Fathometer profiles showing the slope off the end of Homer Spit. Lines of profiles plotted on plate 1. Line 6 approximates line A2–1 of figure 10.

bathymetric survey was not feasible at the time, so a portable fathometer (used successfully by other Survey geologists in determining subaqueous slides in Kenai Lake and elsewhere) was used to run a few continuous profiles offshore to try to determine slide areas (locations on plate 1). Although the runs were hampered by the writer's inexperience with the instrument, the results are believed to confirm the presence of another slide west of the Land's End Hotel.

The instrument, which measures and continually records the water depths on paper, was carried in a small metal boat powered by an outboard motor. The transducer was set on the floor of the boat in a puddle of water. Experience of previous Survey investigators had indicated that this is convenient and satisfactory for obtaining accurate depth soundings.

The depth soundings were made on August 18, 1964, during low tide and a calm sea. Relative tide-gage readings on the U.S. Coast and Geodetic Survey gage on the Homer dock were 23 feet at the start of the first traverse and 21.5 feet at the end of the sixth traverse. The predicted low tide preearthquake level of 7.3 feet) occurred just at the end of the last traverse. Hence, a relative sea level of 22 feet was used as an average. The boat was run out an estimated one-half mile, and a line bearing was taken on two prominent shore landmarks. The fathometer was turned on when the boat reached a preset throttle speed of about 3 miles per hour. The recording of each profile was stopped just as the boat touched shore. Although the traverses were run in a straight line, the lengths of the traverses could not be determined with much accuracy. The profiles made by the Corps (pl. 1) were not continuous, so detailed correlation with the writer's profiles (fig. 11) was not possible. The profiles in figure 11 show various irregularities in configuration of the bottom. Humps that are especially prominent on the steeper (profiles 2–5, fig. 11) are interpreted either as recently deposited loose material that has slid down the slope or as the toes of incipient slides represented by the downdropped and fissured land on the shore (pl. 1).

Lack of horizontal control precluded contouring the offshore slope in detail, so the Corps of Engineers profile data (pl. 1) was used. The upper foreshore has a slope of about 22 percent, whereas the offshore slopes range from 6 to 12 percent. The contours show part of a scarp extending north-northeast and south-southwest transversely to the spit. The scarp terminates the relatively shallow platform of the Archimandritof Shoals (see fig. 14). The spit has been built onto this platform and extends out into the deep entrance of the bay.

Slope failures off the end of the spit apparently may have occurred, or started to occur, as a downward and outward adjustment—including lateral spreading—controlled by the platform scarp and the slope of the foreset bedding. Terzaghi (1956) indicates that subaqueous slides start by liquefaction of a water-bearing silt layer. Internal hydrostatic pressure can be built up by shock waves until relief occurs by lateral movement of the water and silt. Subsidence and slope failure follows, causing a slump or slide. The breakwater slide had the added factor of a heavy artificial load which contributed to the extended movement of the slide. The possible relation of slide planes to subsurface silt zones has already been mentioned.

SUBSIDENCE

An understanding of the cause of the subsidence of Homer Spit is very important as a guide to future construction. If the geologic conditions of areas that become compacted during high-magnitude earthquakes can be determined, an informed decision can be made on whether or not to build in such areas.

Compaction on Homer Spit is indicated by evidence already mentioned. Further evidence confirming that compaction or lateral spreading, or both, occurred was provided by a resurvey of a highway profile. The Alaska Department of Highways had surveyed the spit for a new road shortly before the earthquake. They resurveyed the line within a week after the earthquake and found that the spit was lower, principally on the outer end. A plot of the two surveys is shown on figure 12. The line of the profile is along the east side of the Spit road except near the outer end where it angles toward the dock (pl. 1).

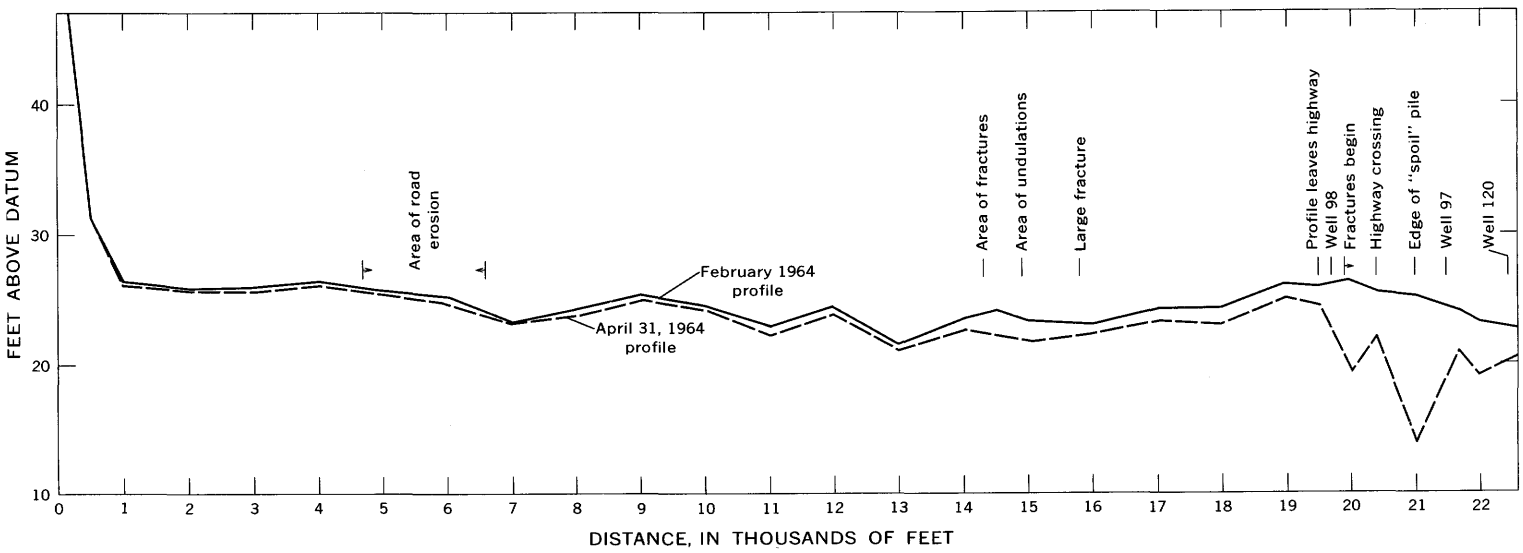
The profiles were tied to a bench mark near the airport, which is considered to have been unaffected by compaction. The resurveyed profile shows little change at the landward end and thus supports this conclusion. The tectonic subsidence, of course, lowered the bench-mark area as well as the spit by about 2 feet. The regional tectonic subsidence increases southeastward toward the hinge zone (Plafker, 1965). The subsidence on bedrock at Seldovia is 3.7 feet (U.S. Coast and Geodetic Survey, 1964b, p. 3); hence the tectonic subsidence at Homer should increase toward the end of the spit, possibly by as much as 1 foot.

The total amount of subsidence, including that resulting from compaction or lateral spreading as well as that from tectonic movements, has been determined at tidal bench marks (table 1) by the U.S. Coast and Geodetic Survey (1964b) and the Alaska Highway Department resurvey. The area of greatest subsidence, about 10 feet, is in the vicinity of the spoil pile formed by excavation of the small-boat harbor. Undoubtedly this material became compacted much more than the natural spit material. However, this area is adjacent to the breakwater slide, and the subsidence may be related to differential compaction or lateral spreading behind the submarine landslide. Release of pore pressure in a compacting silt accompanied the slide, and "progressive liquefaction" could have

TABLE 1.—*U.S. Coast and Geodetic Survey preliminary bench-mark altitudes on Homer Spit (based on April 1964 tide series)*

Bench mark	Altitude above mean lower low water (feet)		Subsidence (feet)
	Prequake	Postquake	
1	21.81	16.97	4.84
2	22.17	17.25	4.92
3	21.74	[1] 15.16	[1] 6.58
4	22.50	17.71	4.79
5	23.29	[1] 17.53	[1] 5.76
Homer East Base	24.37	[1] 19.48	[1] 4.89

[1] Calculations based on U.S. Coast and Geodetic Survey adjustment factor used on other Homer Spit bench marks.



12.—Profiles of Homer Spit surveys by the Alaska Highway Department. Datum is U.S. Bureau of Public Roads temporary bench mark 20, 70.25 feet above (preearthquake) datum. Vertical exaggeration × 200.

extended landward (Terzaghi, 1956).

The conditions indicating differential compaction near the end of the spit may also be related to a submarine landslide. Apparently liquefaction of a water-bearing silt in the material underlying the end of the spit could provide an explanation for the compaction or lateral spreading. The log of well 120 (table 2) shows silty layers at 96–104, 110–123, 130–138, and 140–165 feet which can be correlated with the depths of the anomalous features on the profiles (fig. 11). The earthquake shocks probably liquefied the silt; the liquefaction in turn caused the slope failure and subsidence beyond the scarps. Fortunately, the offshore slopes are not very steep; otherwise an even greater subsidence of the land near shore might have occurred.

An area of the spit about halfway from the mainland (fig. 12) apparently subsided more than adjacent areas. A possible reason for this local difference is suggested by the presence of the adjacent barge harbor. The harbor was recently excavated to a shallow depth to permit barge unloading. The excavation may have provided for the release of water pressure in a metastable formation during the earthquake that caused compaction by progressive liquefaction of some of the silty sediments. Stanley reported postearthquake subsidence in an area south of the groin-protected shore (p. D25). Even the lower high tides flood this area now. Possible causes of postquake subsidence are: (1) the additional diurnal loading of the material in the spit by the high tides, and (2) the gradual release of pore pressure that may have been built up in fine-grained material during the earthquake, and a resultant compression of the material.

TABLE 2.—*Log of well 120. Kachemak Water Co.*

[Drilled and logged by A. H. Thorn]

Material	*Thickness (feet)*	*Depth (feet)*
Deposits of Quaternary age:		
Gravel and sand	16	16
Gravel and sand (salt water from here on)	40	56
Sand, coal float, and gravel	6	62
Gravel, large, and sand	5	67
Gravel, small and medium, and sand	25	92
Gravel, large and medium, and sand	4	96
Silt, sand, gravel, and sea shells	8	104
Sand, coarse, and some gravel	6	110
Silt, sand, small gravel, and coal float	13	123
Gravel, large, and sand	2	125
Gravel and sand; some clay	3	128
Sand, coarse, and some gravel	2	130
Sand, fine, and silt	8	138
Gravel and sand	2	140
Silt, fine sand, and coal float	25	165
Gravel, large, and sand	6	171
Sand, medium	3	174
Gravel, large, and sand	8	182
Silt, sand, coal float, and some gravel	15	197
Silt, sand, coal float, and clay "glacial" (hit hard at about 200 ft)	13	210
Sand, fine, and some gravel; solid	3	213
Sandstone, fine	1	214
Silt and sand, fine, blue	6	220
Sand, fine; hard packed	2	222
Sand and some clay; drilled 5 ft ahead	21	243
Sandstone	4	247
Sand, loose, medium; shells	5	252
Silt, sand, and clay chunks	5	257
Sand, clay, and coal float	6	263
Sand and blue clay; increasing clay to 289 (water shut off at 273 ft)	26	289
Silt, sand, coal, and soft clay	4	293
Sand, fine (salt water ends)	1	294
Sand and clay	3	297
Clay, blue, sand and gravel; unit gradually increasing in clay content	24	321
Clay, blue	6	327
Clay, blue; some gravel and gas (flammable)	15	342
Clay, blue, and sand	1	343
Clay, blue, and semiliquid paste sand (salty water rises to 150 ft)	6	349
Clay, soft (drilled ahead, still water)	2	351
Gravel and clay (no water)	15	366
Clay, "marine" (water slow)	18	384
Clay, soft "marine"; gradually getting harder (no water)	33	417
Clay, blue, hard	8	425
Clay, soft, semiliquid	4	429
Sandstone, fine; contains small shells and coal bits	2	431
Clay, soft	31	462
Clay, hard	6	468
Kenai Formation(?)	9	477

NOTE.—The Kenai Formation may have been encountered at 289 ft. The presence of gas below 327 ft suggests the presence of the Kenai Formation.

HYDROLOGIC EFFECTS

Earthquake shock waves affect water bodies at great distances from the epicenters. Surface-water bodies act like inverted pendulums and are set in motion as the land moves under them. Oscillating waves, called seiches, are formed and can, under some circumstances, develop into large waves that may be destructive. Seiches presumably were developed in Kachemak Bay, Beluga Lake, other smaller lakes, in free pools of water in the creeks, and in water tanks in the Homer area. Most of the lakes and streams were ice covered on March 27. Seiches develop in water standing in wells also, but generally they are not noticeable in artesian wells because the seismic waves are compressing and dilating the confined aquifers and are thus causing a much greater effect on the water in the casing. These surges in artesian wells are usually not noted unless water is forced out of the well or the motion is recorded instrumentally.

At Homer, most of the observed hydrologic effects of the March 1964 earthquake were neglible. Many possible effects cannot be ascertained because few hydrologic data had been collected in the area before the quake.

IMMEDIATE EFFECTS

The most noticeable effect of the earthquake on the hydrology of Homer was the breaking of ice and seiching of water in Beluga Lake. Presumably the other small lakes and ponds in the area reacted similarly. At Beluga Lake, nearshore ice was broken by compression and overriding, and the rest of the ice was broken in random patterns. The north and south shores apparently had the most overridden ice. The ice was not broken as much along the west shore, which is formed by the highway (fig. 2). However, this western section of the lake is probably the deepest part or has the steepest nearshore lake-bottom gradient; either characteristic would tend to reduce the overriding effect. Natural and artificial lakes in other areas appeared to show preferred directions of ice breakage related to the direction of the earthquake-wave propagation (Grantz and others, 1964, p. 6).

Streams were near their lowest annual flow and had their thickest cover of ice at the time of the earthquake. All streams in this area are small and have narrow flood plains. Hence, very few effects on streams were noted by residents.

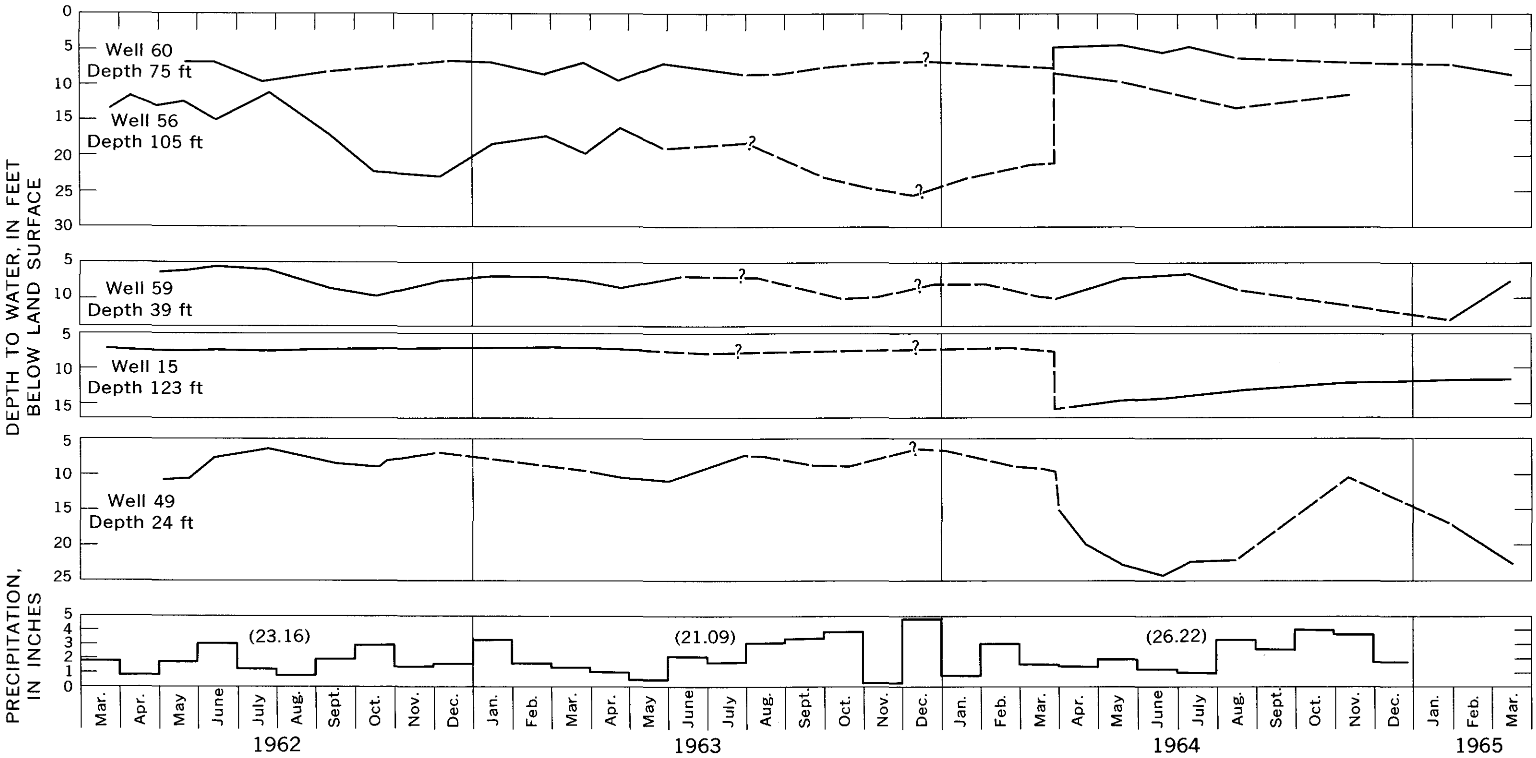
Increased or decreased stream discharge could not be determined because of lack of appropriate records. The only evidence that might indicate a greater discharge is the level of Beluga Lake. Four measurements made at the lake outlet in the May–August 1964 period showed that the lake level was averaging 2–3 feet higher than comparable periods in 1962 and 1963. This higher level may have been due to increased discharge of the escarpment streams feeding the lake.

A temporary increase in sediment load probably resulted from landslides and rockfalls in the canyons along the escarpment; in May extremely silt-laden flows of the streams occurred. Precipitation in April and May was about average. Analogy with daily observations on a stream near Palmer (Waller, 1966) indicates that the increased sediment load probably lasted about a month. As soon as all the finer material of the slide debris was washed away, the streams resumed their normal erosive pattern. The sediment load presumably was carried to the lower reaches of the streams. Bear Creek and five lesser streams deposit their sediment loads in Beluga Lake.

The immediate effects on the ground water included a few failures of domestic water-well systems and muddied or turbid well or spring water. There were no water-level recorders on wells in the Homer area, but the observed movement of the land, the effects noted above, and observations elsewhere (Plafker, 1965; Waller and others, 1965) indicate with certainty that ground water in the Homer area was affected by the earth tremors. These effects are shown by residual changes of water levels in wells which had records of water-level measurements extending back to 1962 (fig. 13, next page).

The failures of some of the well systems resulted from sanding or silting of the pump due to agitation of the wells and differential movement of well casings and the surrounding rock. Most of the wells are unscreened and have 1 to several feet of uncased hole (Waller, 1963, table 1). These conditions readily lend themselves to caving or slumping of the walls under earthquake stress. Hence, pumps turned on or automatically activated when electric power was restored pumped this material into the system and caused turbid water or malfunction of the pump. Other wells that have pumps requiring a full pipe of water for a prime probably lost their prime owing to surging in the well. Thus, reports of dry wells were common, as they usually are after most earthquakes.

Water quality is and has been a serious problem at Homer. The various aquifers differ from one another in chemical quality of the water. Gas is present in the water at many places. Temporary changes in water quality at Homer are probably related to turbidity, whereas any permanent changes that might be noticed later may be due to leakage between aquifers along loosened well casings. The stresses may also have caused local increases in fractures or permeability



13.—Hydrographs of five Homer wells showing long-term effects of the earthquake. Locations of wells shown on figure 2.

which would allow interchange of aquifer waters.

Many wells were reported to have become dry because of the earthquake, but only two of these reports were verified. One well (No. 99, fig. 2) was checked by the local driller who reported (A. H. Thorn, oral commun., July 11, 1964) that the well was "bone dry" and when he poured two pails of water in the well "they drained right out." Mr. Thorn also reported that other wells had sanded up and that one near Bluff Point lost most of its yield. This location is near the bluff, and the water level probably fell because of increased discharge from the aquifer through a fracture in the bluff. All the affected wells obtain water from sand in the Kenai Formation. The gradual loss of water in the other well verified dry is discussed on page D17.

LONG-TERM EFFECTS

Long-term hydrologic effects of earthquakes include increased or decreased stream discharge, increased sediment loads of streams, aggradation or buildup of stream channels resulting from lowered land surfaces, changes in water quality, and residual changes in water levels in wells. The only quantitative data available at Homer relate to water-level changes in wells. An observation-well network was maintained from March 1962 until August 1963 to aid in studying the ground-water hydrology of the area. Data on stream flow consisted of only a few random discharge measurements, and data on sediment load of streams were nonexistent. Data on the quality of ground water, on the other hand, were available for many places (Waller, 1963, table 3), but no long-term changes in water quality appear to have occurred except in a shallow aquifer on Homer Spit.

GROUND WATER

Long-term changes in water levels in wells at Homer were indicated by residual changes from prequake levels. These residuals, whether permanent or semipermanent, indicate changes in the physical structure of the aquifers. Such residual changes in artesian pressure as a result of other earthquakes have been reported (Piper, 1933; Leggette and Taylor, 1935; Piper and others, 1939; Thomas, 1940; LaRocque, 1941; Brown and Ayer, 1948; Tsuya, 1950; Davis and others, 1955; Ferris and others, 1955; Swenson, 1964.) Many of the authors cited also discussed the mechanisms involved in causing the changes. In brief, residual changes are caused by a change in aquifer-pore space created by rearrangement of grains or fractures as a result of the release or development of stress or strain imposed by an earthquake.

Of the 19 Homer wells for which previous periodic water-level observations were made, 15 were remeasured during 1964. The first two rounds of postearthquake measurements showed three wells in which water levels were unchanged, four in which water levels were higher, and eight in which water levels were lower than before the quake. These residual changes, some of which may be permanent, show no apparent correlation with location on the upland, bench, or lowland, nor with Tertiary versus Quaternary aquifers. Because the first measurements were not made until 9 days after the earthquake, the extremes of change are not known.

The hydrographs of the five wells previously used for observation that showed the largest residual changes in water levels are plotted in figure 13. The hydrograph for the 8-month period before March 27, when no water levels were determined, is estimated on the basis of the earlier records and depends on the writer's knowledge of hydrologic conditions at Homer and on correlative seasonal control by measurements in wells in the Matanuska Valley and Anchorage.

The record for well 49, dug on the escarpment near Bluff Point (fig. 2), is of special interest. The well is 24 feet deep and is unused; it taps an unconfined aquifer. The water level in the well dropped steadily for about 3 months after the earthquake. The June measurement found only moist mud at the bottom of the well; thus the water level dropped at least 9 feet and possibly as much as 14 feet. In July the water level made a recovery, and a complete recovery was finally shown, nearly 8 months after the quake, by the November measurement. However, the 1965 winter measurements showed a decline that did not occur in preceding winter periods, but one that is comparable to the postearthquake decline.

Well 49 probably taps a local water body perched on virtually impermeable Tertiary rock. This impermeable layer fractured, probably minutely from surface fissures, and allowed the perched water to drain slowly downward or laterally toward a nearby topographic low. Recharge from summer and fall precipitaton exceeded the percolation rate and allowed the water to accumulate to its former level. As winter frost developed and inhibited recharge, the water table again fell, but to a lower level than previously, attesting to an increase in permeability of at least a nearby part of the Tertiary rocks. Surface fissures were not noticed in the heavily grass-covered area, but numerous fissures were seen nearby (fig. 5). The behavior of this well and the local conditions are similar to those of a well described by Brown and Ayer (1948).

Well 15 on the lowland bench (fig. 2) also shows a change that is obviously due to the earthquake. It is a 123-foot drilled unused well tapping an artesian aquifer in sand of Tertiary age (Waller, 1963). The casing reportedly extends to 123 feet and is open ended. The water level in this well had not varied more than 0.6 foot in the 2 years of measurements before the earthquake. The water level in this well was displaced downward more than 8 feet when measured on April 5, 9 days after the earthquake. Subsequent measurements show a steady rise, and full recovery to preearthquake levels may be achieved in time.

The hydrograph for well 56 shows an immediate residual rise of about 12½ feet, perhaps because compaction of the aquifer caused decreased permeability and a higher static head. The persistence of the higher water level may be a result of decreased use during the summer of 1964. The well is normally used to supply water by tank truck to the Land's End Hotel during the summer tourist season, but the hotel's "face lifting" during the 1964 season cancelled the need for a fresh-water supply. Well 60 also shows a rise that may be due to seismic causes, such as a decrease in porosity of the sand aquifer. Well 59, as indicated by the hydrograph, showed little or no effect from the earthquake.

One well on East Hill Road near East Road should be mentioned for the record. Measurements, started soon after the well was drilled in 1963, showed a water level of about 30 feet in this 121-foot drilled well which taps an artesian aquifer in rocks of Tertiary age. Three measurements in the period from June 1964 to March 1965 show a water level of about 61 feet. The well owner reported that he had installed an automatic clothes washer and used it heavily in the interim between the 1963 and 1964 measurements. The lower water level in 1964 probably reflects the new conditions imposed on the well by relatively continuous withdrawals and not a 30-foot drop resulting from the earthquake.

In summary, some aquifers in the Homer area apparently were disturbed by the earthquake, but most show a gradual return to preearthquake conditions, insofar as these conditions are reflected by water levels in the wells.

QUALITY OF WATER

Changes in quality of water obtained from wells were not noticed by residents of the area, so no water samples were taken for chemical analysis.

A change in quality of the ground water on the spit was made apparent, however, by the death of the evergreen trees at the campground (fig. 2). The low knoll at the campground is probably inundated by extreme high tides that contaminate the thin lens of fresh water available for the trees prior to the earthquake. A thinning of the lens because of subsidence is also a possibility. A dug well at Munson Point reportedly was also salty after the earthquake but the water became fresh by late summer.

SEISMIC HISTORY AND CONCLUSIONS

Homer residents are quite used to earthquake shocks; however, no written history is known of the earthquakes recorded or felt in the area since it was settled about 1888. Heck and Eppley (1958) and Davis and Echols (1962) have compiled lists of Alaskan earthquakes from which the writer has excerpted data on the location, date, and time of earthquakes of magnitude 5 or greater that had a reported effect at Homer or that occurred within a radius of about 100 miles of Homer (table 3). It is hoped that this compilation may encourage a more complete recording of such events, possibly by local residents from local archives. The table shows that the earliest known major earthquake near the Homer area occurred in 1883 at nearby Augustine Island.

There have been four earthquakes of magnitude 6.75–7.75 within a radius of 100 miles of Homer. Two earthquakes at or near Homer had intensities of V to VI on the Modified Mercalli scale.

There is evidence of a large landslide at Bluff Point which may have been set off by a prehistoric earthquake. Barnes and Cobb (1959, pl. 2) mapped the low bench beneath the bluff as a landslide deposit. Karlstrom (1964), however, mapped the same bench as a moraine of Naptowne age, but noted (p. 47) that the moraine is covered by landslide debris during a "sudden impulse" of deposition. In previous fieldwork (U.S. Geological Survey unpub. data) the writer noted the material as landslide debris also but followed Karlstrom's mapping scheme. The discussion above seems warranted to point out the potential of the bluffs—particularly the 700-foot Bluff Point—to slide if a major earthquake occurs close to Homer in the future (fig. 16).

Perhaps of greatest importance to Homer is the potential of future tsunamis acting upon Homer Spit. The 1883 volcanic eruption and(?) earthquake (Dall, 1884) created a wave that undoubtedly hit and probably overtopped the Homer Spit. The reports from Port Graham (fig. 1) observers stated (Dall, 1884, p. 92–93) that an estimated 30-foot wave rolled in at 8:30 a.m. after they had seen and heard the volcano on Augustine Island erupt. The wave deluged houses on the lowland and washed boats and canoes away, even though the tide was "extremely low." Other waves of lesser height followed the first one. It seems certain that these waves were tsunamis and that they struck the Homer Spit also. Evidently, tsunamis that would hit Homer could only be generated from a seismic disturbance in the lower Cook Inlet area because of Homer's somewhat sheltered location from the open sea. Seiches, however, can develop with any major earthquake in the region and can be destructive if they coincide with high tide.

Submarine landslides, usually, but not always, generated by earthquakes, are another potential hazard at the distal end of Homer Spit. Thus extensive building on the outer end of the spit seems very unwise.

TABLE 3.—*Summary of larger earthquakes occurring within about 100 miles of the Homer area in the period 1788–1961*

Date	Local time	Approximate location (lat. N.; long. W.)	Estimated magnitude (Richter scale)	Remarks
Oct. 6, 1883	0800	Augustine Island (59°, 154°).	----------	Volcanic activity; seismic wave struck Port Graham.
Aug. 1898	------	South-central Alaska	----------	Trees swayed violently at Susitna Station.
July 11, 1899	------	Tyonek (61°, 152°)	----------	Severe.
Oct. 7, 1900	------	do	----------	Severe. Probably is same as following one.
Oct. 9, 1900	0216	South-central Alaska	----------	Severe, felt at Seldovia.
Dec. 30–31, 1901.	------	Kenai	----------	Volcanic eruption and several sea waves.
Sept. 19, 1909	1000	Kenai Peninsula	----------	Strong at Seward.
Sept. 21, 1911	0701	Prince William Sound and Kenai Peninsula (60.5°, 149°).	6.9	Severe, felt at Kenai Lake.
Dec. 9, 1927	------	South-central Alaska	----------	Kenai Lake severely shaken by three quakes.
Jan. 27, 1931	0429	do	5–6	Cracked walls in Seward.
Oct. 6, 1932	0705	Homer	----------	Awakened all.
Apr. 26, 1933	1703	Susitna Flats (61.25°, 150.5°).	----------	At Homer, worst shock in 15 years.
May 13, 1933	------	Old Tyonek	----------	Severe, some damage.
June 13, 1933	0219	Northeast of Nikishki (61°, 151°).	6.25	
June 17, 1934	2314	Soldatna (60.5°, 151°)	6.75	
Oct. 10, 1940	2153	Mouth of Kachemak Bay (59.5°, 152°).	6	
July 29, 1941	1551	Northeast of Nikishki (61°, 151°).	6.25	Damage at Anchorage.
Dec. 5, 1942	0428	Mouth of Kachemak Bay (59.5°, 152°).	6.25	
Sept. 27, 1949	0530	Blying Sound (59.75°, 149°).	7	Strong aftershock also. Damage at Seward and Anchorage.
June 25, 1951	0612	Chickaloon Bay (61°, 150°).	6.25	Damage at Anchorage.
Oct. 3, 1954	0118	Caribou Hills (60°, 151°)	6.5–7	Damage at Homer.
Jan. 24, 1958	1317	North-northwest of Anchor Point (60°, 152°).	6.25–6.5	
Mar. 19, 1959	0503	South of Perl Island (58.6°, 152°).	6.25	
June 4, 1959	0231	50 miles W of Homer (59.5°, 153°).	5.5	
Dec. 26, 1959	0819	Stariski Creek (59.9°, 151.7°).	6.25	
Sept. 5, 1961	0134	Bradley Lake (59.8°, 150.6°).	6–6.25	Felt. Anchorage rocked.
Sept. 24, 1961	1627	North of Mount Iliamna (60.3°, 153°).	5.75–6	

BEACH CHANGES ON HOMER SPIT

By Kirk W. Stanley, Alaska Department of Natural Resources

INTRODUCTION

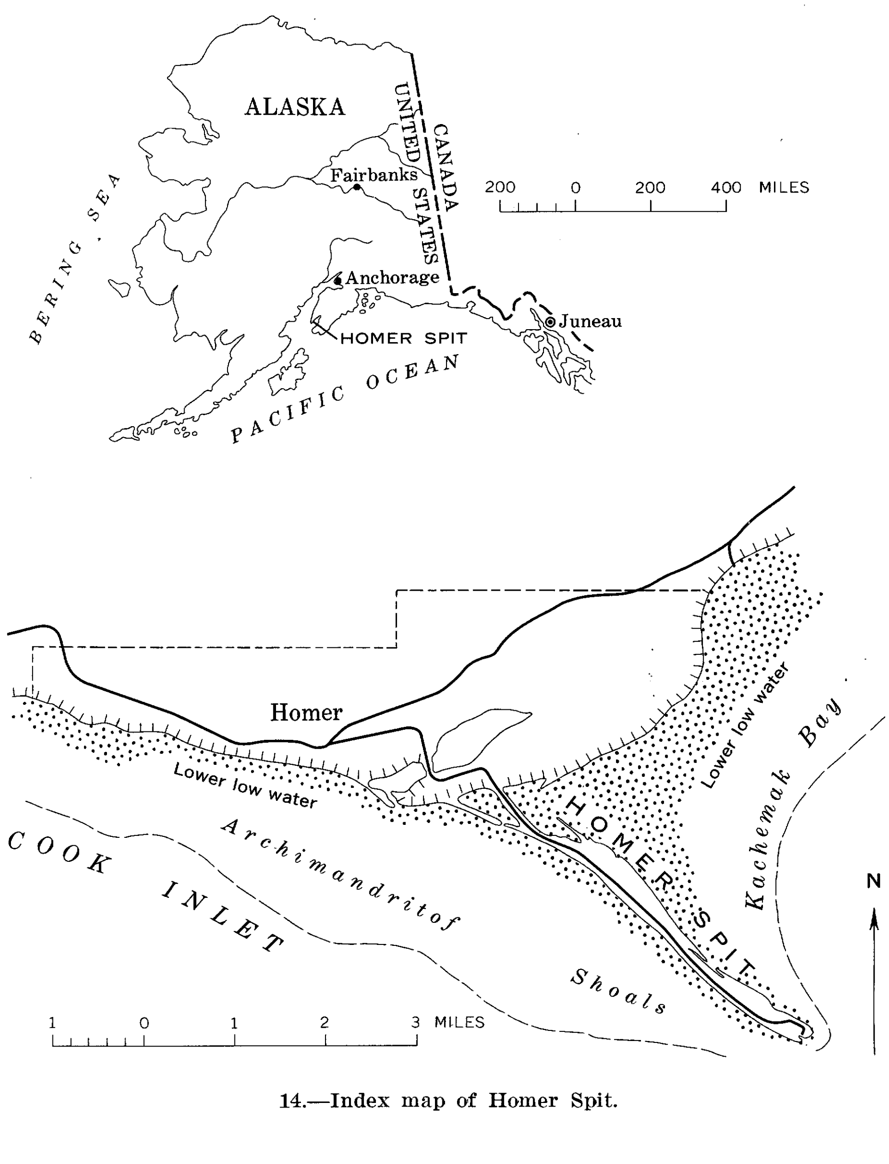
Homer Spit is a well-known landmark on the Kenai Peninsula along the east shore of lower Cook Inlet (fig. 14). Along with its growing popularity as a recreational area, the spit provides one of the few deep-water ice-free ports along the east side of Cook Inlet. During the earthquake of March 27, 1964, the general area subsided tectonically, and the spit is now lower by 4.26–5.70 feet and is nearly 70 percent covered during the higher tides (fig. 15). The relatively higher stand of the sea upon the spit has caused changes in shore processes and beach morphology which are still in progress.

GENERAL SETTING

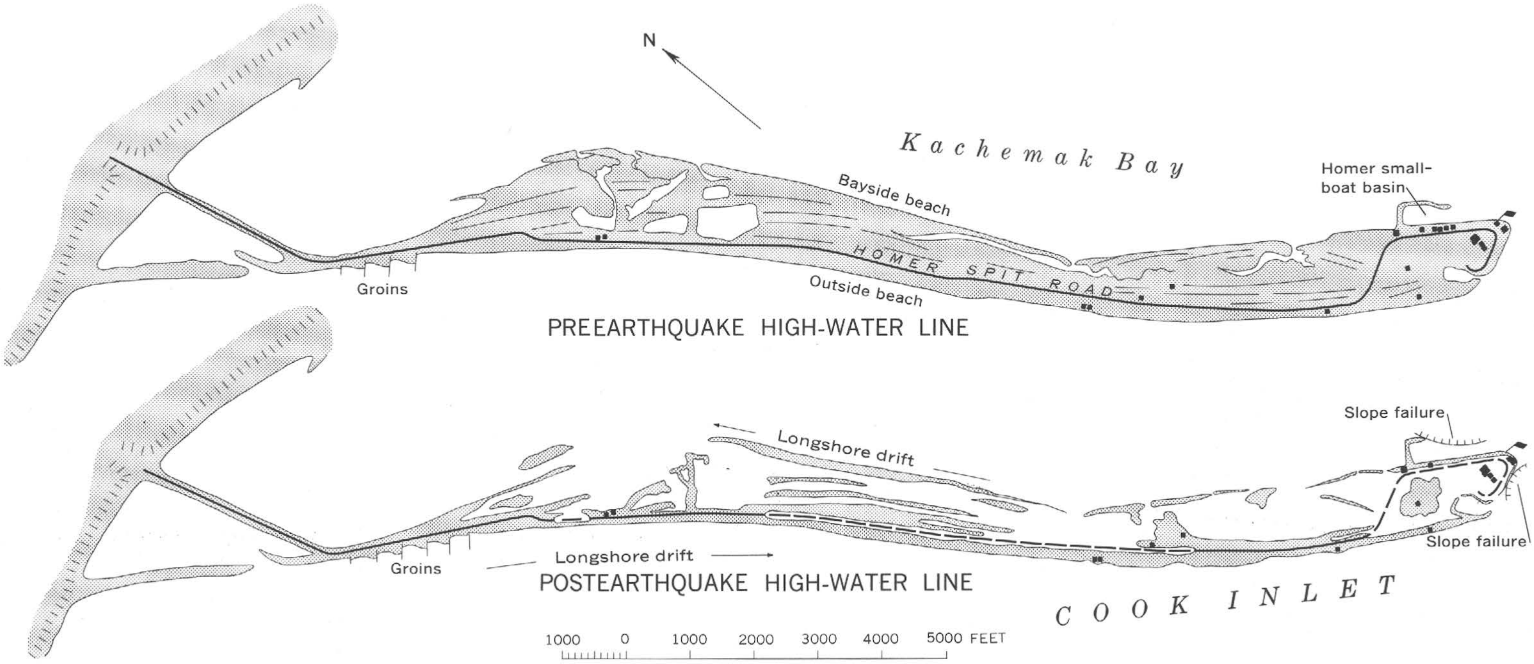
Homer Spit, about 4 miles long and as wide as 1,500 feet, lies partially athwart the entrance of Kachemak Bay on a shallow shelf called Archimandritof Shoals. In plan the spit resembles a scimitar, with its curved blade pointing seaward and its narrow hilt attached to the mainland (fig. 15). The spit is composed largely of medium gravel, or shingle, intermixed with some sand. Although Homer Spit is considered by Karlstrom (1964, p. 20) to be a relic glacial feature, the old lateral beach ridges upon the surface clearly illustrate that the spit is, at least in its present form, a product of littoral processes. The old beach ridges, moreover, indicate that the spit widened from east to west. During the past few decades, however, the west side of the spit has receded slightly eastward near the base.

The source area of material composing the Homer Spit is probably the mainland to the west. The shoreline there is characterized by wave-cut bluffs composed of partially consolidated coal-bearing shale and sandstone (fig. 16). After the earthquake and subsidence, shoreline erosion in the source area increased and much new material has entered the sea and the littoral drift.

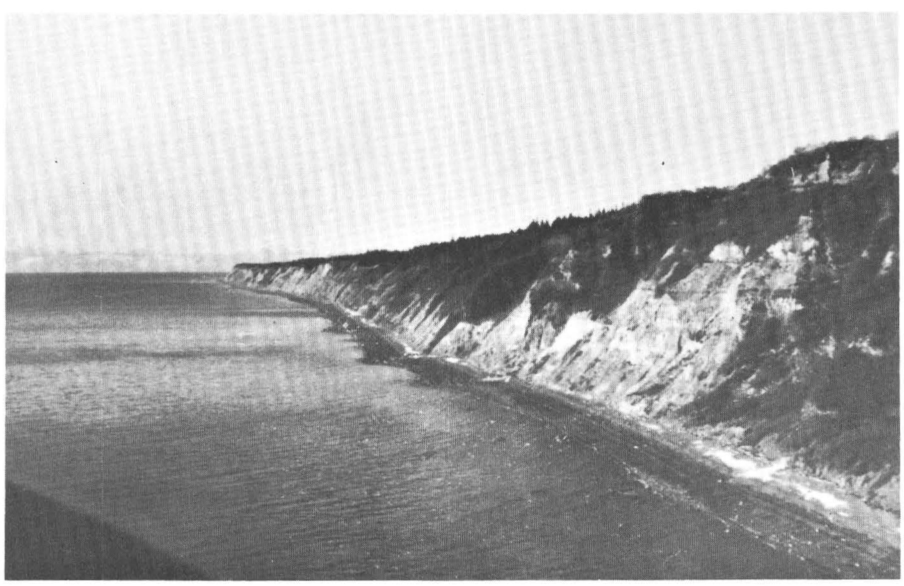
The net direction of the littoral drift along the Cook Inlet side of the spit is southeast, whereas along the bay side it is probably northwest. The maximum calculated wave height along the outside beach is about 10 feet, and along the bay side, about 4 feet. The tides are of the mixed type; two lows and two highs occur



14.—Index map of Homer Spit.



15. Comparison of the high-water line along Homer Spit before and after the earthquake and submergence of March 27, 1964. Light lines on Spit represent old beach berms. High-water line traced from U.S. Army Corps of Engineers aerial photographs, September 1959, and from U.S. Bureau of Land Management infrared photographs, August 1964.



16.—Shoreline west of Homer Spit, probably the source area of material composing the spit.

daily. The maximum tidal range is about 23 feet.

The beach along the spit can be conveniently subdivided into an upper and a lower foreshore. The upper foreshore along both sides of the spit slopes from 1:00 to 1:20, but it steepens to about 1:8 at the seaward, or distal, end. A storm, or frontal, berm forms the beach crest, but because the berm is higher than the old beach ridges along the interior, the spit is slightly basin shaped.

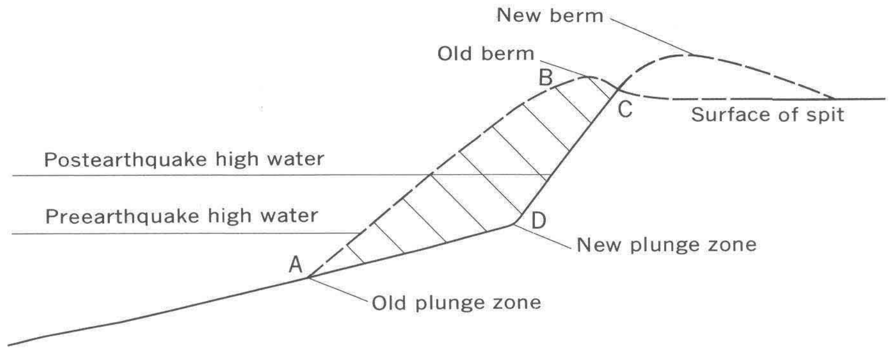
The plunge zone separating the upper and lower foreshore is 100–300 feet seaward of the beach crest and is generally marked along the outside beach by a conspicuous accumulation of cobbles at about the 10-foot level. Seaward of the plunge zone the lower foreshore is characterized by broad sandbars along the outside beach, and by wide silty mudflats along the bay side. The lower foreshore slopes as little as 1:150, but along both sides the slope gradually steepens and the width narrows toward the distal end of the spit where the slope of the lower foreshore steepens to as much as 1:10.

SUBSIDENCE AND POSTEARTHQUAKE CHANGES

The Homer area, including Homer Spit, subsided during the earthquake, as did other regions of south-central Alaska. However, the U.S. Coast and Geodetic Survey has not published final figures confirming the actual drop. The figures released to date are based on short-term tide gage readings and first-order leveling from Anchorage. These data show that the total subsidence, including regional subsidence, measured at the end of Homer Spit, ranges from 4.26 to 5.70 feet.

The spit in subsiding apparently underwent progressive, but not uniform, consolidation and compaction of sediments from the landward to the distal end. To determine how much the spit proper had subsided, the Alaska Department of Highways (1964, p. 8) made a resurvey of the spit soon after the earthquake. The control used for the survey was an existing U.S. Coast and Geodetic Survey bench mark on the mainland. The survey showed the distal end of the spit to be 2.5 feet lower, relative to this bench mark, than it was prior to the earthquake. Early evidence indicated that the spit subsided progressively from the landward to the distal end, however, much of the subsidence due to compaction apparently occurred at the distal end (see p. D13).

At least one beach slope failure, or submarine landslide, and possibly others (p. D10), occurred at the distal end of the spit (fig. 15). There is no direct evidence of slope



17.—Beach-face recession diagram showing the preearthquake upper foreshore slope (line *AB*) and the postearthquake slope (line *CD*). After subsidence, material within *ABCD*, as a result of the higher water level, was scoured and in part carried onto the spit where it formed a new frontal berm.

18.—Storm berm developed along spit within 6 months after subsidence. Berm before subsidence was less than 3 feet high and 4–5 feet wide at the base.

failures elsewhere. Instead, the changes and alterations of the beach along the Homer Spit are related to slow shore processes that can be attributed to: (1) the ability of storm waves to act higher upon the beach face and (2) the increased quantity of material carried to and deposited along the spit by the littoral drift.

BERM DEVELOPMENT AND BEACH-FACE RECESSION

Immediately after subsidence the relative higher stand of the sea resulted in erosion and the consequent recession of the upper beach face. A large part of the material eroded from the face was carried onto the spit where it formed a new storm or frontal berm. The most conspicuous berm development is along sections of the outside beach. The process of berm development and beach-face recession is shown by figure 17. The relative higher water level has shifted the plunge zone shoreward and caused material within area ABCD of figure 17 to be scoured by wave action. Part of the scoured material is transported onto the spit by the swash and accumulates as a new berm.

As an illustration of berm growth, the preearthquake berm at the distal end of the spit was less than 3 feet high, and 4–5 feet wide at the base. Six months after the earthquake, the berm, as shown by figure 18, had built up to 6 feet in height and had widened to nearly 60 feet. The same berm after another 6-month period had widened an additional 20 feet. Elsewhere the berm has migrated around buildings and covered and blocked roads.

The size of the new berm is not in proportion to material lost from, nor to the recession of, the adjacent beach face. Figure 19 shows an example of this disparity. Such examples show that a large part of the material scoured from the beach face was was not carried onto the spit and deposited as part of the berm. According to King (1959, p. 280), most of the scoured material is carried seaward and is lost. To what extent this is true along Homer Spit is not known. However, the absence of noticeable new shingle along the lower foreshore fails to support the conten-

19.—Photographs taken 6 months after subsidence (top) and a year after subsidence (bottom) show that the size of frontal berm is not proportional to the recession of the beach face.

tion that any appreciable material is migrating toward the sea. More likely, the bulk of material scoured from any one section of the beach has merely drifted farther along the beach. Material drifted to the distal end and not deposited on the beach there is probably lost to the sea.

The entire beach face along the spit has retreated, but not uniformly so. The most noticeable recession is along the outside beach where local areas show a loss of nearly 30 feet, but 10–15 feet probably approximates the overall average. The maximum beach-face recession was about 56 feet and occurred along one limited section at the distal end of the spit.

20.—Section removed from seaward end of groin to allow bypassing of material.

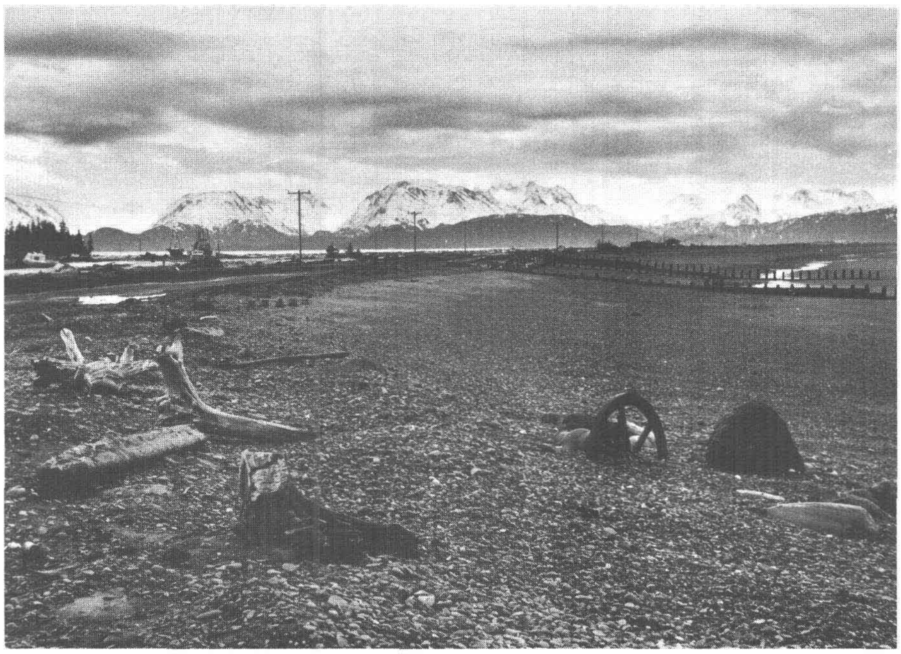
MATERIAL SUPPLY AND TRANSPORT

Subsidence has ushered in what can be loosely described as a new cycle of shoreline erosion. As a result of accelerated erosion in the source area, much additional material has entered the littoral drift and migrated to the spit. The quantity of material now being transported by the littoral drift can only be estimated, but it clearly exceeds the quantity carried before the earthquake. For example, observations of groins along the spit (fig. 15) indicate that about 1 month after subsidence the fill behind the groins began to enlarge noticeably. The 1-month lag apparently represents the time required for material to enter the drift and migrate from the source area to the spit.

21.—Erosion on the lee side of the last of a series of four groins, a few days after the earthquake.

As more material is eroded from the source area and migrates to the spit, it replaces and augments that lost by scour from the beach face. Moreover, the frontal berm has grown in height and width to the extent that after 1 year it is overtopped by only the stronger storm swashes. Thus, although more material has become available to the spit, less is carried onto the frontal berm and a larger amount remains upon the beach face. As a result, the outside beach is beginning to build, particularly along the outer two-thirds of its length.

Only a minor quantity of material migrates from the outside beach around the end of the spit to the bay side. Moreover, since sub-



22.—The same area as shown in figure 21, 1 year later, after construction of two new groins (right background).

23.—Cobble-filled baskets placed on beach face to prevent erosion.

sidence the flooding of the low areas along the bay side at high tide separates the beach into relatively short sections. Material that does find its way around the spit or is scoured from the bay-side beach face is obstructed in its longshore migration by these numerous inlets. The bay-side beach therefore is gradually wasting (Stanley and Grey, 1963, p. 5), a condition also evident before the earthquake.

SHORE PROTECTION WORKS

Erosion, always a problem along the exposed side of the spit near its base, was controlled in one area prior to the earthquake by four timber groins (fig. 15). Shortly after the earthquake the fill between the groins was eroded and the face receded, but after 1 month additional material accumulated and the fill exceeded the preearthquake level. Because the groins were adequately protecting the shoreline, additionally entrapped material served only to deplete the amount moving along the beach. Therefore, to allow bypassing but still preserve the existing fill, a 50-foot section near the end of the last two groins was removed (fig. 20). Some loss of fill occurred, but in general the slope of the fill adjusted to the new conditions. However, erosion on the downdrift or lee side of the last groin became critical. The eroding area on the lee side of the groin is shown by figure 21, taken a few days after the earthquake. To protect the lee side, two additional groins were constructed. Figure 22, taken 1 year after the earthquake, shows the extent of accretion in that area.

Prior to the earthquake, old car bodies were placed along one eroding section on the exposed side of the spit, and they provided some protection. Within a few weeks after subsidence, however, the larger waves scattered the car bodies about the beach.

At one location a small cannery was endangered by undermining. Specially manufactured and prefabricated wire baskets were filled with cobbles and placed along the beach face (fig. 23). After 1 year the beach has built up and has shown no tendency to scour in front of the cobble-filled baskets.

24.—Bar being built across the entrance of a tidal inlet at distal end of Homer Spit. Photograph by U.S. Army Corps of Engineers, April 30, 1964.

TIDAL INLETS

Since the earthquake and subsidence, more water enters and leaves the tidal inlets on each tidal change. During the flood tide, material drifting along the beach is deflected inward toward the basin, whereas on the ebb tide the outflow tends to deflect the material seaward. As a result, the tidal entrances tend to interrupt longshore drifting.

Some of the finer material migrates into the tidal entrances, and considerable sand and silt are being deposited in each basin. The coarser material tends to be deposited near the entrances where it forms deltalike features. As the delta features enlarge, they tend to further obstruct material drifting along the beach by promoting additional deposition or by deflecting the drift seaward.

A somewhat different situation has developed at the tidal entrance on the distal end of the spit (fig. 24). There the increased rate of deposition brought about by the added load of material in the littoral drift has caused a bar to build outward from the updrift side across the original tidal entrance. As the bar has enlarged, the entrance channel has gradually shifted toward the downdrift side. Deprived of natural increase by the bar, the downdrift side of the channel is gradually wasting.

SUMMARY

Prior to the earthquake, Homer Spit had probably attained a stage of maturity. Active erosion along the landward third of the spit on the Cook Inlet side reflected an absence or scarcity of nourishment from the source area. Material, while accreting along the outer two-thirds of the spit, was partially derived from the landward third. The growth rate of the spit may therefore have been declining through a lack of adequate material supply.

Following subsidence the upper beach face along the spit was eroded and receded. But regional subsidence also accelerated erosion in the source area—the mainland adjacent to the spit. More material thus began to enter the littoral drift and migrate to the spit. This added material has tended to offset the loss of material eroded from the beach face along the spit following subsidence.

The increased supply of material is not likely to decline appreciably for many years, and eventually the frontal berm will, if not artificially disturbed, achieve a height sufficient to prevent overtopping by all but the larger storm swashes. As the process of deposition continues, the beach along the Cook Inlet side, especially along the outer two-thirds of the spit, will gradually widen. Along the bay side, the beach face will probably recede further, and its stability will depend, in part, on the type and location of artificial improvements that may obstruct longshore drifting.

Subsidence has not materially altered the nature of shore processes along the spit; instead it has merely accelerated their rate. Therefore, the lasting effect of subsidence upon the spit (excluding flooding) will be the accentuation of deposition along the beach on the Cook Inlet side and continued erosion and gradual wasting of the beach along the bay side of the spit.

REFERENCES CITED

Alaska Department of Highways, 1964, Homer Spit: Alaska Dept. Highways Reconn. Rept. Proj. F-021-(14), 16 p.

Barnes, F. F., and Cobb, E. H., 1959, Geology and coal resources of the Homer district, Kenai coal field, Alaska: U.S. Geol. Survey Bull. 1058-F, p. 217-260.

Brown, R. H., and Ayre, G. R., 1948, Upstate New York *in* Water levels and artesian pressure in observation wells in the United States in 1945, pt 1, Northeastern States: U.S. Geol. Survey Water-Supply Paper 1023, p. 191-195.

Dall, W. H., 1884, A new volcano island in Alaska: Science, v. 3, no. 51, p. 89-93.

Davis, G. H., Worts, G. F., Jr., and Wilson, H. D., Jr., 1955, Water-level fluctuations in wells, *in* Earthquakes in Kern County, California, during 1952: California Div. Mines Bull. 171, p. 99-106.

Davis, T. N., and Echols, Carol, 1962, A table of Alaskan earthquakes, 1788-1961: Alaska Univ. Geophys. Inst. Geophys. Research Rept. 8 [UAG-R113], 43 p.

Federal Reconstruction and Development Planning Commission for Alaska, 1964, Response to disaster, Alaskan earthquake, March 27, 1964: Washington, U.S. Govt. Printing Office, 84 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Ground-water hydraulics—Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536-E, p. 69-174.

Grantz, Arthur, Plafker, George, and Kachadoorian, Reuben, 1964, Alaska's Good Friday earthquake, March 27, 1964, a preliminary geologic evaluation: U.S. Geol. Survey Circ. 491, 35 p.

Heck, N. H., and Eppley, R. A., 1958, Earthquake history of the United States, pt. 1: Revised ed., U.S.

Coast and Geod. Survey serial 41–1, 80 p.

Karlstrom, T. N. V., 1964, Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geol. Survey Prof. Paper 443, 69 p.

King, C. A. M., 1959, Beaches and coast: London, E. Arnold, 403 p.

LaRocque, G. A., Jr., 1941, Fluctuation of water level in wells in the Los Angeles Basin, California, during five strong earthquakes, 1933–1940: Am. Geophys. Union Trans., v. 22, p. 374–386.

Leggette, R. M., and Taylor, G. H., 1935, Earthquakes instrumentally recorded in artesian wells: Seismol. Soc. America Bull., v. 25, no. 2, p. 169–175.

Piper, A. M., 1933, Fluctuations of water surface in observation wells and at stream-gaging stations in the Mokelumne area, California, during the earthquake of December 20, 1932: Am. Geophys. Union Trans., 14th Ann. Mtg., p. 471–475.

Piper, A. M., Gale, H. S., Thomas, H. E., and Robinson, T. W., 1939, Geology and ground-water hydrology of the Mokelumne area, California: U.S. Geol. Survey Water-Supply Paper 780, 230 p.

Plafker, George, 1965, Tectonic deformation associated with the 1964 Alaska earthquake: Science, v. 148, no. 3678, p. 1675–1687.

Stanley, K. W., 1965, Effects of post-earthquake conditions on the Homer Spit, Alaska, *in* Science in Alaska, 1964: Alaskan Sci. Conf., 15th, College, Alaska, 1964, Proc., p. 89–90.

Stanley, K. W., and Grey, H. J., 1963, Beach erosion study of the Homer Spit and adjoining shoreline, Alaska: Alaska Dept. Natural Resources Prelim. Rept., 12 p.

Swenson, F. A., 1964, Ground-water phenomena associated with the Hebgen Lake earthquake: U.S. Geol. Survey Prof. Paper 435–N, p. 159–165.

Terzaghi, Karl, 1956, Varieties of submarine slope failures: Texas Conf. Soil Mechanics and Found. Eng., 8th, September 1956, Proc., 41 p.

Thomas, H. E., 1940, Fluctuation of ground-water levels during the earthquakes of November 10, 1938, and January 24, 1939: Seismol. Soc. America Bull., v. 30, no. 2, p. 93–97.

Tsuya, Hiromichi, ed., 1950, The Fukui earthquake of June 28, 1948; report of the special committee for the study of the Fukui earthquake: Tokyo, Japan, 197 p.

U.S. Coast and Geodetic Survey, 1964a, Prince William Sound, Alaskan earthquakes, March–April 1964: U.S. Coast and Geod. Survey, Seismology Div., Prelim. Rept., 83 p.

—— 1964b, Tidal datum plane changes Prince William Sound, Alaskan earthquakes March–April 1964: U.S. Coast and Geod. Survey, Office of Oceanography, Prelim. Rept., 4 p.

Waller, R. M., 1963, Data on wells in the Homer area, Alaska: Alaska Dept. Health and Welfare Hydrol. Data, no. 23, 24 p.

—— 1966, Effects of the March 1964 Alaska earthquake on the hydrology of south-central Alaska: U.S. Geol. Survey Prof. Paper 544–A (in press).

Waller, R. M., Thomas, H. E., and Vorhis, R. C., 1965, Effects of the Good Friday earthquake on water supplies: Am. Water Works Assoc. Jour., v. 57, no. 2, p. 123–131.

U.S. GOVERNMENT PRINTING OFFICE: 1966 O—797–974