The Alaska Earthquake
March 27, 1964

Effects on Communities

Kodiak

GEOLOGICAL SURVEY PROFESSIONAL PAPER 542-F

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

Effects of the Earthquake Of March 27, 1964 On the Communities of Kodiak and Nearby Islands

By REUBEN KACHADOORIAN and GEORGE PLAFKER

A description of the property damage and loss of life due to earthquake-induced seismic sea waves and regional tectonic subsidence at Kodiak and nearby communities

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THE ALASKA EARTHQUAKE SERIES

The U.S. Geological Survey is publishing the results of its 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), Seward (542–E), and Kodiak (542–F); one other chapter is being prepared on several smaller communities. Other professional papers 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.

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EFFECTS OF THE EARTHQUAKE OF MARCH 27, 1964 ON THE COMMUNITIES OF KODIAK AND NEARBY ISLANDS

By Reuben Kachadoorian and George Plafker

ABSTRACT

The great earthquake (Richter magnitude of 8.4–8.5) that struck south-central Alaska at 5:36 p.m., Alaska standard time, on March 27, 1964 (03:36, March 28, Greenwich mean time), was felt in every community on Kodiak Island and the nearby islands. It was the most severe earthquake to strike this part of Alaska in modern time, and took the lives of 18 persons in the area by drowning; this includes two in Kodiak and three at Kaguyak. Property damage and loss of income to the communities is estimated at more than $45 million.

The largest community, Kodiak, had the greatest loss from the earthquake. Damage was caused chiefly by 5.6 feet of tectonic subsidence and a train of 10 seismic sea waves that inundated the low-lying areas of the town. The seismic sea waves destroyed all but one of the docking facilities and more than 215 structures; many other structures were severely damaged. The waves struck the town during the evening hours of March 27 and early morning hours of March 28. They moved from the southwest and northeast and reached their maximum height of 29–30 feet above mean lower low water at Shahafka Cove between 11:00 and 11:45 p.m., March 27. The violently destructive seismic sea waves not only severely damaged homes, shops, and naval station structures but also temporarily crippled the fishing industry in Kodiak by destroying the processing plants and most of the fishing vessels. The waves scoured out 10 feet of sediments in the channel between Kodiak Island and Near Island and exposed bedrock. This bedrock presented a major post-earthquake construction problem because no sediments remained into which piles could be driven for foundations of waterfront facilities.

Because of tectonic subsidence, high tides now flood Mission and Potatopatch Lakes which, before the earthquake, had not been subject to tidal action. The subsidence also accelerated erosion of the unconsolidated sediments along the shoreline in the city of Kodiak.

Seismic shaking lasted 4½–5½ minutes at Kodiak and had a rolling motion. Inasmuch as most of Kodiak is underlain by bedrock or by only a thin veneer of unconsolidated sediments, very little if any damage occurred from ground motion or seismic shaking. The ground motion, however, did cause a massive short circuit and power failure at Kodiak.

The Kodiak Naval Station, 5 miles southwest of Kodiak, was also severely damaged by the earthquake. The station was inundated by at least 10 seismic sea waves which reached a maximum height of 25 feet above postearthquake mean lower low water between 11:16 and 11:34 p.m. on March 27, 1964. The first seismic sea wave that inundated the station did not do severe damage because it behaved much like a rapid rise of tide, but the subsequent and more violent waves destroyed most of the docking facilities and several other shoreline structures. The waves struck the station from the southwest and from the east.

The shoreline structures that were not destroyed required rehabilitation because the 5.6 feet of tectonic subsidence put them under water during the highest tides. Furthermore the subsidence accelerated erosion during high tide of the soft unconsolidated sediments and fill in the low-lying areas of the station.

Seismic shaking did little damage to the station housing facility, but it was responsible for compaction of sediments, lateral displacement of a seawall, and the development of fissures in the aircraft parking area. The ground motion was south-southeast—north-northwest to north-south in direction.

An unusual case of radioactive contamination was reported at the naval station. The inundating seismic sea waves entered a building in which radionuclides were stored. The contamination was restricted to the building only, however, and did not spread throughout the station.

Afognak was abandoned because of the extensive damage incurred from tectonic subsidence and seismic sea waves. The seismic effects, estimated Mercalli intensity VI–VII, did not directly cause any significant property damage at Afognak. Serious long-term damage, however, resulted from tectonic subsidence estimated to be from 3½ to 5½ feet. The subsidence has resulted in rapid erosion of the coast, landward shift and building up of beach berms to the new higher sea levels, and flooding of extensive low-lying areas behind the barrier beaches. Inundation of low-lying parts of the village by a train of

seismic sea waves having maximum heights of 10.8 feet above postearthquake tide level (14.5 ft above postearthquake mean lower low water) caused losses of about half a million dollars to homes, vehicles, bridges, and personal possessions.

Uzinki was damaged by tectonic subsidence and seismic sea waves. No significant damage resulted from the ground motion during the earthquake; the Mercalli intensity was about VI. However, tectonic subsidence, estimated to be 5 feet, caused inundation of a narrow zone along the waterfront. Structures and vessels were damaged as a result of the seismic sea waves that repeatedly flooded the waterfront area after the earthquake.

Old Harbor was damaged by seismic shock, subsidence, and seismic sea waves. The tremors, which had a Mercalli intensity estimated at VII–VIII, toppled two concrete-block chimneys, cracked interior walls, and caused minor breakage of personal property in the homes. Regional tectonic subsidence and superficial subsidence of the unconsolidated deposits on which the village is situated apparently caused incursion of salt water into the school well. A quarter of million yards of fill was required to raise the waterfront areas to their preearthquake elevations relative to sea level. Seismic sea waves having a maximum runup of about 12 feet above tide level (16 ft above postearthquake mean lower low water) destroyed 34 of the 35 residences in the village and presumably drowned one man who lived immediately across the strait from Old Harbor.

At Kaguyak, seismic sea waves having a maximum runup of about 25 feet above mean lower low water carried away all 10 buildings in the village, took three lives, and damaged an unknown number of fishing vessels. The village site has been abandoned.

The communities of Akhiok, Karluk, and Larsen Bay were virtually undamaged by the earthquake tremors, which had estimated Mercalli intensities of VI–VII, but tectonic subsidence of about 2–2½ feet at Larsen Bay made it necessary to raise the cannery dock level at an estimated cost of $80,000.

INTRODUCTION

The great earthquake that struck south-central Alaska at 5:36 p.m., Alaska standard time, on March 27, 1964 (03:36, March 28, Greenwich mean time) was felt strongly throughout Kodiak Island and the nearby islands as well as throughout much of the rest of Alaska. The earthquake had a Richter magnitude of 8.4–8.5 and was the most disastrous one to strike the islands in modern time. The communities of the Kodiak Island area were severely damaged as a result of regional tectonic subsidence and by seismic sea waves. (In this report, the terms "seismic sea wave" and "seismic seiche" are used in referring to waves that were generated by the tectonic movements of the sea floor associated with the earthquake. Neither the term "tidal wave," nor the Japanese term "tunami," or "tsunami," is used. The word "tunami" is a combination of the Japanese word "tu," meaning a port, and "nami," meaning a long wave. The literal definition of tunami, therefore, is a long wave in a harbor or port; the origin of the wave is not implied. "Seismic seiche" is used instead of "seiche" in order to specify the cause of the wave.)

Loss of life in the area was low because of the quick action taken by personnel of the Kodiak Naval Station in alerting the various communities of incoming seismic sea waves. Of the 18 persons drowned by the seismic sea waves in the region, 3 were at Kaguyak and 2 at Kodiak. The other 13 persons who lost their lives were on the highway, on boats, or in isolated areas.

The earthquake left hundreds of people homeless and caused about $45.5 million damage to the communities on Kodiak Island and the islands nearby.

PURPOSE AND SCOPE OF INVESTIGATION

The chief objective of this report is to evaluate the extent and nature of damage to the communities on Kodiak Island and the islands nearby. Effects of the earthquake on uninhabited areas have been described in a companion report by Plafker and Kachadoorian (1966). The communities described in this report and their losses are listed in table 1.

Fieldwork for this study was done by George W. Moore, George Plafker, and Reuben Kachadoorian. Moore made regional observations of the island May 13–21, 1954. Plafker made reconnaissance studies of the island by fixed-wing aircraft and helicopter during the period July 14–20, 1964, and July 15–21, 1965. Kachadoorian conducted studies in Kodiak, at the Kodiak Naval Station, and on the highway system July 14–18, 1964. The sections of this report on damage to the smaller communities were written by Plafker; the rest of the report was written by Kachdoorian.

ACKNOWLEDGMENTS

We are indebted to numerous eyewitnesses who gave us oral and written accounts of their experiences during and immediately after the earthquake.

Personnel of Fleet Weather Central, Kodiak Naval Station, under Cmdr. A. L. Dodson, provided data on the seismic sea waves that struck Womens Bay and the naval station. Naval personnel also provided helicopter transportation to Narrow Cape. Lt. Cmdr. W. D. Barber, of the U.S. Coast and Geodetic Survey, furnished tide records and data on changes in land level at tide-gauge stations on Kodiak Island. The U.S. Coast and Geodetic Survey and the U.S. Army supplied excellent post-earthquake aerial photographs. Preearthquake photographs were obtained from the Bureau of Land Management. Mr. James R. Barr of Kodiak contributed base maps of the town of Kodiak and also maps indicating structures that were damaged by the earthquake. The Public Works Office of the U.S. Navy provided the maps of the naval station. The Navy also furnished excellent photographs of damage on the station and in Kodiak. The U.S. Army-Alaska (USARAL) furnished air transportation to Kodiak for a 1-day evaluation of the damage immediately after the earthquake.

TABLE 1.—*Losses of property and income in communities on Kodiak and nearby islands*

Location	Nature of damage	Estimated replacement cost
Kodiak	Losses of private, commercial, and public property.	[1] $24, 736, 000
Afognak [2]	Losses of public and private property.	[3] 816, 000
Old Harbor	do	[3] 707, 000
Uzinki	do	[3] 349, 800
Kaguyak [2]	do	[3] 321, 000
Larsen Bay	do	[3] 80, 000
Akhiok	do	0
All communities	Vessels damaged	[4] 2, 466, 500
Do	Loss of income to fishing industry.	[4] 5, 087, 000
Kodiak Naval Station.	Damage to structures and equipment.	[1] 10, 916, 800
Total		45, 480, 100

[1] Estimate from U.S. Navy.
[2] Village site abandoned.
[3] Data from Bur. Indian Affairs, Sept. 25, 1964.
[4] Data from Alaska Dept. Fish and Game (1965).

GEOGRAPHIC SETTING AND SETTLEMENTS

Kodiak and the nearby islands lie in the western border of the Gulf of Alaska and are bounded on the south by lat 56°30′ N., on the north by lat 58°40′ N., on the west by Shelikof Strait, and on the east by the Gulf of Alaska.

The largest island is Kodiak with an area of 3,508 square miles (fig. 1, next page). Afognak is the second largest with an area of 700 square miles. The other major islands include Tugidak, Sitkinak, Sitkalidak, Uganik, Spruce, Raspberry, Marmot, and Shuyak and have a combined total area of about 530 square miles. The total area of all the islands, including some small ones not listed here, is 4,900 square miles.

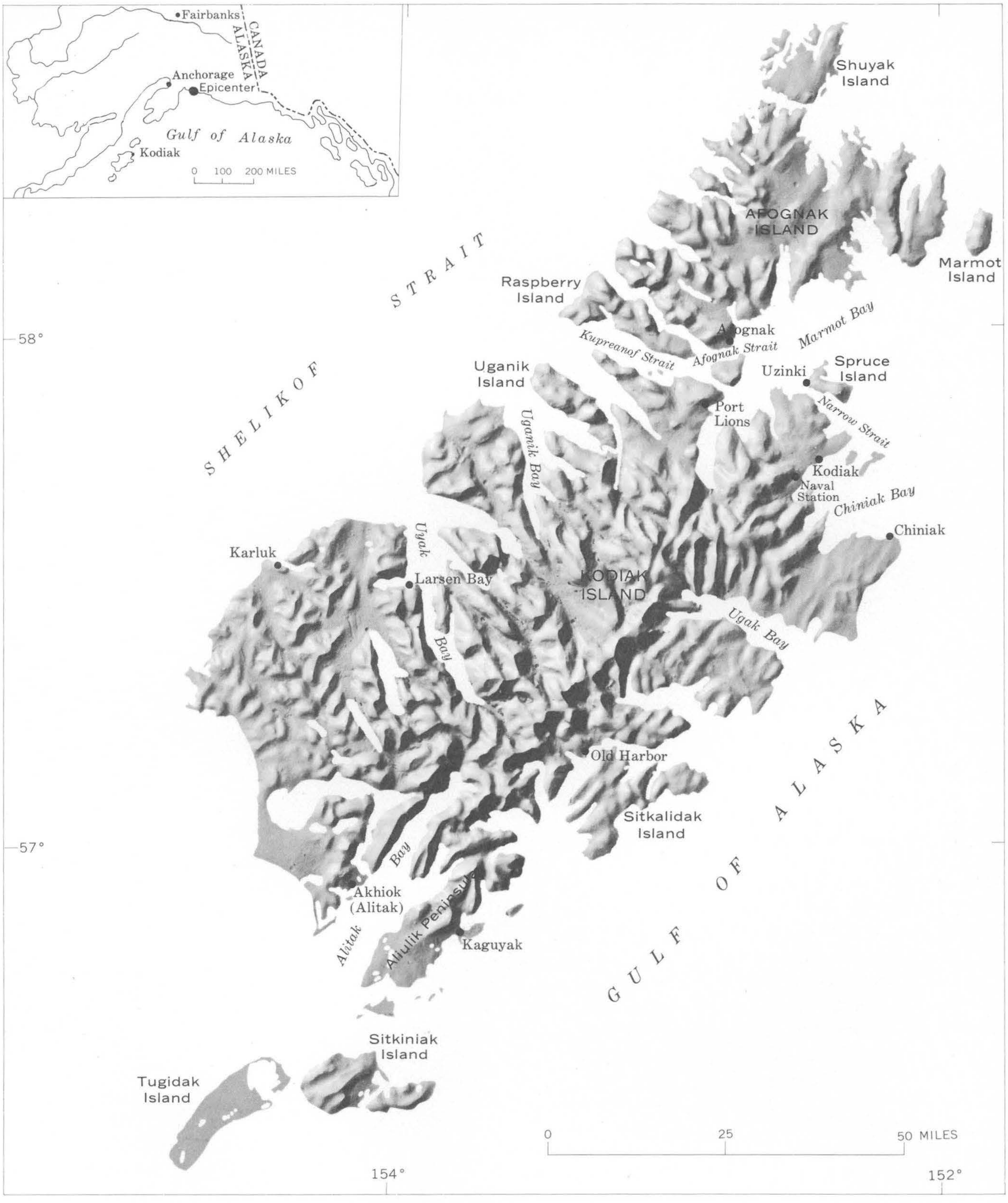
The permanent population of the Kodiak group of islands totals only 5,760, including the personnel of the Kodiak Naval Station. The city of Kodiak and the nearby naval station have the only concentrations of population; the other communities are small native villages (table 2). Because the economy of the island is based primarily on fishing, the population of the towns varies. During the summer fishing season the population, particularly at Kodiak, is greater than indicated on table 2.

Except by means of a highway (largely unpaved) along the northeast coast of Kodiak Island that ties Kodiak, the Kodiak Naval Station, and Chiniak together, there is no ground transportation on the islands. Travel to Afognak, Uzinki, Karluk, Larsen Bay, Old Harbor, Akhiok, and Kagayuk is by boat or aircraft.

TABLE 2.—*Population of communities on Kodiak and nearby islands*

	Population
Kodiak	[1] 2, 628
Kodiak Naval Station	[2] 2, 160
Afognak	[1] 190
Akhiok (Alitak)	[3] 72–75
Kaguyak	[1] 36
Karluk	[1] 129
Larsen Bay	[1] 72
Old Harbor	[1] 193
Uzinki	[1] 214

[1] U.S. Bur. Census (1963).
[2] On March 27, 1964; information from U.S. Navy, Kodiak Naval Station.
[3] Estimate.



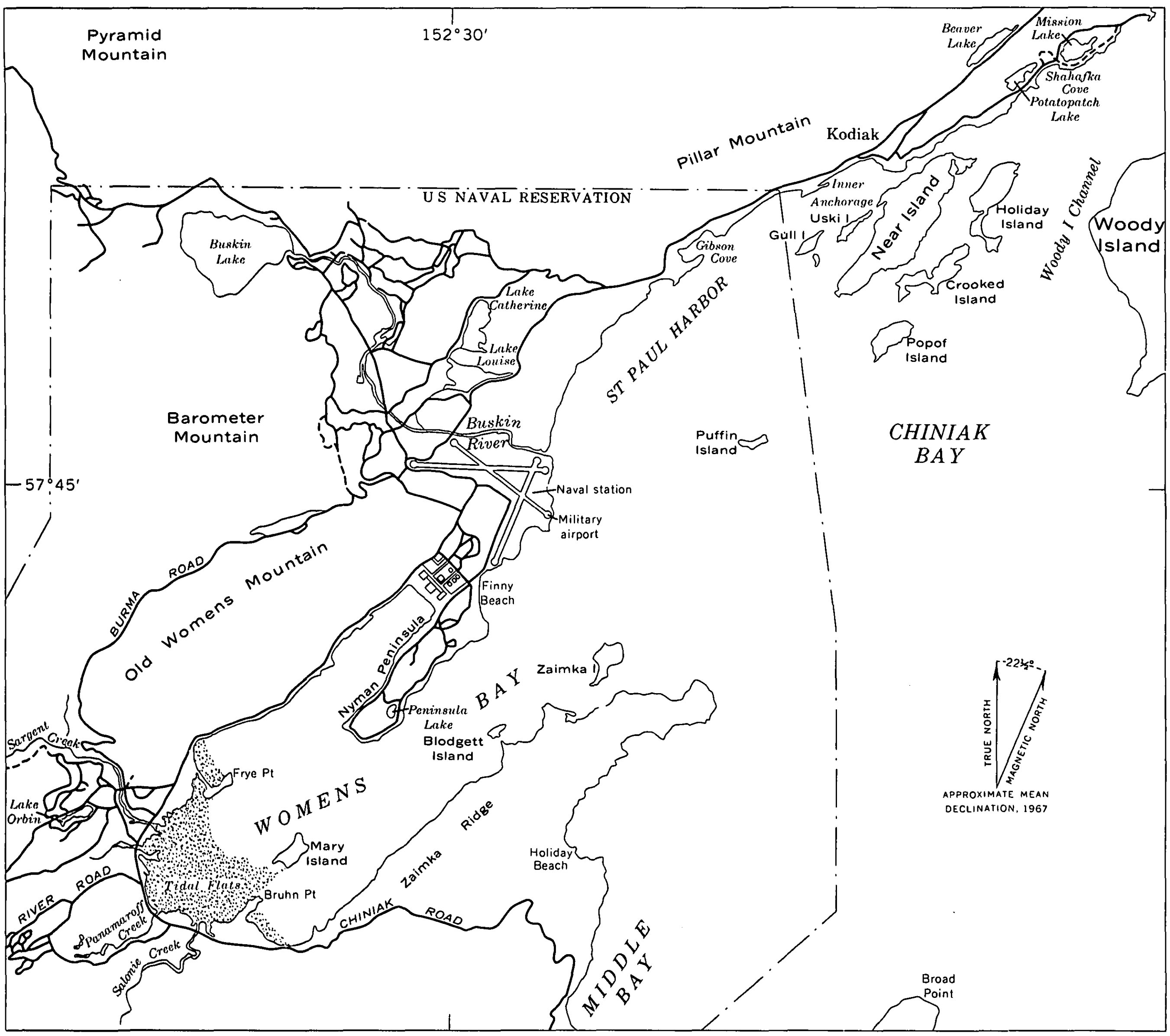
1.—Location of communities on Kodiak Island and nearby islands.

EFFECTS ON COMMUNITIES

The 1964 earthquake damaged every community on Kodiak and nearby islands except Akhiok and Karluk. The chief causes of damage were inundation by a train of seismic sea waves and by regional tectonic subsidence. The two major population centers, Kodiak and Kodiak Naval Station, were most severely stricken and sustained about 80 percent of the financial loss. Structural damage directly attributable to seismic shock during the earthquake was light.

KODIAK NAVAL STATION

The U.S. Naval Reservation is on the northeast coast of Kodiak Island southwest of the city of Kodiak (fig. 1) and about 280 miles southwest of the epicenter of the 1964 earthquake. The main station complex, where most of the damage on the reservation occurred, lies 5 miles from Kodiak at lat 57°45′ N. and long 152°30′ W. (fig. 2).



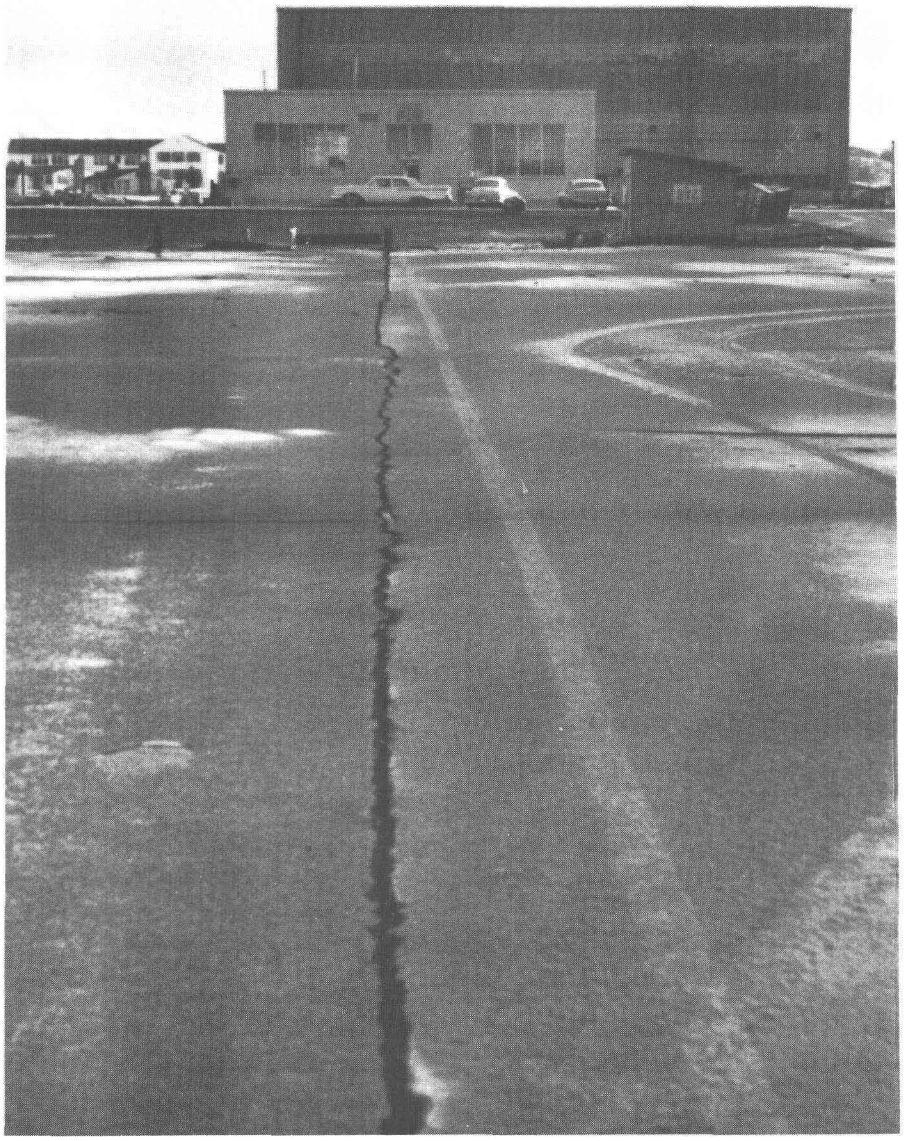
2.—Location of the Kodiak Naval Station and the city of Kodiak.

The main docking facilities of the naval station are on the northward extension of Womens Bay and are protected from the open sea by Nyman Peninsula. West of Nyman Peninsula the average depth of Womens Bay is about 60 feet and east of the peninsula it is approximately 65 feet.

The maximum tide range at the station is about 17 feet. The lowest tide to be expected is −4.0 feet, the highest 13.0 feet. The tide has a mean range of 6.6 feet and a diurnal range of 8.5 feet (U.S. Coast and Geod. Survey, 1964a). Mean lower low water is 4.3 feet below mean sea level.

The Kodiak Naval Station site is underlain by slate and graywacke that has a local veneer of unconsolidated deposits. At the higher altitudes most of the structures rest upon bedrock, but in the low-lying areas structures rest upon unconsolidated deposits of glacial till and artificial fill. The hangar complex at the head of Womens Bay is built on 15–20 feet of fill obtained from deposits of glacial till. The easternmost part of the landing strip also rests upon fill, which locally is as much as 8–10 feet thick. Throughout the low-lying areas of the station, structures rest upon local areas of fill, glacial debris, stream gravels, or reworked glacial debris. Although the maximum depth of this debris is unknown, in places it may be as much as 25 feet.

The earthquake did $10,916,800 worth of damage to the facilities of the Kodiak Naval Station. There were no casualties at the station, although six people from the station were drowned along the coastal highway. Prompt evacuation of the waterfront area prior to arrival of the first seismic sea wave undoubtedly saved many lives.



3.—East-west-trending fissure in aircraft parking ramp at Kodiak Naval Station. View is west. Photograph by U.S. Navy, March 29, 1964.

Damage was due to seismic shaking, fissuring, compaction, tectonic subsidence, and seismic sea waves. The chief damage was caused by the train of seismic sea waves that struck the station throughout the evening of March 27 and morning of March 28, 1964.

GROUND MOTION

Some eyewitnesses reported that, a few seconds before the initial shock of the earthquake was felt, they heard a low rumbling analogous to the sound that might be produced by a slow-moving freight train. The seismic shaking started as a slow rolling motion that lasted for about ½–1 minute, gradually becoming more intense. The intense motion continued for approximately 2½ minutes and gradually subsided after about 1½–2 minutes. Thus, ground motion or shaking lasted 4½–5½ minutes at the Kodiak Naval Station.

Estimates of the direction of ground motion in the Kodiak area, as well as at the naval station, vary from east-northeast—west-southwest to north-south.

Damage from seismic shaking was slight even to structures

4.—Displacement of seawall toward Womens Bay, Kodiak Naval Station. View is east. Photograph by U.S. Navy, April 1, 1964.

underlain by unconsolidated deposits and artificial fill. The tremors cracked water mains and caused minor structural damage.

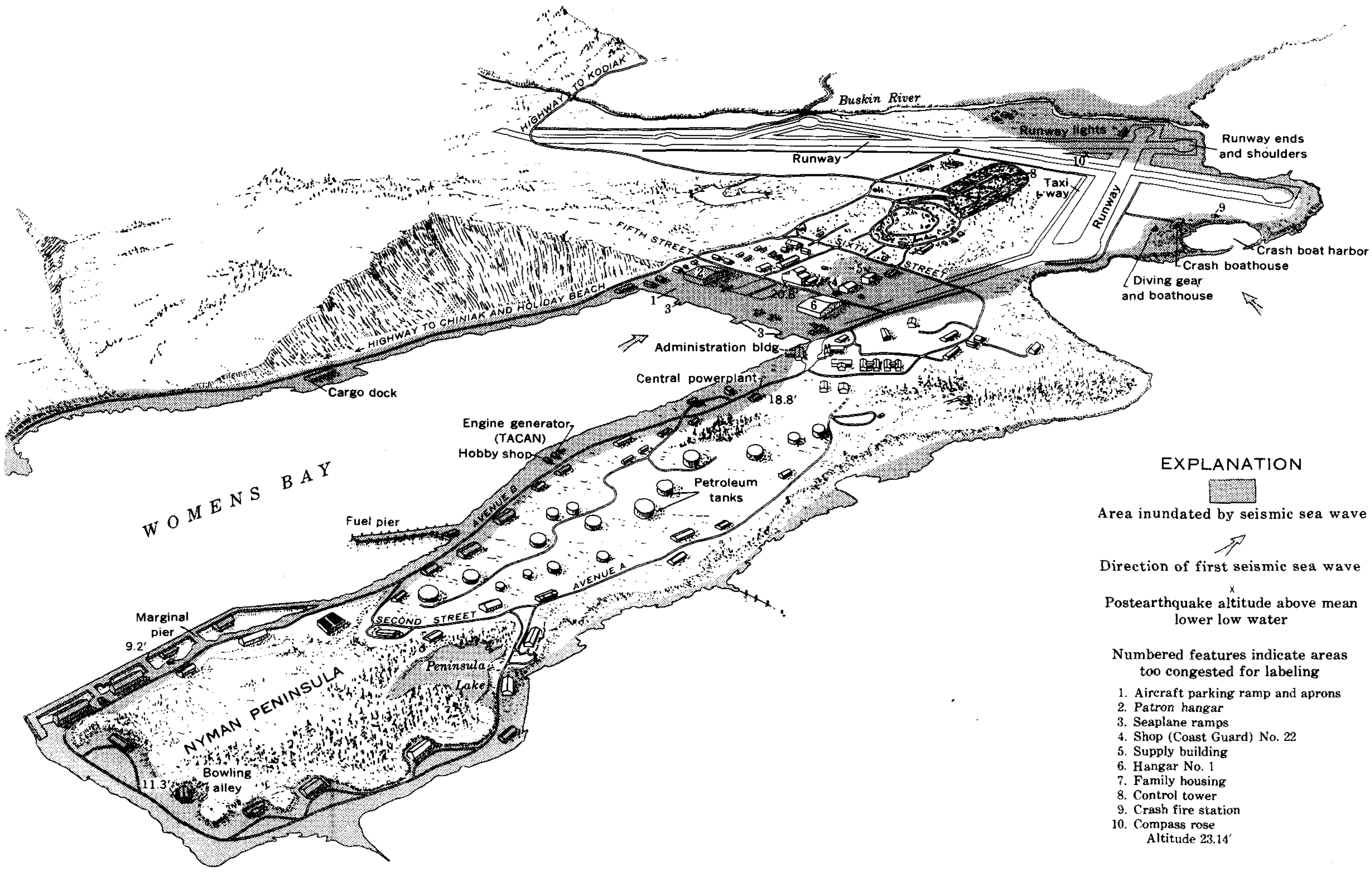
FISSURES

One of the effects of the earthquake was the development of fissures in the low-lying areas underlain by unconsolidated sediments and artificial fill. Fissuring occurred in the asphalt of the aircraft parking ramps at the head of Womens Bay (fig. 3) and along the highways throughout the station. Figure 3 shows a long east-west-trending fissure. The surface expression of the fissure may in part be controlled by the type of construction that was employed when the asphalt was placed and may actually represent a construction joint. The fissures developed only in areas where more than 5 feet of unconsolidated deposits or fill overlay the bedrock. In at least one locality, at the aircraft parking ramps, fissures developed primarily as a result of seismic shaking that caused some lateral extension or displacement of the unconsolidated deposits and artificial fill toward a free face. The sediments underlying the parking ramp moved southward toward Womens Bay. The seawall (fig. 4) has been moved because of the lateral displacement of the sediments.

COMPACTION

Differential settlement, or compaction, took place in the unconsolidated sediments underlying some of the structures at the Kodiak Naval Station. The compaction was due to seismic action and amounted to as much as 1 foot beneath hanger 1. Compaction of fill also occurred under the asphalt aircraft ramp outside a hangar (fig. 5, next page). The compac-

5.—Result of compaction of fill debris underlying asphalt aircraft ramp outside hangar at Kodiak Naval Station. Note the settlement of back-fill material adjacent to foundation of structure in the foreground. Photograph by U.S. Navy, March 29, 1964.



Revised from an original drawing by U.S. Navy, Kodiak, Alaska, March 31, 1964

6.—Area of maximum inundation by seismic sea waves and structures damaged at Kodiak Naval Station.

tion here was so great that a step several inches high developed between the footing of the hangar and the ramp. The hangar footing itself had some slight differential settling. Locally, the backfill material against the foundation of the hangar has compacted substantially. One might expect that scouring would have occurred during the retreat of the inundating seismic sea waves, but if it had occurred, it would have been widespread throughout the naval station, and none was observed. Furthermore, we noted the same phenomenon of differential compaction at the Eklutna Hydroelectric Project near Anchorage, Alaska, where seismic sea waves had not inundated the area. The hangars were constructed on 15–20 feet of engineered fill consisting of glacial debris (Tudor, 1964). The columns of the hangars rested on piles, whereas the deck of the hangars rested on fill. There apparently was not settlement of the columns of the hangars, but differential settlement of the fill beneath the hangar footings caused slight deformation of the bracing and broke windows in the hangar walls.

Differential settlement or compaction occurred in other areas in the main complex of the naval station. The concrete deck of the supply building between Fifth and Sixth Streets (fig. 6) settled about 6 inches. Three or four inches of settlement of the supporting sediments also occurred in the floor of building 22, a small structure near Fifth Street, about 500 feet southwest of the supply building.

The maximum compaction noted occurred on the Chiniak Road at

7.—Inundation of fuel pier during high tide at Kodiak Naval Station. Photograph by U.S. Navy, 12:59 p.m., April 12, 1964.

the southwest end of Womens Bay (fig. 2) where the highway crosses a low-lying area underlain by fine-grained silt, sand, and gravel. During a 4½-foot tide on July 17 and 18, 1964, the deck of a bridge was about 6 feet above the water. Assuming that the original altitude of the bridge was 15 feet (2 ft above the maximum expected tide of 13 ft) and that there was tectonic subsidence of 5.6 feet, the area had a differential settlement of 3–4 feet.

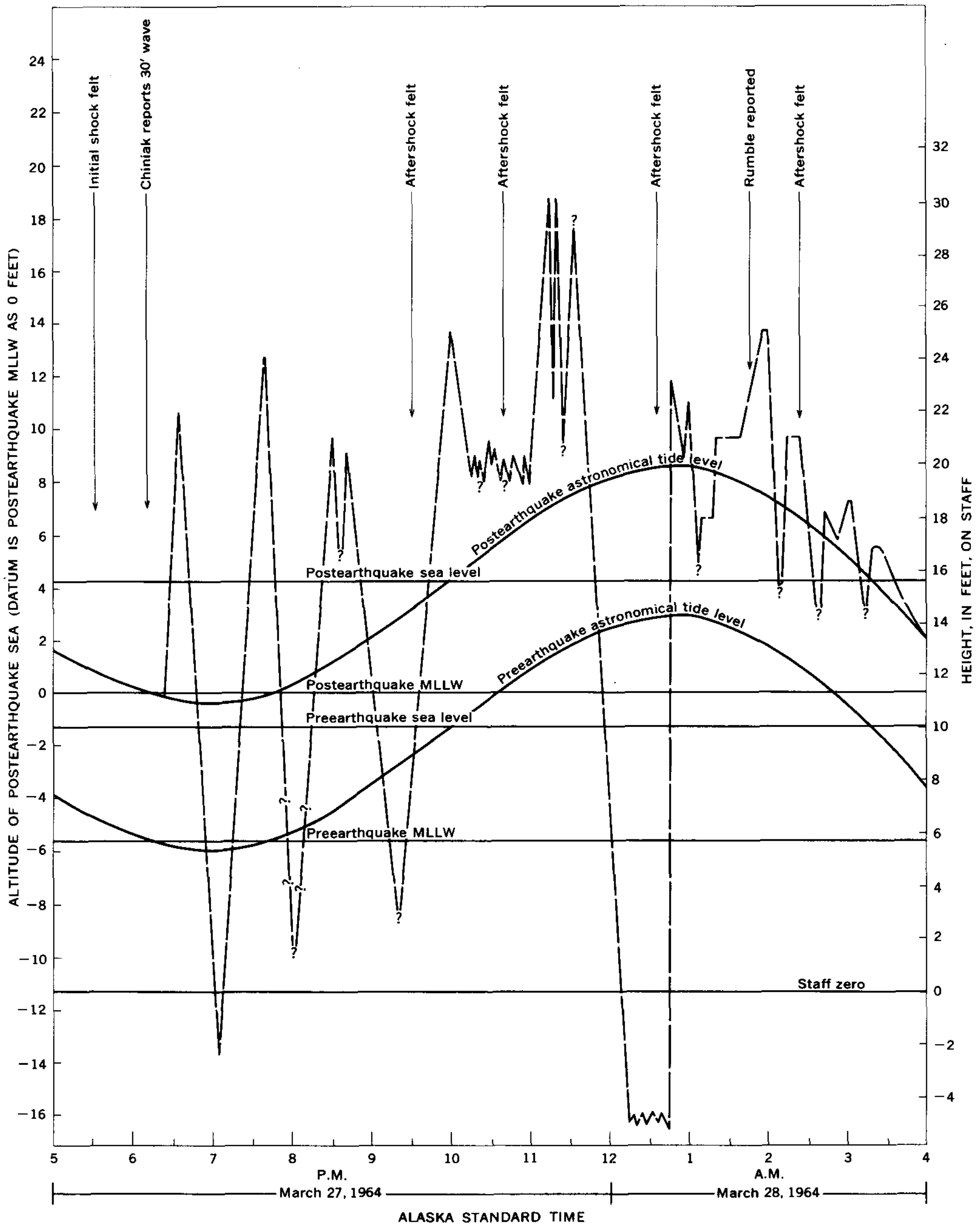
TECTONIC SUBSIDENCE

Regional tectonic subsidence of 5.6 feet occurred at the Kodiak Naval Station and at the city of Kodiak, 5 miles northeast of the station. This subsidence, which is from 1 to 1½ feet less than the maximum observed in the region (Plafker and Kachadoorian, 1966, fig. 16), occurred during the seismic shaking. Tectonic subsidence created a serious problem for all the waterfront installations, particularly at the naval station. Structures that had been above highest tide before the earthquake were inundated during the spring high tides.

The seaplane ramps were inundated during a 10.0-foot tide at 12:49 p.m., April 12, 1964. The predicted tide for that day was 8.7 feet. The difference between the predicted and actual tides is well within the margin of error of tide tables. However, the difference might also be due to 1 foot or more of compaction of the unconsolidated debris underlying the aircraft parking ramp. Figure 7 shows the deck of the fuel pier at the naval station under several inches of water. This photograph was taken on April 12, 1964, several minutes after the predicted high tide.

The subsidence exposed much more of the coastline to erosion during high tides. Coastal areas, especially those underlain by unconsolidated sediments, are now being eroded throughout the naval reservation.

Flooding of the Chiniak Road also occurred along the south shore of Womens Bay during a 4- to 5-foot tide after the earthquake. The flooding was due to a combi-



8.—Reconstructed marigram of seismic sea waves at Kodiak Naval Station.

nation of a 5.6-foot regional subsidence, compaction of the unconsolidated sediments underlying the roadbed, and erosion of the roadbed during inundation by the seismic sea waves. Three miles of the highway had to be rebuilt, as well as two bridges that had been destroyed.

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SEISMIC SEA WAVES

The only reliable record of seismic sea waves along the part of the Gulf of Alaska coast that was affected by the earthquake was made by personnel of Fleet Weather Central, Kodiak Naval Station. A marigram was reconstructed by the authors from a log supplied by Lt. C. R. Barney of Fleet Weather Central (fig. 8). Times are Alaska standard, and staff zero is 11.3 feet below postearthquake MLLW (mean lower low water). Mean sea level is 4.3 feet above MLLW. The measurements were made at the head of Womens Bay near the vicinity of the aircraft ramps.

After each crest, a mark based on the visual estimate of the high water was made on a building at the head of the bay. According to Lt. Barney, 50 percent of the visual estimates were correct to within 0.1 foot.

At least 10 seismic sea waves inundated low-lying areas of the naval station during the evening of March 27 and early morning of March 28, 1964 (table 3). Maximum high water occurred between 11:34 and 11:36 p.m. on March 27, 1964, at which time water level reached an altitude of 18.8 feet above postearthquake MLLW near the hangar area. Runup from this inundation reached postearthquake altitudes of about 21 feet on Fifth Street, 23 feet at the compass rose at the main runway, and approximately 25 feet at the crash boat harbor.

The seismic sea waves that struck the station came in from the northwest extension of Womens Bay west of Nyman Peninsula in a northeast direction, after being refracted off the coast at the southeast end of Womens Bay. The seismic sea waves that inundated the main air strip and the crash boat harbor came in directly from the sea. As shown on figure 6, the high water inundated (1) most of the structures along the shoreline of Nyman Peninsula, (2) all the station southwest of Fifth Street, (3) the eastern half of the area between Fifth and Sixth Streets, (4) the taxi strip from the aircraft parking ramp to the runway, (5) the crash boat harbor, (6) much of the eastern end of the main airstrip, and (7) the Chiniak Highway along the shore of Womens Bay.

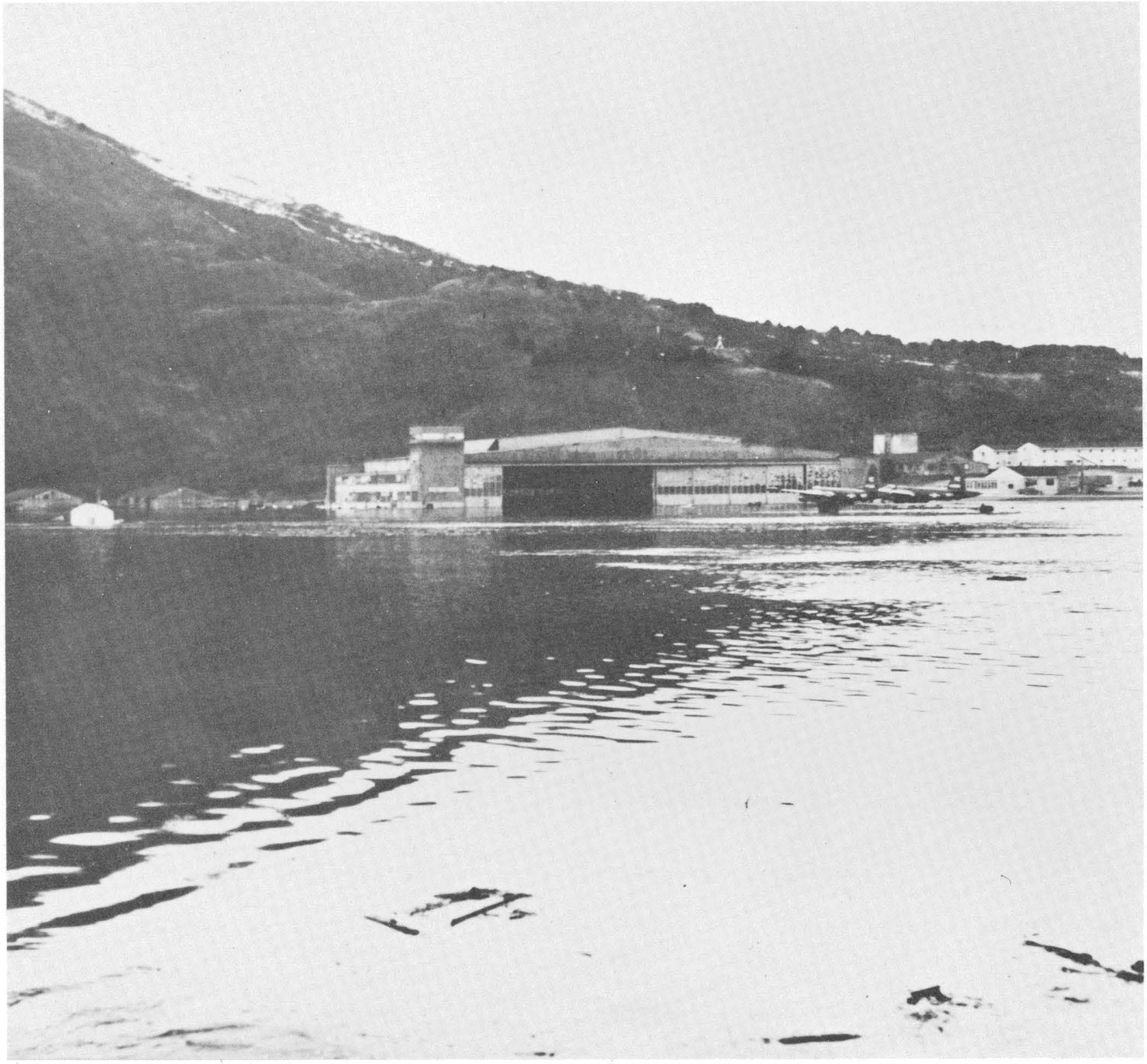
The first seismic sea wave, which struck the station at 6:35 p.m., March 27, flooded the central powerplant; all electrical power and steam to the centrally heated

TABLE 3.—*Arrival times, periods, and heights of seismic sea waves at Womens Bay, Kodiak Naval Station*

[Data from U.S. Navy Fleet Weather Central, Kodiak Naval Station]

Wave	Time (Alaska standard)	Period (minutes)	Crest height (feet)	
			Above postearthquake tide level	Above postearthquake MLLW
March 27, 1964, p.m.				
1	6:35		10.8	10.6
2	7:40	65	12.8	12.8
3	8:30-8:44	50	8.6	9.7
4	10:00	76	9.4	13.7
5	11:16-11:34	66	11.4	18.8
March 28, 1964, a.m.				
6	12:47	73	3.2	11.6
7	1:54	67	6.4	13.8
8	2:20	26	3.0	10.0
9	2:58	38	2.2	7.2
10	3:20	22	1.6	5.6

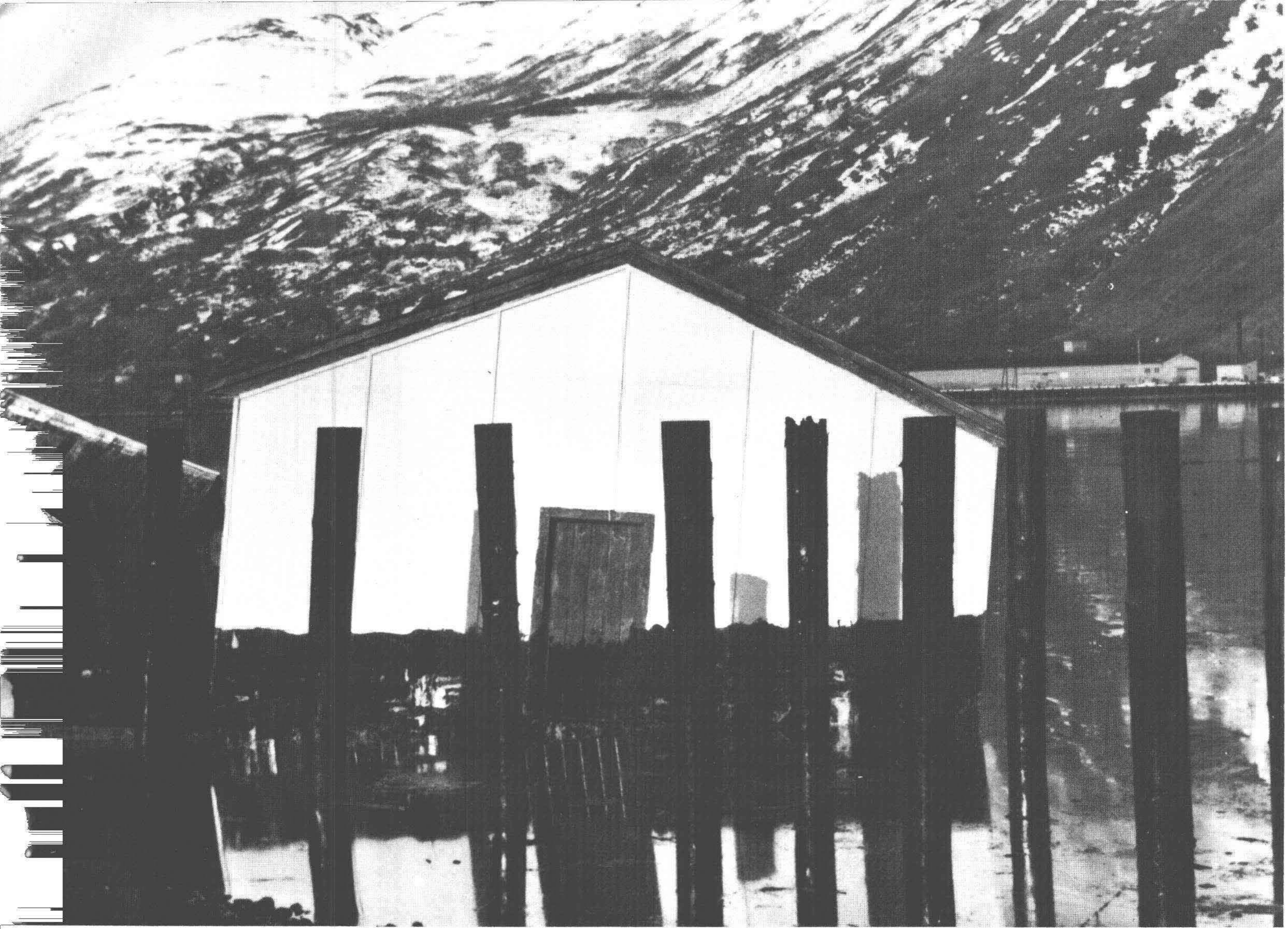
9.—Clock in the intelligence office, Kodiak Naval Station, showing time power failed at the station. Black watermark on the wall indicates maximum height of inundation. Photograph by U.S. Navy, March 29, 1964.



10.—First seismic sea wave flooding parts of the Kodiak Naval Station. View is west. Photograph by U.S. Navy, March 27, 1964.

station buildings and living quarters were lost. The same wave broke water mains and disrupted water service to the structures. Figure 9, a photograph of the naval station intelligence office, indicates that power was cut off at about 6:39 p.m. Figure 10 shows the first seismic sea wave striking the hangar area at the northeast head of Womens Bay. The two PV2 Neptune aircraft of Patrol Squadron Two parked in front of the hangar were undamaged because quick-thinking station personnel moved them to higher ground. This wave was not a wall of water, but moved into the area more like a rapidly rising high tide. Eyewitnesses reported that the second wave, which struck the station at 7:40 p.m., was a breaking wave when it struck the southwest shoreline of Womens Bay.

Mr. and Mrs. Louis Schultz were on a bridge of the Chiniak Road when the waves struck. They reported that the first wave came up like a tide, only much more rapidly, and that they did not observe any previous withdrawal of water. They described the second wave as a wall of water about 3 feet high coming in very rapidly. After the initial 3-foot wave front, the water level rose in



11.—Hobby shop swept off its piling foundation by seismic sea waves, Kodiak Naval Station. Black poles are piles upon which structure rested prior to the earthquake. Photograph by U.S. Navy, March 28, 1964.

surges. Their description of the second seismic sea wave agrees with eyewitness accounts of the same wave in Kodiak.

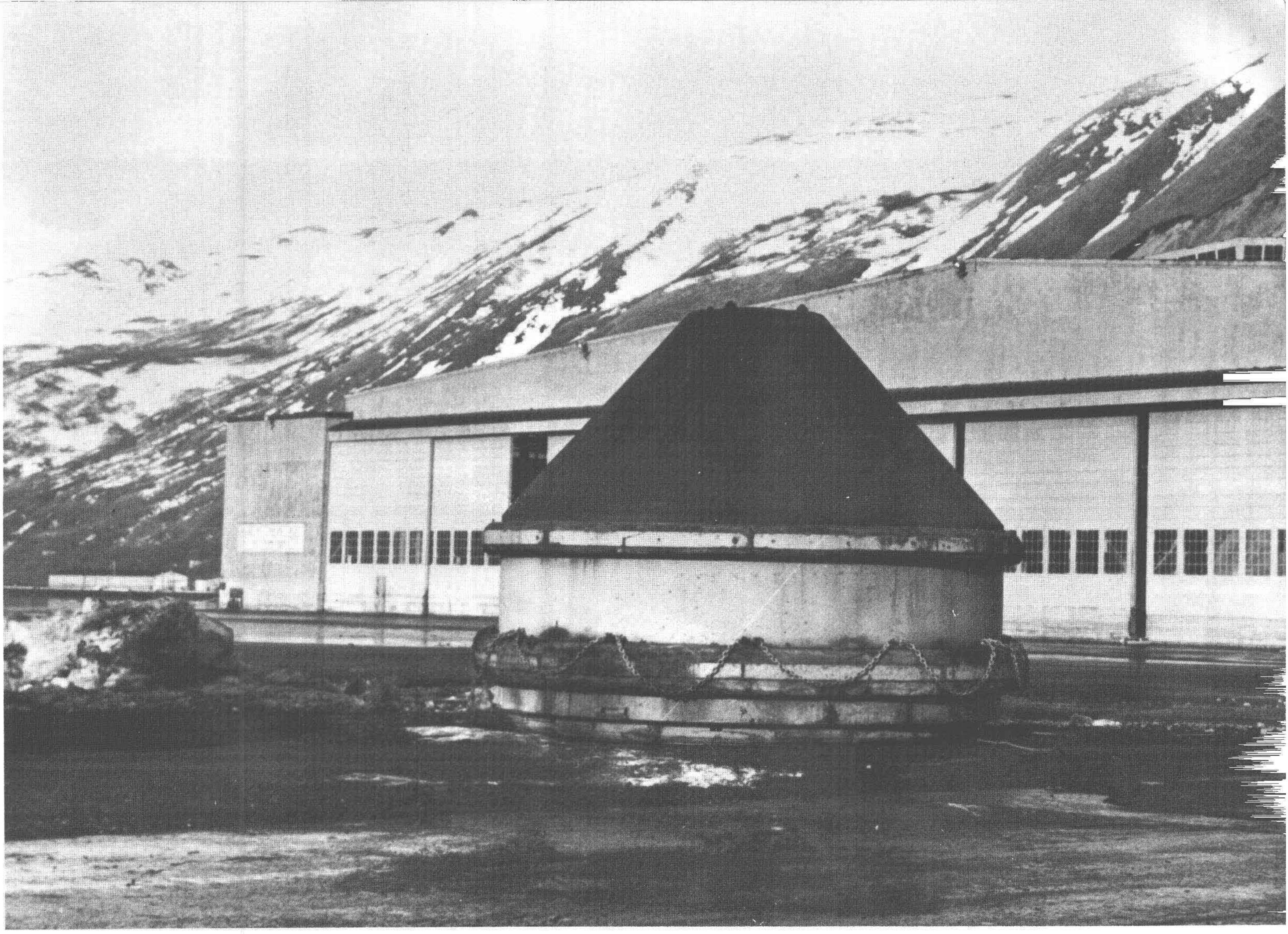
Damage from the seismic sea waves was severe, and some structures were totally destroyed. Table 4 lists the facilities damaged and the estimated cost of restoration or replacement.

Although the marginal pier was only slightly damaged from the sea waves, it had to be replaced because it was being inundated by high tides. Before the earthquake its altitude was 14.8 feet; its postearthquake altitude was 9.2 feet. Thus, during normal high tides, which are about 11 feet, the pier was inundated.

TABLE 4.—*Description and cost of restoration or replacement of facilities on the Kodiak Naval Station damaged by the earthquake*

[Estimates furnished by U.S. Navy, Kodiak, Alaska]

Facility	*Action*	*Estimated cost*
Roads and bridges from naval station to Holiday Beach	Rebuild	$1, 677, 000
200-kv generator, Holiday Beach	Replace	147, 500
Central powerplant	Repair	177, 500
Hangars 1, 2, and 3 and aprons	do	936, 400
AUW facility	do	35, 400
Microwave installation	do	900, 000
Runway ends and shoulders	do	215, 000
Runway lights	do	17, 200
Generators (OPCON)	Replace	31, 000
Marginal pier (new)	do	1, 716, 000
Crash boathouse	Repair	29, 800
Diving gear and boathouse	Replace	75, 000
Station electrical	Repair	61, 750
Rawin Aerological Building	do	13, 200
Fuel Pier S-40	do	37, 900
Shop (Coast Guard) 22	do	6, 200
Public works maintenance shop	do	224, 000
Crash fire station	do	88, 500



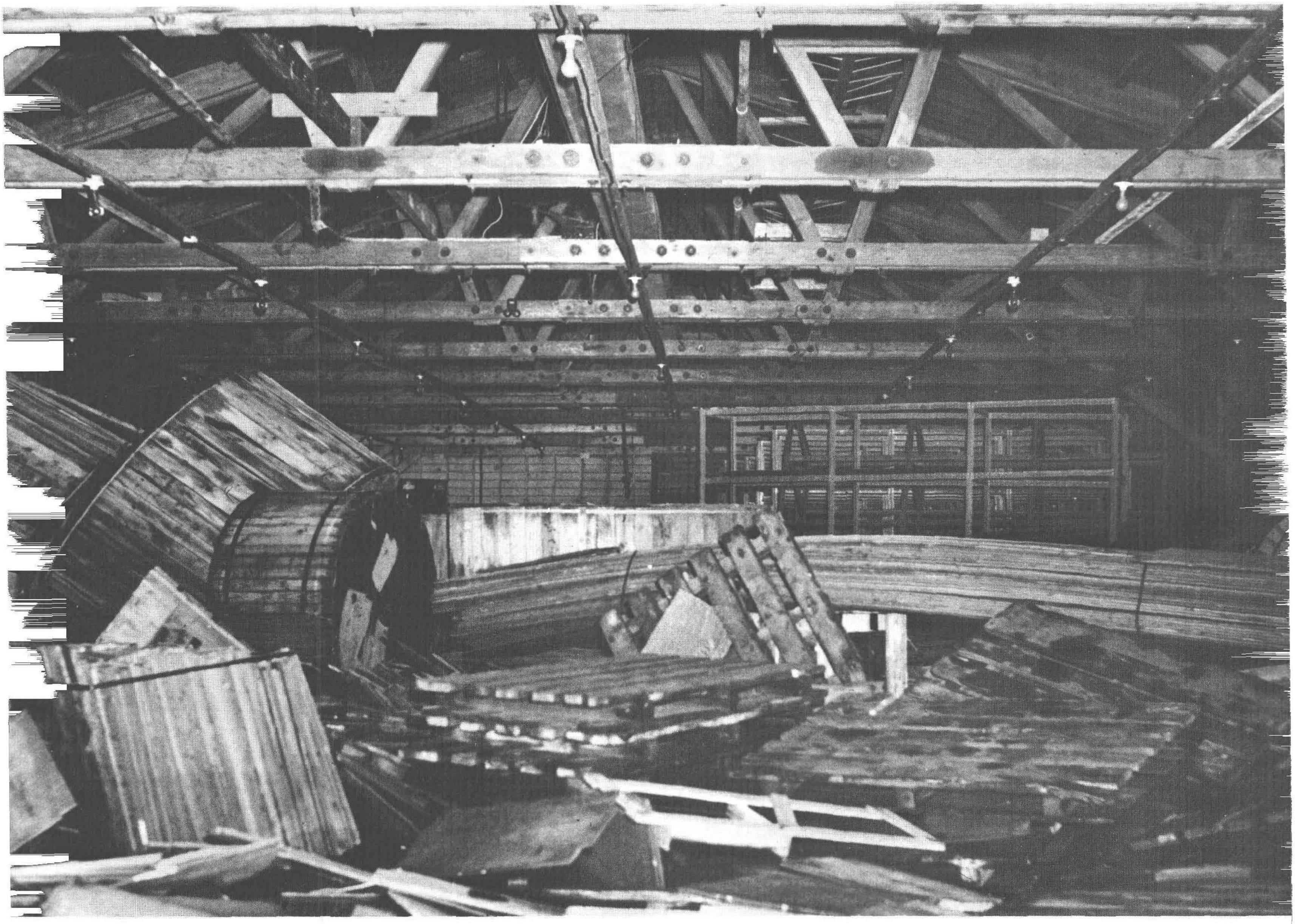
12.—Mooring buoy washed ashore by seismic sea waves, Kodiak Naval Station. Photograph by U.S. Navy, March 28, 1964.

TABLE 4.—*Description and cost of restoration or replacement of facilities on the Kodiak Naval Station damaged by the earthquake*—Continued

Facility	*Action*	*Estimated cost*
Aviation warehouse	Repair	$14, 500
Hobby shop	Replace	166, 000
Supply building	Repair	70, 100
Waterfront facilities	do	67, 000
Station communication system	do	38, 150
Engine generator (TACAN)	Replace	25, 500
Bowling alley (8-lane)	do	993, 000
Family housing	Repair	25, 000
Seaplane ramp	do	17, 200
Road and bridges (main station)	Rebuild	2, 594, 500
Power-plane high-pressure structure	Repair	516, 500
Total		10, 916, 800

The hobby shop and the engine generator buildings were swept off their pile foundations by the seismic sea waves (fig. 11). The structures were not adequately tied down to the piling and thus were floated away by a combination of buoyancy and lateral drag. In contrast, the small white structure in the left central part of figures 7 and 10 was repeatedly inundated but was not swept away by the waves because it is firmly secured to its foundation by three tiedown cables on each side of the building which connect the roof to deadmen anchored in the ground.

The water also tore loose a 10-ton mooring buoy from its anchorage and deposited it on the taxiway near the supply building (fig. 12). The buoy was carried about a quarter of a mile inland by the water and came to rest at a postearthquake altitude of about 16 feet. It was carried to this position by the fifth seismic sea wave, which crested, between 11:16 and 11:34 p.m. on March 27, 18.8 feet above postearthquake MLLW.



13.—Photograph of interior of supply building, Kodiak Naval Station, showing condition of supplies stored in building after the retreat of the seismic sea waves. Photograph by U.S. Navy, March 29, 1964.

Tudor (1964) reported that the cargo dock, which was in a deteriorated condition prior to the earthquake, was severely damaged by the seismic sea waves. The docks rested on piles, some of which were placed in augered holes because it was difficult to drive the piles into the rocky bottom of Womens Bay. Tudor (1964) thought that the inundating high water buoyed up the deck of the cargo dock and pulled up some of the piles from their augered holes.

The ground floor of the central powerplant was repeatedly flooded by the seismic sea waves. The high water had a high silt content, and fuel and this silt coated the boilers, blowers, pumps, and other equipment on the ground floor and made them inoperative. The water did not reach the generator floor where the high-voltage switching gear and controls of the powerplant were located (Tudor, 1964).

Repeated inundation of the Kodiak Naval Station by seismic sea waves eroded some of the roads, aprons, and approaches of the runway. The roads and aprons are underlain by unconsolidated fill derived from glacial till. Locally, as much as 40 feet (horizontally) of the fill was eroded by the waves. Besides the erosion that occurred during the inundation by the seismic sea waves, the tectonic subsidence of 5.6 feet has exposed fill to continuous erosion during high tides. Corrective measures were necessary to prevent the runway from being undercut.

Except for the marginal pier, structures damaged only slightly to moderately were put back into use in a short time. Damage in the buildings was primarily to equipment, supplies, and goods, and to such items as heating units, generators, motors, and blowers, which can be considered as part of the building. Figure 13, a photograph of the interior of the supply building, after the earthquake, shows the chaotic condition of the supplies stored there.

Besides the damage already described, the seismic sea waves caused miscellaneous other damage throughout the low-lying inundated areas of the station. The high water (1) washed vehicles inland or into Womens Bay, (2) washed all types of debris onto the beach areas of the naval station, (3) destroyed the small footbridge across Buskin River, (4) in several localities washed ice across the highway and against buildings, and (5) destroyed several small shed-type structures. The cost of the general cleanup of the station and other miscellaneous damage is not included on table 4.

SEISMIC SEICHES

Seismic seiches in Womens Bay may have been superimposed on the train of seismic sea waves because short-period rises of water level occurred at intervals of 4, 7, 13, 14, 19, and 22 minutes. The natural seiching period of the bay is difficult, however, to establish because of its location and its irregular physical characteristics. The tide gauge at the naval station was destroyed and there is no instrumental record of the waves. Therefore, it cannot be determined with any degree of certainty whether seismic seiching did develop in Womens Bay and, if it did, the characteristics of the seiching.

RADIOACTIVE CONTAMINATION

An unusual type of damage due to low-level radioactive contamination occurred in the Kodiak Naval Station when seismic sea waves scattered traces of radionuclides. Because the level of radioactive contamination was low and the contamination was restricted to the Ground Electronics Building in which the radionuclides were stored, station personnel were not affected.

KODIAK

The 1964 earthquake took the lives of two persons in the city of Kodiak by drowning from seismic sea waves and caused estimated damage to public, private, and commercial facilities of approximately $24,736,000 (table 5). Effects of the seismic shaking of the earthquake itself were slight, but the train of seismic sea waves that followed it left the downtown area of Kodiak and the low-lying areas of Potatopatch Lake and Mission Lake a shambles. The waves destroyed more than 215 structures and left more than 600 people homeless out of a total population of 2,658.

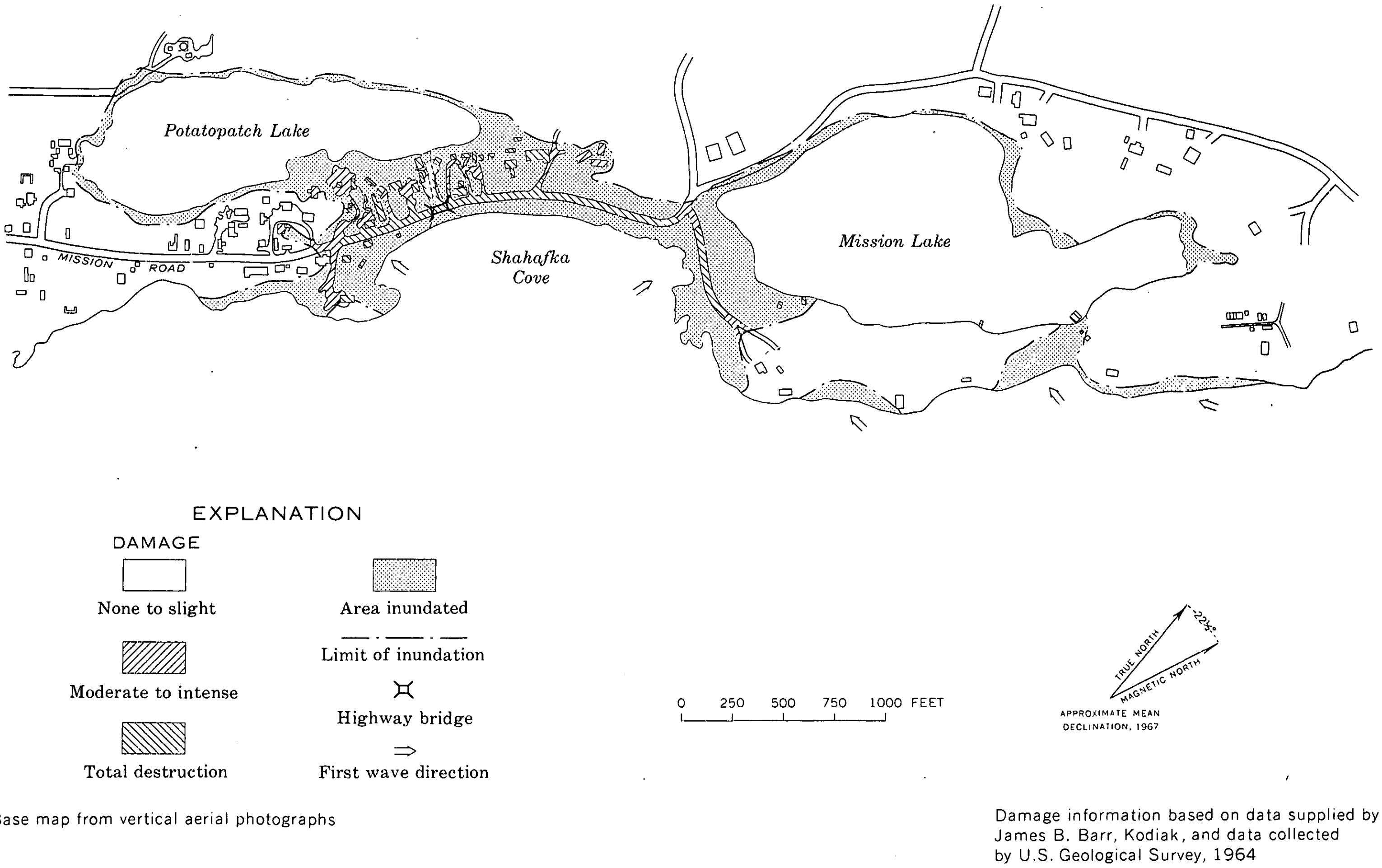
GEOGRAPHIC AND GEOLOGIC SETTING

The town of Kodiak is on the northeast coast of Kodiak Island at lat 57°47′30″ N. and long 152° 24′ W. (fig. 2). The downtown area is at the head of Inner Anchorage, a northeast extension of

TABLE 5.—*Earthquake damage to public and private facilities at Kodiak*

[Data from Civil Defense and from the Kodiak Mirror, v. 24, No. 15, Apr. 10, 1964]

		Estimated cost	
Public facilities:			
Roads:			
Alaska Street and Mills Bay Road	$90,000		
Marine Way and parking lot	160,000		
Mission Road at Shahafka Cove	75,000		
Tagura	120,000		
		$445,000	
Harbor:			
Boat harbor (inner facilities)	250,000		
Dredging boat harbor	150,000		
Breakwater	500,000		
City dock and warehouse	1,200,000		
City dock equipment	55,000		
		2,155,000	
Sewer and storm:			
10 sewer outlets	60,000		
Storm sewers	125,000		
Sewer ejection station and line	120,000		
Water and sewer lines	200,000		
		505,000	
Water system (Kraft Springs)		185,000	
Latent damage (loss of revenue)		2,100,000	
			$5,390,000
Private and commercial structures		11,346,000	
Private and commercial stock (clothing, food, and other)		6,000,000	
Equipment		2,000,000	
			19,346,000
Total, all losses			24,736,000



14.—Map of Shahafka Cove area, Kodiak, showing damage, area of inundation, and direction of initial seismic sea waves.

St. Paul Harbor. Kodiak is sheltered from Chiniak Bay and the Gulf of Alaska by several islands east of the town. The major protective islands are Long Island, Woody Island, and Near Island. Long Island is about 1 mile east of Woody Islands and is not shown on figure 2.

The tides at Kodiak are similar to those at the naval station. The lowest expected tide is −4.0 feet, the highest 13.0 feet. Mean higher high water is 8.5 feet, and mean lower low water (0.0 ft) is 4.3 feet below mean sea level.

Kodiak is underlain by slate and graywacke and unconsolidated deposits consisting of lake sediments, beach gravels, glacial till, and artificial fill. The downtown area of Kodiak is underlain chiefly by bedrock, especially at the higher altitudes. Most of the structures are built on the slate and graywacke; some that border Benson Street are on a thin veneer of artificial fill which overlies lake sediments and ranges in thickness from 10 to 16 feet (J. R. Barr, consulting engineer, Kodiak, oral commun., 1966). The fill is composed of reworked glacial till. The docking facilities and the parking lot area southwest of Marine Way were constructed upon unconsolidated deposits consisting primarily of artificial fill (derived from glacial till) overlying, in part, fine-grained marine sediments.

Most of the structures along the coastline from downtown Kodiak northeast to Shahafka Cove rest on bedrock although some buildings were constructed on small patches of artificial fill (glacial till) in places where cut-and-fill construction procedures were necessary to provide suitable foundations.

From Shahafka Cove to Mission Lake (fig. 14) the area is underlain by unconsolidated deposits consisting chiefly of beach gravel. The thickness of the beach gravel is unknown but is probably greater than that of the unconsolidated deposits that underlie Benson Street in downtown Kodiak; the gravel may be as much as 20–25 feet thick.

Southwest of town, along the east coast of Inner Anchorage (fig. 2), all the structures are on slate and graywacke that have local veneers of unconsolidated deposits of glacial till, in place or reworked, and generally are less than 5–8 feet thick.

GROUND MOTION

Several eyewitnesses in Kodiak reported they heard a rumbling sound a few seconds before the initial seismic shock. The shaking was similar to that at the Kodiak Naval Station—a rolling motion that built up for ½–1 minute, remained intense for about 2½ minutes, and then gradually subsided for 1½–2 minutes. The direction of ground motion given by eyewitnesses varies from east-northeast—west-southwest to north-south.

According to Moore (1964), a massive power failure occurred in town at 5:39± p.m., during the early phase of the seismic shaking. The time of origin of the earthquake at the epicenter (about 275–280 miles northwest of Kodiak) is placed at 5:36:13± (U.S. Coast and Geod. Survey, 1964b). Surface waves from the initial seismic shock at 5:36:13± were probably responsible for the seismic shaking that caused the power failure; these surface waves should have arrived at Kodiak about 2 minutes after the initial shock, or a few seconds after 5:38 p.m.

Because the town of Kodiak is underlain chiefly by bedrock, the ground motion, or seismic shaking, did very little damage. The only severe damage was the massive short circuit and consequent power failure at the Kodiak Electric Association generating plant. Automatic equipment in the plant made four unsuccessful attempts in 3 seconds to reclose the circuits and then cut the electrical power off completely. Mr. Gronna, an employee at the plant, reported that during the earthquake he saw flashes emanating from the generating plant. Apparently the power failure was due to a short circuit at the plant itself, not in the feeder or distribution lines. The power had already failed before the first seismic sea waves struck the city.

COMPACTION

Compaction, or differential subsidence, and lateral movement of unconsolidated deposits occurred in the Kodiak area, but the amount of damage it caused is difficult to estimate. All the area in which differential settlement great enough to generate damage may have occurred was later inundated by the seismic sea waves, and any evidence was thus largely destroyed. For example, water and sewer lines were damaged, but it is not known whether differential settlement or ground cracks was responsible. The breakwater was damaged, probably as a result of differential settlement, according to Mr. James P. Barr of Kodiak (oral commun., 1965).

TECTONIC SUBSIDENCE

Kodiak, as well as the Kodiak Naval Station, had 5.6 feet of tectonic subsidence. The subsidence caused no immediate damage to the facilities, but it had a long-range effect upon all the port facilities and on some surviving near-shore structures.

All the port facilities except the city dock were destroyed by the seismic sea waves, and therefore little raising of facilities was necessary. However, the breakwater for the small-boat harbor had to be raised 5.6 feet plus an amount due to differential settlement and an amount that had been eroded away by the violent incoming and outgoing seismic waves.

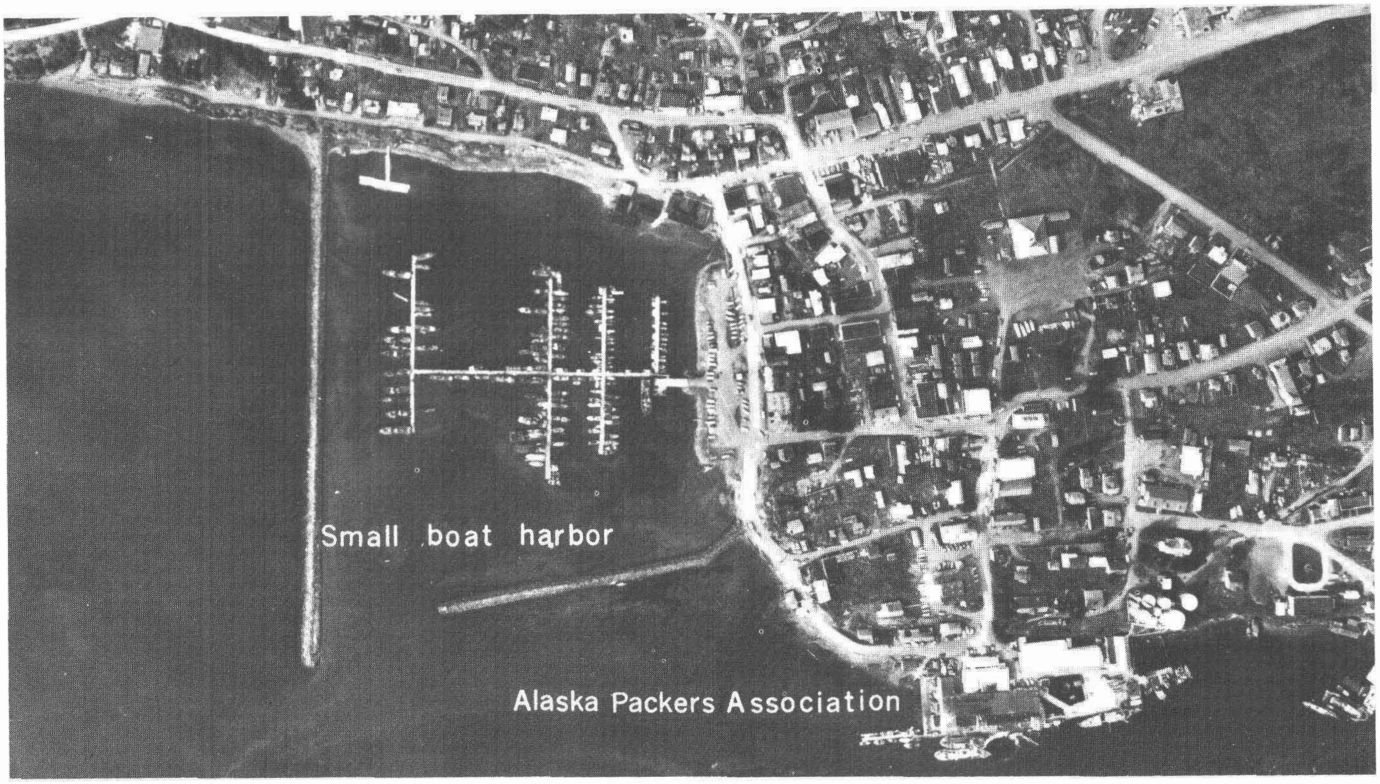
For the near-shore structures that survived, such as Kraft's Supermarket, the regional subsidence did create a problem. George Moore of the U.S. Geological Survey noted at 1:07 a.m. on May 13, 1964, when the tide was 10.6 feet, that water from Inner Anchorage had reached the floor level of Kraft's Supermarket and had half filled the bowling alley. He also noted that the water was calm and thus the tide was not a storm tide. The highest expected tide at Kodiak is 13 feet, or 2.4 feet higher than the tide that Moore observed. During high tide the low-lying area east of Kraft's Supermarket was under 3–4 feet of water.

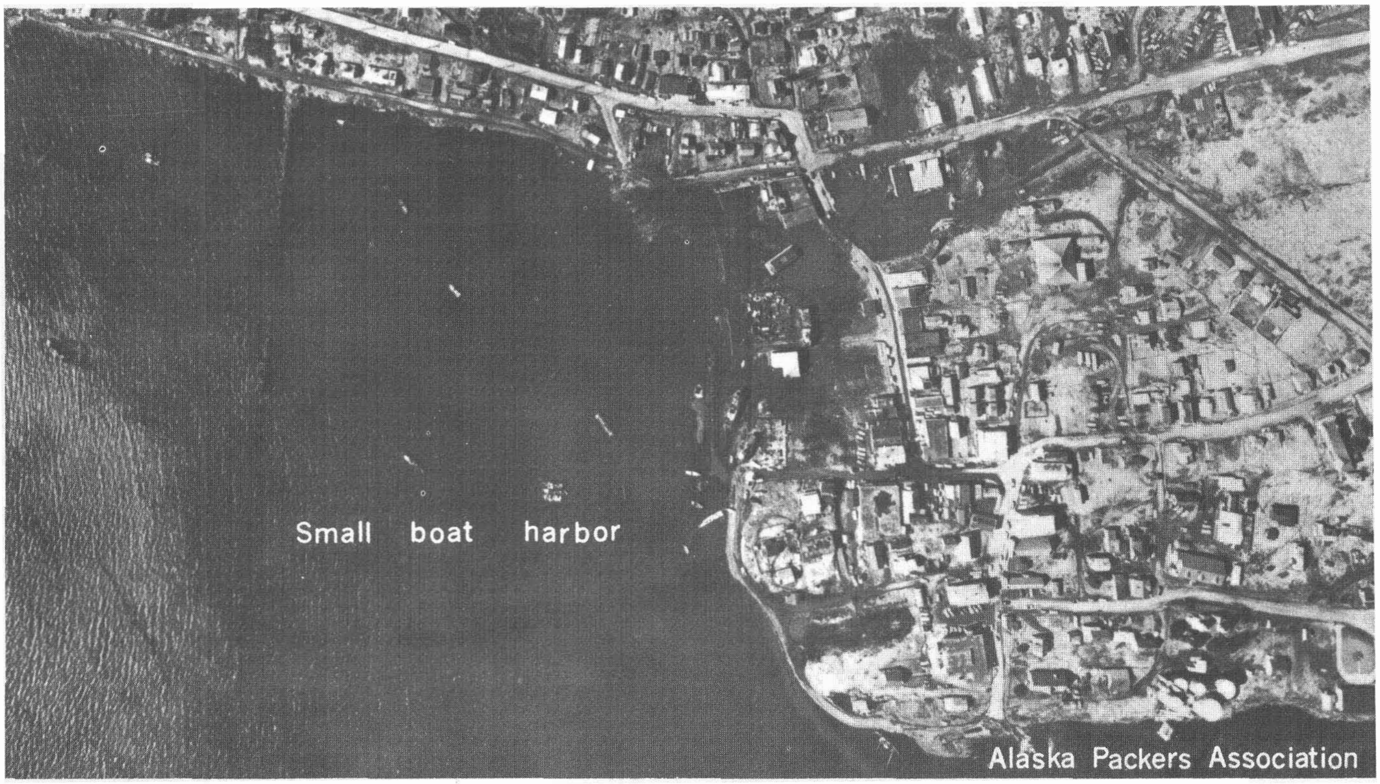
Before the earthquake, Mission Lake and Potatopatch Lake were not affected by tidal action, but since the earthquake both lakes have been tidal lagoons as a result of the tectonic subsidence. In October 1964, local residents constructed an outlet spit with tide gates on Mission Lake. However, this spit was soon eroded away by tidal action and a new one was constructed by November 9, 1964 (Alaska Dept. Fish and Game, 1965). Whether the second spit is still standing is not known.

SEISMIC SEA WAVES

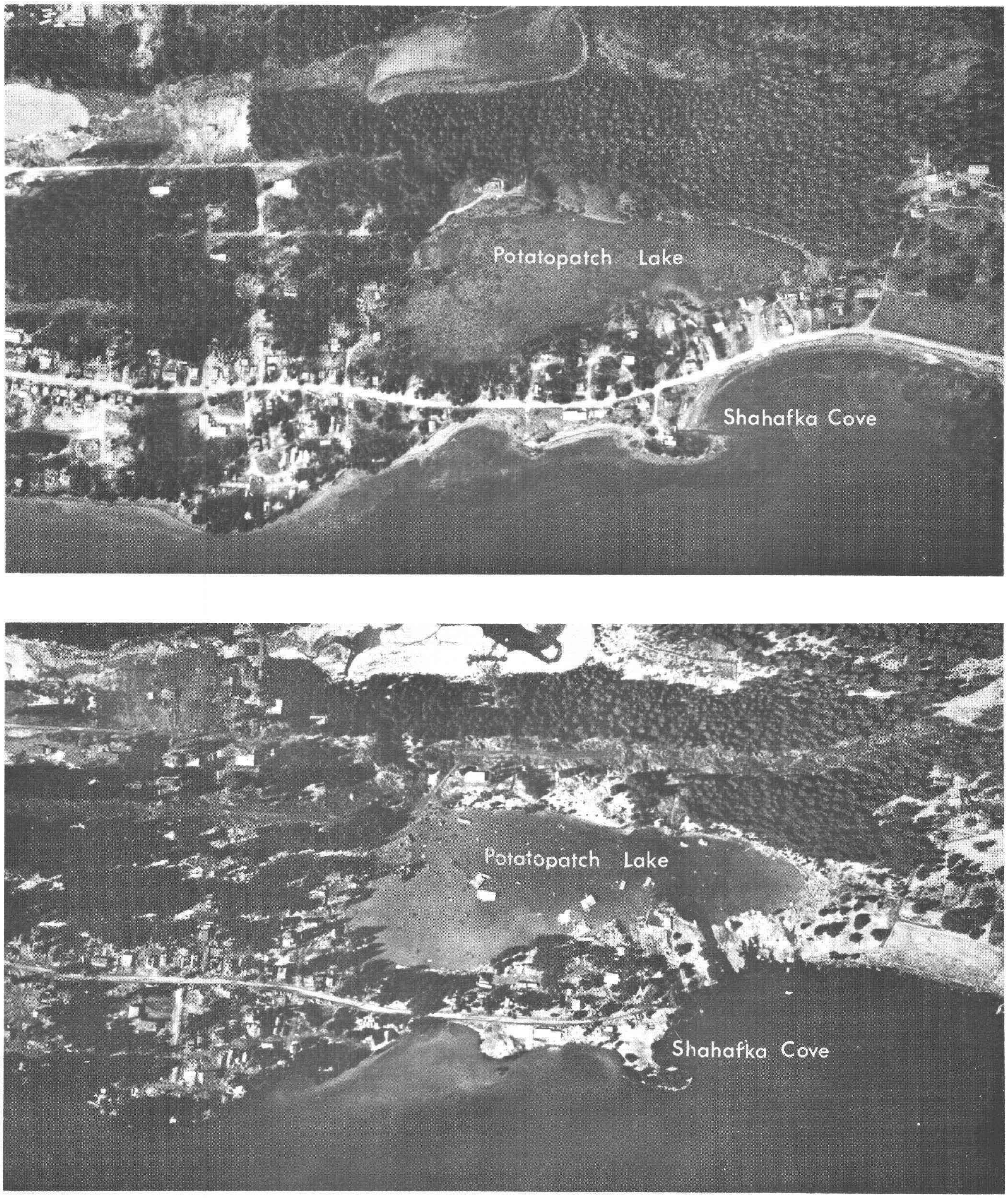
Very few eyewitness accounts of the earthquake were obtained from which the sequence of events during and immediately after the earthquake could be reconstructed. Local residents observed at least four seismic sea waves during the early evening hours of March 27, 1964, and when it became apparent that the earthquake had set up a train of seismic waves, those who had not already retreated to higher ground did so. Therefore no one observed in detail the later waves that inundated the low-lying areas of the town. On the basis of observations at the Kodiak Naval Station, at least 10 seismic sea waves struck the town.

The destructive force of the seismic sea waves in the Kodiak area is shown by figures 15 and 16, on following pages.





15.—Vertical aerial views of downtown Kodiak, scale 1 : 6,000. Top, preearthquake photograph by Bureau of Land Management, September 10, 1962. Bottom, postearthquake photograph by Air Photo Tech, Anchorage, April 14, 1964.



16.—Vertical aerial views of Potatopatch Lake area, northeast of downtown Kodiak, scale 1:6,000. Top, preearthquake photograph by Bureau of Land Management, September 10, 1962. Bottom, postearthquake photograph by Air Photo Tech, Anchorage, April 14, 1964.

One of the eyewitnesses to some of the events was Mr. Jerry Tilley of Kodiak, a crewman on the 75-foot shrimp-fishing vessel, the *Fortress*. The *Fortress* was tied up at the city dock receiving ice from King Crab, Inc., at the time of the earthquake. Mr. Tilley's account, with minor deletions and editing, is as follows; his times are estimates only:

At 5:35 or 5:36 p.m. the boat began jumping straight up and down violently. The dock was shaking from west to east and snapping piling that boats were tied on. During the shaking, a huge boil of reeking black water rose from under the boat moving west and receded east nearly severing our line.

At 5:45 p.m. the tide in St. Paul Harbor was 4 feet below the dock. At that time the predicted tide was 0.5 feet. [The water level was actually at about 13 feet, or 12.5 feet higher than it should have been.] We cut our line about 5:50 p.m. and pulled away from the dock. Immediately following this maneuver the water began to recede rapidly leaving an 85-foot King Crab, Inc., vessel sitting on bottom in front of Alaska Ice and Storage, even though there is ample water even during low tide. Conservatively speaking, I would say the tide was 10 feet below mean lower low water.

We were about 50 feet from this vessel when the first tsunami [seismic sea wave] hit at about 6:15 p.m. It [the wave] raised the 85-foot boat from the bottom and hurled it at least 50 feet in a southwest direction. The water level rose at least 15 feet in 5 seconds, then slowed until it reached its peak at about 6:20 p.m.

Mr. Tilley stated that the first seismic sea wave came in from the south as a large swell, although the 85-foot vessel was hurled to the southwest. A reconstruction of the sequence of events on March 27 described by Mr. Tilley is as follows:

5:35 or 5:36 p.m.—Felt shock aboard boat. Boil of reeking black water arose from beneath the boat.

5:45 p.m.—Approximately 13-foot tide at dock, when predicted tide should have been +0.5 foot. The 13-foot level is preearthquake altitude above MLLW. Postearthquake altitude is 7.5 feet above MLLW.

5:50 p.m.—Cut boat loose from dock as water began to recede.

5:50–6:10 p.m.—Water receding.

6:10 p.m.—Water at lowest level, approximately at −10 feet below MLLW.

6:15 p.m.—Waved moved in from south as large swell.

6:15–6:20 p.m.—Water rising at initial rate of about 15 feet in 5 seconds.

6:20 p.m.—Wave crested.

The 13-foot (preearthquake MLLW as datum) high water at 5:45 p.m. was in part due to regional subsidence of 5.6 feet. However, the regional subsidence plus the 0.5-foot tide accounts for only 6.1 feet of the 13 feet of water. The other 7 feet might have been from a locally generated wave. The black boil of water reported by Mr. Tilley might indicate that a small submarine landslide had generated a wave, but the water offshore is so shallow and the sediments in the floor of St. Paul Harbor so thin that a slide is unlikely. One other explanation that should be considered is that some artificial fill at the dock slid into the harbor. Such a slide, if indeed it did occur, would also have moved on a gentle slope, and it is doubtful that it could have caused the 7-foot anomaly. Thus, the 7-foot discrepancy was probably the result of (1) seismic seiching, (2) runup because of tilting due to tectonic subsidence coupled with possible horizontal regional displacement, or (3) a combination of both. The black boil may have been due to a sudden upwelling of the water which contained mud and debris from the floor of St. Paul Harbor.

All the seismic sea waves that inundated parts of downtown Kodiak came from the south, from St. Paul Harbor into Inner Anchorage. The first wave was described by Mr. Tilley and other eyewitnesses as a very rapid rise in sea level. In downtown Kodiak the wave reached a postearthquake altitude of 11 feet, which is about the same as the altitude of the first wave that struck the Kodiak Naval Station. Northwest of downtown Kodiak the initial wave was from the northeast (fig. 14) according to eyewitnesses at the Kodiak Airways offices and at the Kodiak Electric Association generating plant.

Mr. James Branson, an employee of the U.S. Bureau of Commercial Fisheries, was at home eating his dinner when the initial shock occurred. He went to the Bureau of Commercial Fisheries dock near the Kodiak Airway's hangar to save any equipment he could. Mr. Branson said the first seismic sea wave came in from the northeast as a nonturbulent rapid rise of high tide. The water rose about 3 feet above the dock, or to a postearthquake altitude between 8½ and 12½ feet. This first wave did relatively little damage in the immediate area, according to Mr. Branson. The water then retreated to about a 2-foot holdup (2 ft above MLLW). The water surged about 1 inch and then dropped about 18–20 inches. When the water had finally retreated to its maximum lowest level, only 2 feet of water was left where normally there was 15–16 feet; thus the water level was 15–20 feet below postearthquake MLLW.

Mr. Carl Gronna of the Kodiak Electric Association estimated that he arrived at the plant about 2 minutes after the earthquake stopped. About 45 minutes later he saw the low water that Mr. Branson estimated to be 15–20 feet below MLLW. Mr. Gronna noticed that the water intake for the generating plant was 1 foot above the water level, so he went into the dry channel and cut the cables holding the intake in place. The intake was 8 feet below preearthquake MLLW or 13.6 feet below postearthquake MLLW. Therefore, Mr. Gronna's account would place the lowest withdrawal level of the first wave at about 14.6 feet below postearthquake MLLW. This estimate agrees fairly well with the low water level of 13.7 feet after the first wave at the Kodiak Naval Station.

Mr. Robert Hall, owner of Kodiak Airways, arrived at his facility a few minutes after 6 p.m. About 15 minutes later he noticed that the water was roily about 2 feet above MLLW. The water then retreated to the northeast very rapidly. Mr. Hall stated that the water looked like a 12-foot fall as it left.

Neither Mr. Hall nor Mr. Gronna stated whether he saw a high-water level at about 8–8½ feet above MLLW as did Mr. Branson. Mr. Gronna did state that he was very busy in the generating plant and may have missed the first wave. The 2-foot level of roily water Mr. Hall reported was probably the 2-foot holdup reported by Mr. Branson.

The first wave probably came from the northeast, because it was being refracted around Woody Island and again around Near Island. However, water from the south must have entered the channel between Kodiak Island and Near Island also because both Mr. Hall and Mr. Gronna reported that water was running southwest and northeast in the channel at the same time, especially after the first wave; they saw boats and debris floating in both directions in the 300-foot-wide channel between Kodiak and Near Islands. Thus, the wave that struck downtown Kodiak at 6:20 p.m. continued northeastward into the channel about the same time a wave was entering the channel in a southwesterly direction.

All three eyewitnesses reported that the second wave came in 2–3 minutes after the first wave reached its lowest level (about 15 ft below postearthquake MLLW).

Mr. Branson was in the channel untying a boat that was "high and dry" when the second wave arrived. He reported that it came in as one surge 6 feet high. It stayed there for about 2 minutes, then rose rapidly to about 3 feet above the Bureau of Commercial Fisheries dock, or to a postearthquake altitude of about 14 feet. The water then retreated to the northeast at a rate of 14–20 knots; Mr. Branson stated that the channel between Kodiak Island and Near Island looked like a minor rapids.

Mr. Hall, who watched the second wave come in, stated that it came in as a surge, crested for 3–4 minutes, and retreated to the northeast at an estimated speed of 20–25 knots. He described the noise of the outflow as "half roar and half hissing."

Mr. Gronna said that after he cut the cable holding the cooling-water intake he immediately left the channel and retreated to high ground. By the time he had walked up to a high platform about 22 feet above MLLW, the second wave had reached its maximum height. Mr. Gronna also stated that water in the channel was flowing northeast and southwest at the same time.

Mr. Branson reported that after the second wave had crested 3 feet above the dock it temporarily retreated 6 feet. It stayed at this temporary level about 5–10 minutes and again crested to its original point 3 feet above the dock. The seismic sea wave crested for 3–4 minutes and again retreated at an estimated 15–20 knots.

The following tentative sequence of events of the first two waves that struck the Kodiak Electric Association and Kodiak Airways facilities has been put together from the accounts of Branson, Hall, and Gronna:

- 6:00–6:05 p.m.—First wave arrived from northeast as rapid high tide; crested about 8½–12½ feet above postearthquake MLLW.
- 6:08 p.m.—Water began to retreat.
- 6:10 p.m.—Water at 2-foot holdup, surging 1 inch and retreating 18–20 inches.
- 6:15 p.m.—Water at minimum level, 14.6 feet below MLLW.
- 6:20–6:21—Second wave arrived from northeast; first wave arrived from southwest and crested at about 14 feet above MLLW.
- 6:23–6:25 p.m.—Water retreated 6 feet.
- 6:28–6:35 p.m.—Water crested again to about 14 feet above MLLW.
- 6:30–6:38 p.m.—Water retreated.

This reconstructon indicates that the first seismic sea wave from the northeast that struck the Kodiak Airways and Kodiak Electric Association facilities arrived about 15–20 minutes before the seismic sea wave from the south that struck downtown Kodiak. It must be pointed out again that the eyewitness accounts of time are only estimates. Furthermore, because the seismic sea waves were refracted around Woody and Near Islands, the wave train became exceedingly complex. There is also a possibility that seismic seiching developed in the channel between Kodiak Island and Near Island. Mr. Hall stated that, after the second seismic sea wave, the waves struck the Kodiak Electric Association and Kodiak Airways facilities at intervals of 10 minutes. A combination of (1) refraction of the seismic sea waves around the islands, (2) a possible earlier arrival (by 15–20 min) of the first seismic wave, (3) seismic sea waves from the south, and (4) seismic seiching may have been responsible for the 10-minute intervals reported by Hall.

Maximum inundation in downtown Kodiak occurred along Benson Street between 11:16 and 11:34 p.m. during the fifth wave. Here water reached a postearthquake altitude of about 22 feet. At the Kodiak Electric Association facility the water of this same wave reached a maximum altitude of approximately 20 feet.

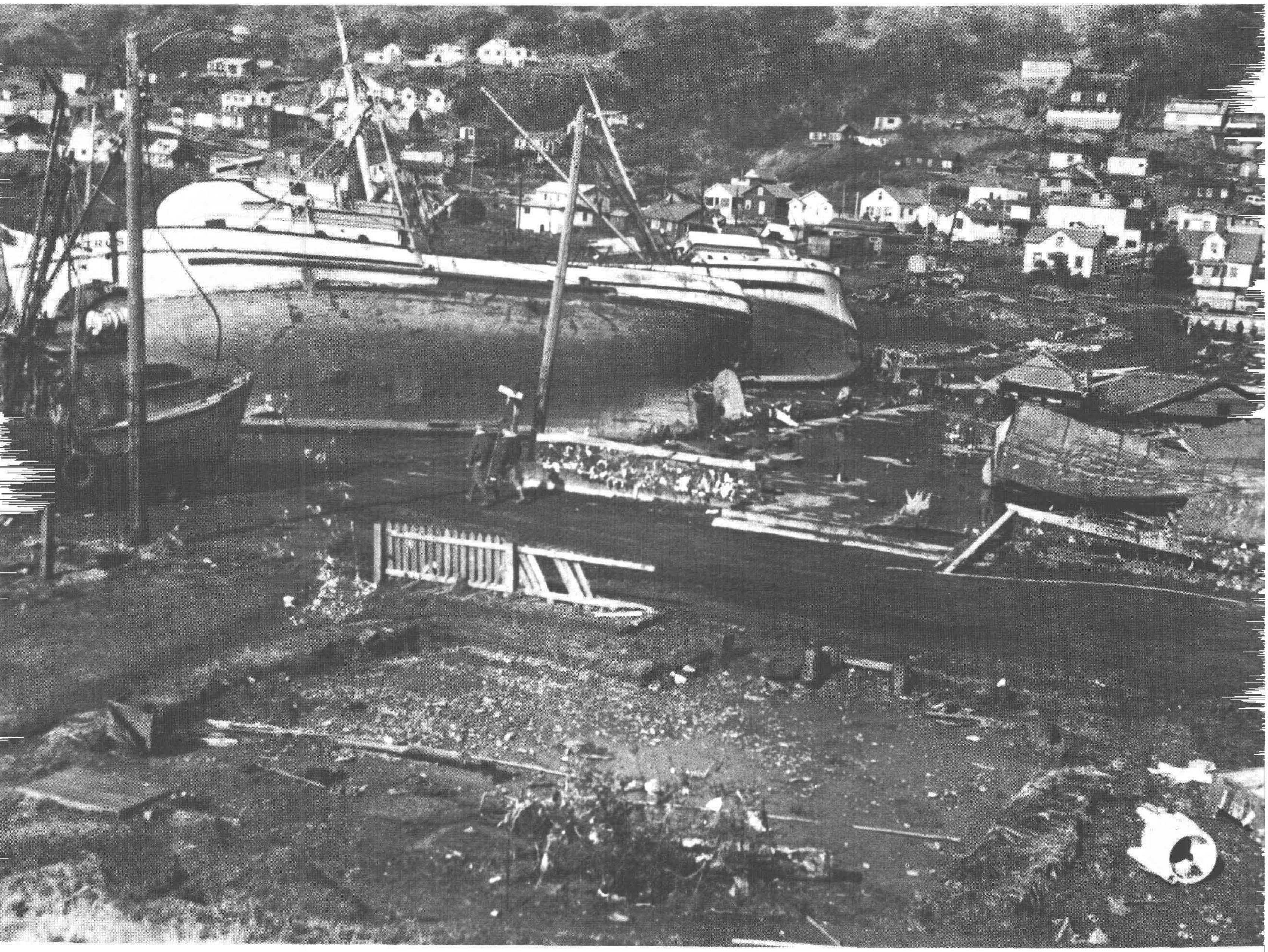
At Potatopatch Lake, debris was found on trees about 29 feet above MLLW. Therefore, the maximum seismic sea wave that inundated the lake was 29–30 feet above MLLW (fig. 14).

Maximum inundation of downtown Kodiak, along the channel between Kodiak Island and Near Island, and at Potatopatch and Mission Lakes, occurred between 11:00 and 11:45 on the evening of March 27, 1964.

On March 28, after the waters of St. Paul Harbor and Inner Anchorage had calmed, much of downtown Kodiak lay in shambles. Familiar landmarks had disappeared, and there was little evidence that they ever existed. The destruction caused by the seismic sea waves was the worst disaster ever to strike the town of Kodiak. About 75 percent of the commercial facilities of the town were laid to ruin. Streets were clogged with debris, including boats, buildings, and merchandise. The fishing fleet was almost completely destroyed, and then, on April 3, 1964, high winds struck the city. Many of the few boats that had managed to survive the earthquake were damaged by the winds because no sheltered harbor facilities were available.

The violent incoming and outgoing waves destroyed more than 215 structures. About 200 of these were on land and approximately 15 were private and commercial docking facilities. The inland structures included 158 homes, 25 commercial structures, and about 20 miscellaneous buildings such as sheds. Some are shown in figure 14 and on plate 1.

17.—Structures displaced by seismic sea waves, downtown Kodiak. View is west toward intersection of Benson and Reganoff Avenues. Photograph by Mr. Alf Madsen, Kodiak, March 1964.



18.—Foundations of structures swept away by seismic sea waves, downtown Kodiak. View is west from intersection of Marine Way and Mill Bay Road. Foundation across Mill Bay Road was the Elks Bowling Alley; the boats are the *Cindy*, *Albatross*, and *Hekla*. Photograph by U.S. Navy, March 28, 1964.

Many of the displaced structures were moved by the seismic sea waves to the low-lying area on Benson Street; figure 17 shows some of these structures. Along Alaska Way in downtown Kodiak, only structures in the low-lying area east of Benson Street were totally destroyed. Many structures along Marine Way also were destroyed; figure 18 shows the foundations of some of these and several boats aground.

The Alaska Packers Association, Donnelley and Acheson, and Standard Oil structures at the foot of Marine Way and Main Street were swept off their foundations by the second seismic sea wave, about 7:40 p.m. Mr. Robert Hall watched the Donnelley and Acheson structure float northeast along the channel between Kodiak and Near Island. The building hit the Kodiak Airways hangar, in which a Gruman Goose aircraft was parked, and knocked the hangar off its foundation. The last time Mr. Hall saw the aircraft it was "cartwheeling" along the channel in a northeasterly direction. All that remained of the complex of structures, including the Alaska Packers Association building, were the piles upon which the structures rested.

In addition to those structures that were completely destroyed, numerous buildings in downtown Kodiak were moderately to severely damaged by the seismic sea waves. Most of these structures, as well as those that suffered only slight damage, are indicated on plate 1.

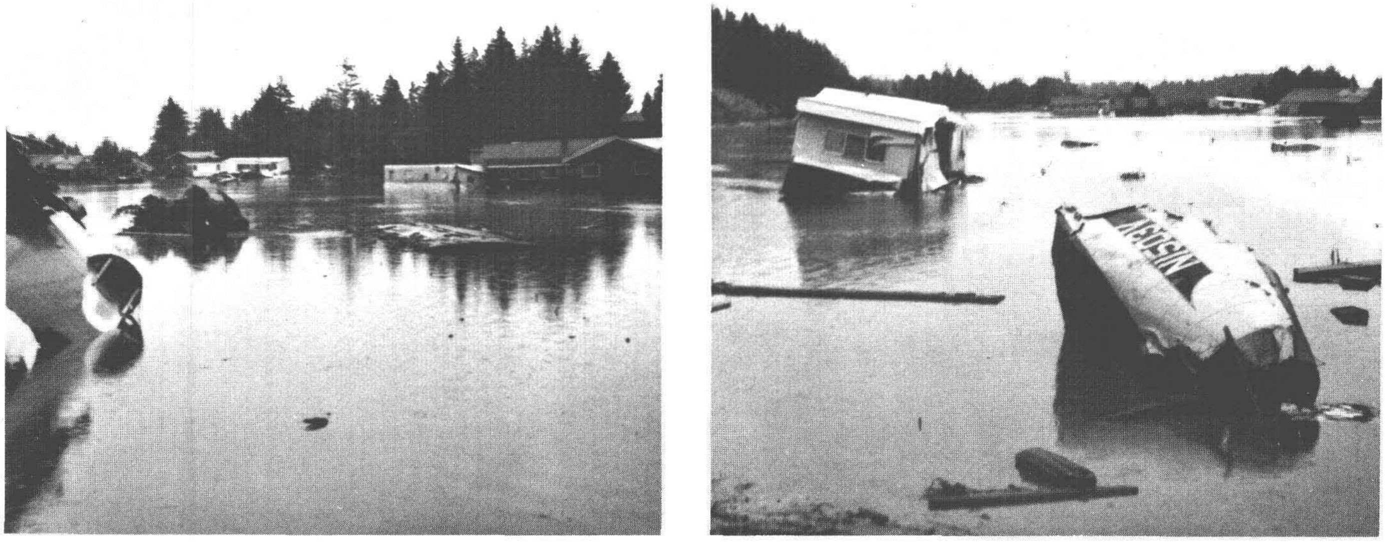
There were no commercial facilities at the Shahafka Cove area; damage was restricted to homes and private dock facilities along Mission and Potatopatch Lakes and on Mission Road and to a bridge at Potatopatch Lake that was destroyed. About 32 homes were completely destroyed—most were washed into Potatopatch Lake (fig. 19)—and an additional 8–10 homes sustained major damage.

Mission Road between Potatopatch Lake and Mission Lake was washed out by the seismic sea waves and by erosion (fig. 14). The erosion was the result of tidal action caused by the 5.6-foot regional subsidence of the Kodiak area. The estimated cost of replacement of the road between Mission and Potatopatch Lakes is $75,000.

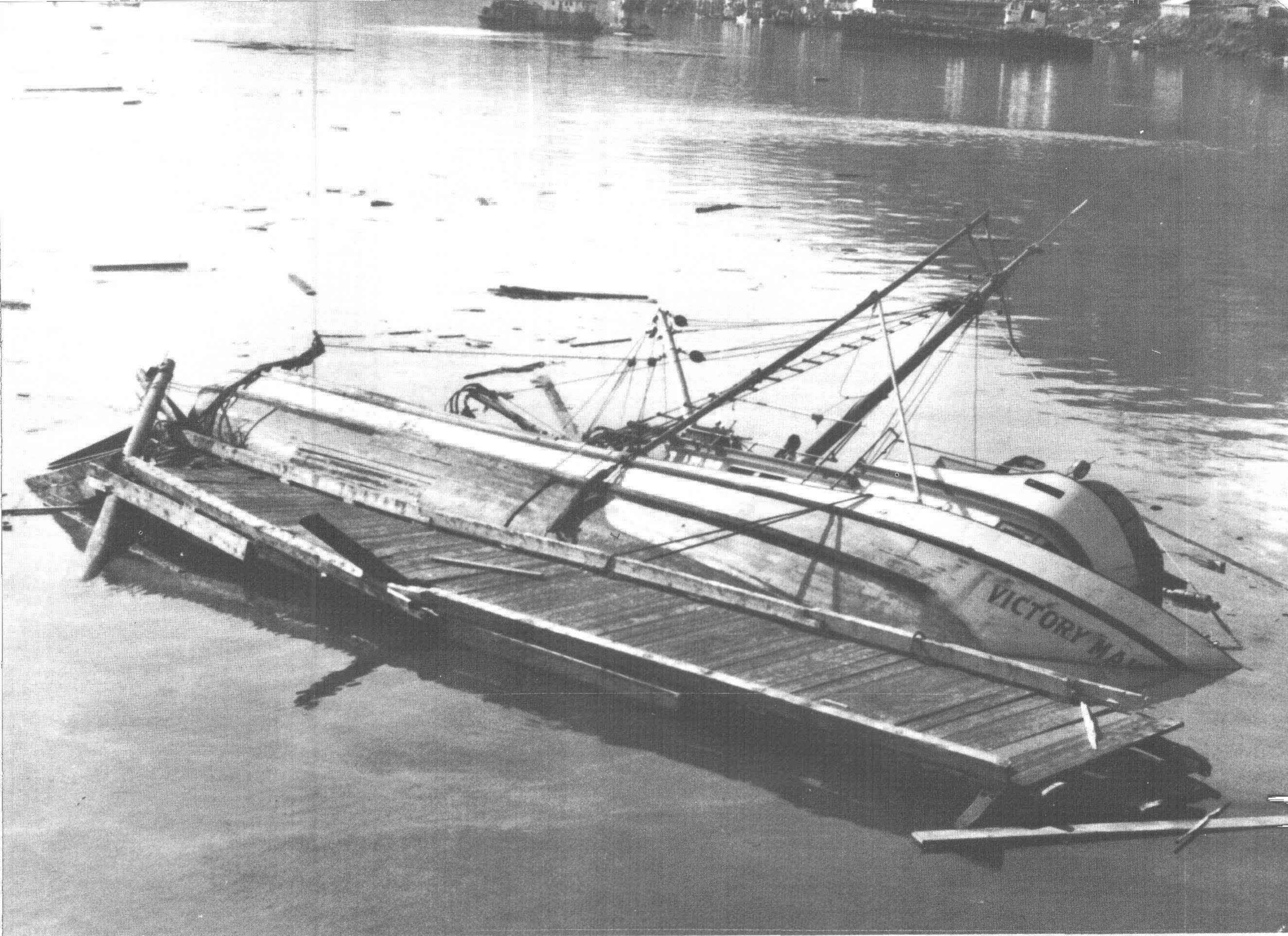
The road net in downtown Kodiak was also damaged, although not as severely as Mission Road near Shahafka Cove. Alaska Street and Mills Bay Road had $90,000 worth of damage, Marine Way and the small-boat harbor parking lot $160,000, and Tagura Road approximately $120,000. These roads, as well as Mission Road, were damaged first by seismic sea waves and later by high tides resulting from the regional subsidence. Most of the roads were not hardtop, so the roadbeds were badly eroded. None of the roadways in Kodiak showed any extensive fracturing that would indicate damage by seismic shaking or compaction of the underlying sediments.

Most of the 101 boats that were damaged, destroyed, or missing were moored in the small-boat harbor when the earthquake started. For example, the *Victory Maid* was still moored to its dock when it ran aground (fig. 20). Others were underway or, like the *Fortress* of which Mr. Tilley was a crew member, were tied up at the other docking facilities at Kodiak. Some of these boats managed to get underway before the first seismic sea wave struck the town. The *Selief*, which came to rest behind the school, was one of those that were underway. She rode out the first four waves but finally went aground during the fifth between 11:16 and 11:34 p.m., March 27.

Boats damaged at the town of Kodiak are listed in table 6. Not all the boats listed however, were



19.—Debris and houses washed into Potatopatch Lake by seismic sea waves. Photographs by Alaska Department of Highway, Kodiak.



20.—The *Victory Maid* still tied to its dock but aground in Inner Anchorage. City dock is background. Photograph by U.S. Navy, March 28, 1964.

TABLE 6.—*Intensity of damage to boats at Kodiak and vicinity*

[From the Kodiak Mirror, Apr. 10, 1964]

Sunk or aground:
- 2 jitneys
- 2 boats named "Cindy"
- Hekla
- Yukon
- Bétts
- Selief
- Albatross
- Victory Maid
- Leading Lady
- Ribich
- Mary Ruby
- Explorer
- Henning J
- Laurel
- Halcyon
- Arrow
- Toots
- Davy J
- Tiny
- Hazel A
- Joanne
- Mary L
- Norman U
- Vagabond
- Fidelity
- Miss Arctic
- Neptune
- Padilla
- Sophia King
- Shuyak
- Innicta
- Marguerite
- Wind A

Missing:
- KFC6
- Isabel N
- Jaguar
- Widgeon
- Sea Scout boat
- SJ7
- Spruce Cape
- Roosevelt E
- UF2
- Lucky Star
- Oranius
- Frieda
- Marmot Cape
- Peril Cape
- Sitka
- Waffico 12

Major damage:
- Anna A
- Beluga
- Chief
- Fortress
- Lex
- Coogan
- Pelican
- Robbie
- Sea Lion
- Sue
- Sunrise

Moderate damage:
- Chacon
- C. H. Andersen
- Crash boat
- Georgie
- Jan M
- Karen Sue
- Marmot
- Marten
- Mary Carrol
- Mermaid
- Nargene Ray
- New Stranger
- Sea Quail
- Swallow
- Widgeon

Slight damage:
- Banshee
- Cape Horn
- Cape Uganik
- Commander
- Fedair
- FAA boat
- Fern
- Gladys R
- Hildur
- Homeward
- Hadenia B
- San Juan
- Jo G
- King
- Jay Gallagher
- Laurie
- Lady Jean
- Nick Andrich
- Ripple
- Michael M
- Parakeet
- Rustler
- Stork
- Yankee Trader

destroyed at Kodiak. For example, the *Spruce Cape* was destroyed, ironically, at Cape Spruce near the town of Uzinki. Many boats came to rest in the heart of downtown Kodiak; some were carried down the channel into the open sea. Still others wound up on rocks and beaches of Near Island and adjacent islands. The repair and replacement cost of these boats was estimated to be $1,600,000.

SCOURING

The violent incoming and outgoing seismic sea waves generated a postearthquake construction problem in the channel between Kodiak Island and Near Island. Hall and Branson reported that before the earthquake in the vicinity of the Kodiak Electric Association and Kodiak Airways facilities there was at least 10 feet of unconsolidated sediments into which piling could be driven for the foundations of structures such as piers and docks. The waves scoured out all but 1 inch of the sediments, and bedrock was exposed in many places in the channel after the earthquake. The importance of this scouring phenomenon cannot be overemphasized. The removal of the sediments into which piling can be set now presents a difficult construction problem.

AFOGNAK

Afognak, a native fishing village of about 190 inhabitants, was severely damaged both by seismic sea waves and by encroachment of the sea after tectonic subsidence. The subsidence forced relocation of the village. The new village will be named Port Lions (fig. 1) and will cost an estimated $816,000 (Bur. Indian Affairs, written commun., Sept. 25, 1964).

The summary of earthquake effects at Afognak is based on two brief visits by Plafker of less than half a day each during July 1965, on a study of vertical and oblique aerial photographs, and on the accounts of eyewitnesses given in interviews and on questionnaires.

GEOGRAPHIC AND GEOLOGIC SETTING

Afognak is located on the southwest coast of Afognak Island at the head of Marmot Bay (fig. 1). The village stretches along 2 miles of rocky coast and is exposed to easterly winds. Kelp-covered shoals known as village Reefs extend seaward as much as 1 mile. The area inland from the village is mostly a swampy lake-studded lowland that extends ½–1 mile westward to the base of a steep mountain front that rises to altitudes of about 2,000 feet. The lakes behind the barrier beaches are drained by seepage through the beach gravels or by small sluggish outflow streams that incise the beach berms. Poorly drained areas characteristically support a growth of muskeg and low brush; the higher, better drained areas are covered with spruce forest to altitudes of 200–300 feet.

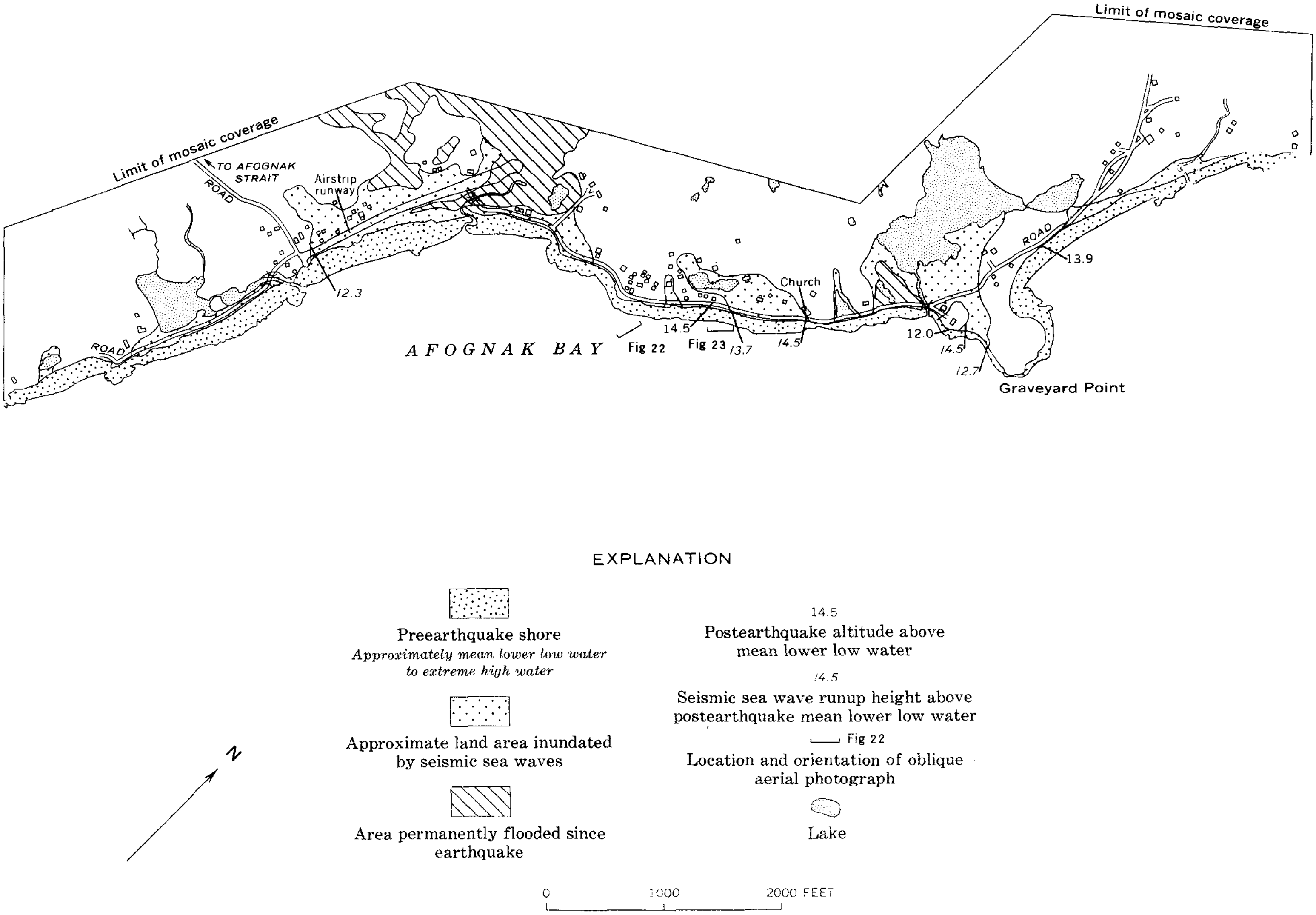
The village is on a series of low bedrock capes tied together by gravel barrier beaches. Bedrock is exposed continuously between the capes at extreme low tide, and undoubtedly lies close below the surface of the beach gravels and surficial swamp and lake deposits behind the barrier beaches. The rocks consist of northeast-trending slate and minor graywacke of probable Mesozoic age (Capps, 1937, pl. 2).

Most of the dwellings are located just off the beach along an unpaved road that runs from the northern end of the village across the neck of Graveyard Point, thence along the storm beach berm and airstrip runway to the south end of the village (fig. 21). From the south end of the airstrip runway, the road runs 0.8 mile southwestward to a small-boat anchorage and a sawmill along the north shore of Afognak Strait (fig. 1). All the village is low-lying, the highest altitude at Graveyard Point being only about 40 feet above preearthquake lower low water. Some parts of the barrier beach storm berms between the bedrock capes were as low as 16½ feet in altitude, and much of the area behind the beaches was even lower, or within a few feet of the extreme high tide.

Diurnal tide range at Afognak is about 10.0 feet; preearthquake annual mean high water was 9.1 feet, extreme high tides reaching altitudes of 12.3 feet (U.S. Coast and Geod. Survey, 1964a). Local residents reported that for several years preceding the earthquake, higher than normal storm tides had caused severe erosion of the beaches.

DIRECT SEISMIC EFFECTS

The earthquake, which was strongly felt in Afognak, was described by village residents as a rolling and jarring motion that lasted 3–4 minutes. Ground movement was reported by one person as north-south and by another as either northeast-southwest or east-west. Several individuals saw ground waves but were unable to furnish estimates of their amplitudes or period. Ice on swampy ground and lakes in the village area was cracked almost as soon as the tremors were felt, and at one locality water was ejected as high as 15 feet during the period of strong ground motion. Trees and bushes oscillated with motions that various observers described as moderate to violent; however, it was possible to move about during



Base from uncontrolled aerial-photograph mosaic
by U.S. Bureau of Land Management, 1962

21.—Planimetric sketch map of Afognak showing approximate limits of inundation by seismic sea waves and the areas flooded by ponding behind barrier beaches.

the most violent tremors without serious difficulty. A few small rockslides occurred along the mountain front west of the village.

Surprisingly little damage was sustained in the village as a result of the shaking. All structures are wood frame on shallow dug piling or concrete foundations. A few homes had brick chimneys but the majority had metal stovepipes. The only noteworthy damage was slight cracking of plaster on interior walls. Even the brick chimneys, such as the one shown in figure 22 (next page), survived with no visible cracking. Few light-weight objects within the buildings were shifted or toppled. In at least one house, a refrigerator and stove were thrown down in a room even though small objects on shelves remained undisturbed. The intensity of the earthquake on the Modified Mercalli Scale is estimated as VI–VII, on the basis of its direct effects on people and structures.

TECTONIC SUBSIDENCE

The earthquake was accompanied by marked tectonic subsidence at Afognak as well as throughout much of Kodiak and the nearby islands (Plafker and Kachadoorian, 1966). Subsidence resulted in relatively higher tide levels along the shore, an occurrence noticed by all the village residents in the days immediately following the earthquake. An estimate of the amount of subsidence made by one of the residents is $3\frac{1}{2}\pm\frac{1}{2}$ feet; an estimate made in July 1965 by measuring the difference in height between the upper growth limits of pre- and postearthquake barnacles and

22.—Part of Afognak; note eroded road along coast, new beach berms (outlined by dashed line), and part of large lagoon ponded behind beach berm. The arrow points to undamaged brick chimney. Location of this view is shown on figure 21.

algae along the shore suggests that it may have been closer to 5½ feet. Although the exact amount of subsidence is not known, it was clearly enough to result in tidal inundation and accelerated erosion of parts of the village near the shore and extensive flooding of some low-lying areas behind the barrier beaches. Permanent damage resulting from the subsidence was the primary factor that forced abandonment of the village.

It is not known how much, if any, surficial subsidence may have occurred as a result of compaction of unconsolidated deposits in the village area.

Wave action at the relatively higher sea level has caused erosion of the coast at the village, the greatest amount of erosion occurring in areas of poorly consolidated beach deposits (figs. 22, 23). Shoreline retreat in beach deposits at the locality shown in figure 23 amounted to about 30 feet by July of 1965, and the road that formerly ran along the coast was obliterated. Lesser amounts of erosion occurred at those parts of the coast made up of bedrock, although in one locality at Graveyard Point at least 12 feet of retreat is indicated by partial undermining of the root systems of large spruce trees.

Landward shift of the coastline was accompanied by the building of new beach berms in equilibrium with the new, relatively higher sea level. As illustrated by figures 22 and 23, berm construction has resulted in burial of terrestrial vegetation beneath 3–5 feet of beach gravel.

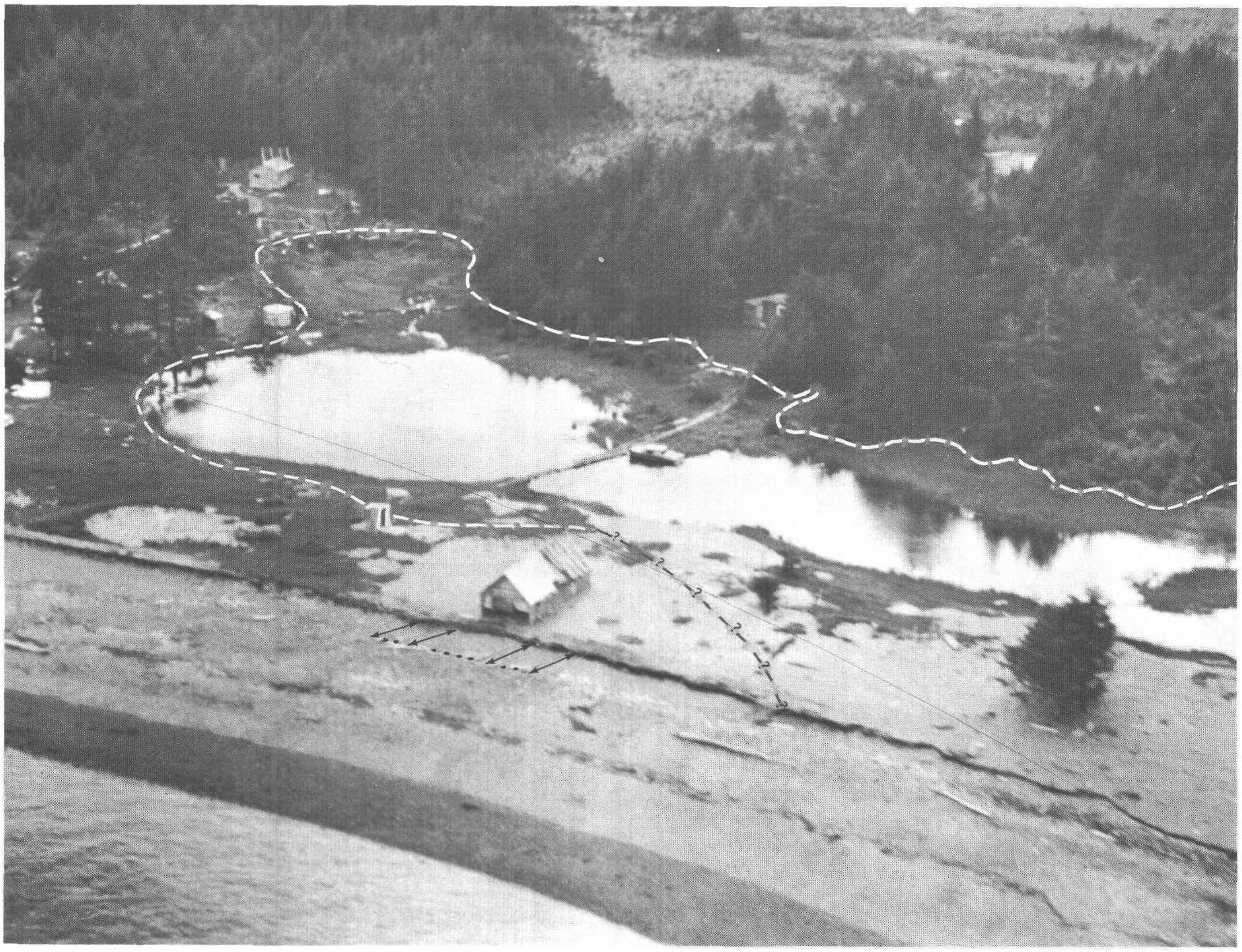
In two localities, streams draining across the barrier beaches have been partly dammed by the raised beach berms and have flooded the low-lying areas behind the barrier beaches. Newly flooded areas are shown on figure 21, and a part of the largest area now entered by the sea at extreme high tide is shown on figure 22. Flooding at this locality has submerged about 300 feet of the north end of the airstrip.

A further consequence of the tectonic subsidence at Afognak seems to be the encroachment of salt water into some of the numerous nearshore shallow wells used for domestic water supplies. Some of these wells reportedly became saline only at high tide; these were clearly affected by salt-water incursion resulting from the subsidence. However, the increased salinity reported after the earthquake may have resulted in part from inundation of the wells and their surroundings by seismic sea waves.

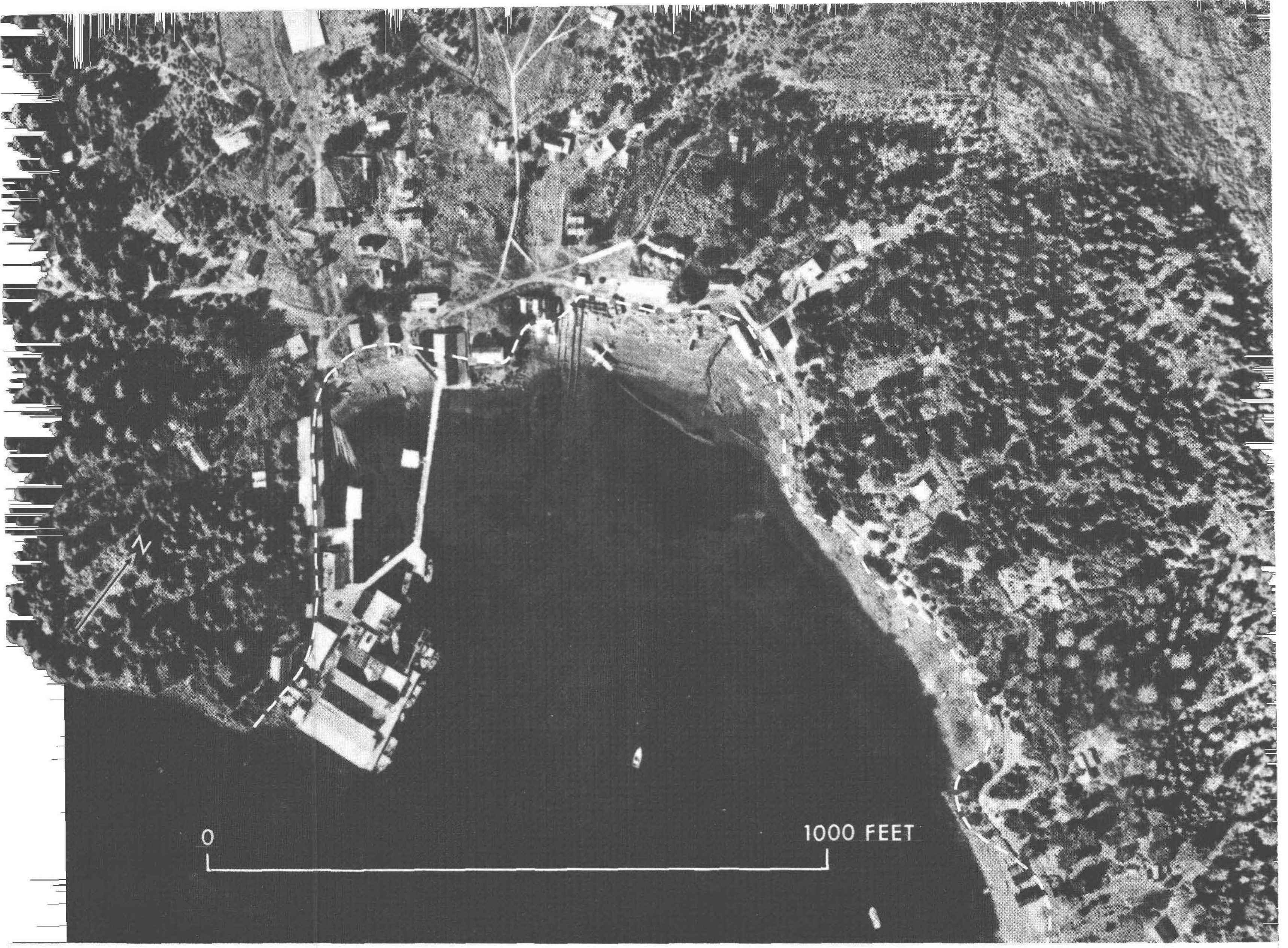
SEISMIC SEA WAVES

The train of seismic sea waves that followed the earthquake caused severe property damage in Afognak, although miraculously no one was drowned or injured. Of an estimated 38 structures in the village, 23 were either extensively damaged or destroyed (Capt. E. L. Mayfield, Alaska State Police, written comm., Mar. 5, 1965). Many structures, including the grocery store and community hall, were floated from their foundations and washed as much as half a mile inland. Captain Mayfield estimated the replacement cost of the damaged or destroyed homes to be about $550,000. In addition, most of the estimated 26 automobiles in the village were either damaged by water or destroyed by the waves; two bridges were washed out along the coastal road.

The initial wave at Afognak coincided approximately with low tide, but its exact arrival time is uncertain. It was variously estimated by different observers as having been from ½ to 1 hour after the start of the earthquake. Mr. Willis Nelson of Afognak described the waves as successive tides that were accompanied by a powerful current action and roaring sounds, especially at withdrawal. Mr. Nelson believes that the current velocity is indicated by a truck which was rolled into the trees by a wave and demolished—the speedometer had jammed at 22



23.—Part of coast at Afognak. Arrows show approximate amount of landward retreat; newly formed beach berm is gray, and approximate extent of seismic sea wave inundation is indicated by dotted line. Note partly submerged automobile in pond.



24.—Aerial mosaic of Uzinki in 1962 showing large cannery complex along the waterfront belonging to the Ouzinkie Packing Co. and approximate inland limit of seismic sea wave inundation (dashed line).

mph. The initial wave was followed by progressively higher waves that came in on a flooding tide. The highest wave, which stopped a clock in one residence at 9:27 p.m., was either the third or fourth of the train. By this time the residents had evacuated their homes and fled to the hills behind the village; from there they saw, by moonlight, most of the structures floating away on the highest wave.

The approximate extent of wave inundation outlined on figure 21 was mapped from the distribution of driftwood, debris from wrecked structures, and abraded bark or broken limbs of trees and brush. By far the largest area inundated was in the vicinity of the airstrip and the adjacent low area to the north that was formerly a swamp but is now a shallow lagoon. The waves also flooded smaller low-lying segments of the village, mainly at the seven localities shown on the map. Most of the property damage, however, occurred in the vicinity of the airstrip and in the two smaller inundated areas about 2,000 feet to the north.

Maximum measured wave runup heights above postearthquake MLLW (assuming an average 4½-ft subsidence at the time of the earthquake) was 12½–14½ feet on the south side of Graveyard Point, 13½–14½ feet in the area between Graveyard Point and the airstrip, and 12½ feet at the south end of the airstrip. Because the maximum inundation reportedly occurred at 9:27 p.m., at which time the predicted astronomical tide would have been 3.7 feet above MLLW, maximum height of the seismic sea wave above the normal postearthquake tide level was only 10.8 feet.

UZINKI

At the native fishing village of Uzinki (also spelled Ouzinkie), which had 214 inhabitants, seismic sea waves caused six fatalities and damaged the waterfront facilities. The estimated cost of replacing the damaged or destroyed homes and boats is $49,800 (Bur. Indian Affairs, written commun., Sept. 25, 1964), and the cost of replacing the facilities of the Ouzinkie Packing Co.'s salmon cannery is $300,000 (Alaska Dept. Fish and Game, 1965, p. 21).

The summary of earthquake effects at Uzinki is based on the accounts of eyewitnesses given in interviews or on questionnaires and on observations made from a light plane.

GEOGRAPHIC AND GEOLOGIC SETTING

Uzinki is located near the southwest tip of Spruce Island, immediately northeast of Kodiak Island (fig. 1). The island, which is about 6 miles long and 2–4½ miles wide, is separated from the north shore of Kodiak Island by Narrow Strait, a body of water that tapers from a width slightly more than 2 miles at its east end, where water depths exceed 300 feet, to about one-fourth mile at the west end near Uzinki, where there is less than 40 feet of water. The village is located along the west and north shore of a small cove sheltered from all but southeasterly winds (figs. 24, 25). The village site slopes upward from the shore of the cove, most of the homes being situated on rocky ground well above sea level. A few homes, the grocery store, and the cannery with its appurtenant structures were located either along the narrow beach or out over the water on pile foundations. An unpaved road extends 2½ miles southeastward from the village to a small sawmill on the south shore of the island. All the village appears from the air to be located on slate and graywacke bedrock or on bedrock mantled by beach gravel.

DIRECT SEISMIC EFFECTS

No detailed descriptions of the effect of ground movements at Uzinki during the earthquake are available, but fragmentary data suggests that movements were almost similar to those at nearby Afognak and Kodiak. In a questionnaire, Mr. John Pestnikoff described the ground tremors as an initial swaying motion for the first minute followed by a violent up and down motion. He estimated that the duration of the strong motion was 3–4 minutes and that the main direction of ground movement was northwest-southeast. Trees and bushes were shaken violently. There was no noteworthy damage to the wood-frame structures. Some small objects in the houses, such as dishes, lamps, and knicknacks, were shifted about or toppled,

25.—Oblique aerial view of Uzinki in July 1965 showing approximate inland limit of seismic sea wave inundation (dashed line) and remains of the Ouzinkie Packing Co.'s salmon cannery (left center).

but large heavy objects were unaffected. No ground cracks or landslides occurred in the vicinity of the village site. The slight damage resulting from the tremors suggests a Mercalli intensity of about VI.

TECTONIC SUBSIDENCE

Tectonic subsidence at Uzinki resulted in relatively higher tide levels along the shore which were noticed by the inhabitants the day after the earthquake. Mr. Edward Pestnikoff's estimate of the amount of subsidence is 5 feet, an amount consistent with measurements made nearby on Kodiak and Afognak Islands (Plafker and Kachadoorian, 1966, fig. 16). The relatively higher sea level undoubtedly has caused some landward shifting of beach berms and inundation of areas that formerly were above highest tide levels. However, most of the near-shore facilities that would have been endangered by inundation resulting from the subsidence were either destroyed or severely damaged by the seismic sea waves that followed the earthquake; these facilities have since been rebuilt above the new relatively higher tide levels.

OLD HARBOR

The native fishing village of Old Harbor, which had a preearthquake population of 193, was virtually wiped out by earthquake-generated seismic sea waves. All the 35 homes with their auxiliary buildings were destroyed or seriously damaged, a loss estimated at approximately $707,000 (Bur. Indian Affairs, written commun., Sept. 25, 1964). At Old Harbor also, there were no casualties, though one old man, who lived alone immediately across the strait from the village, is missing and presumably was drowned in the waves. Differential compaction of unconsolidated surficial deposits and regional tectonic subsidence resulted in only slight damage from tidal inundation.

The following description of earthquake effects at Old Harbor is based largely on the accounts of eyewitnesses given in interviews and on questionnaires, supplemented by observations made by Plafker during a flight over the village in July 1964 and a brief ground inspection in July 1965.

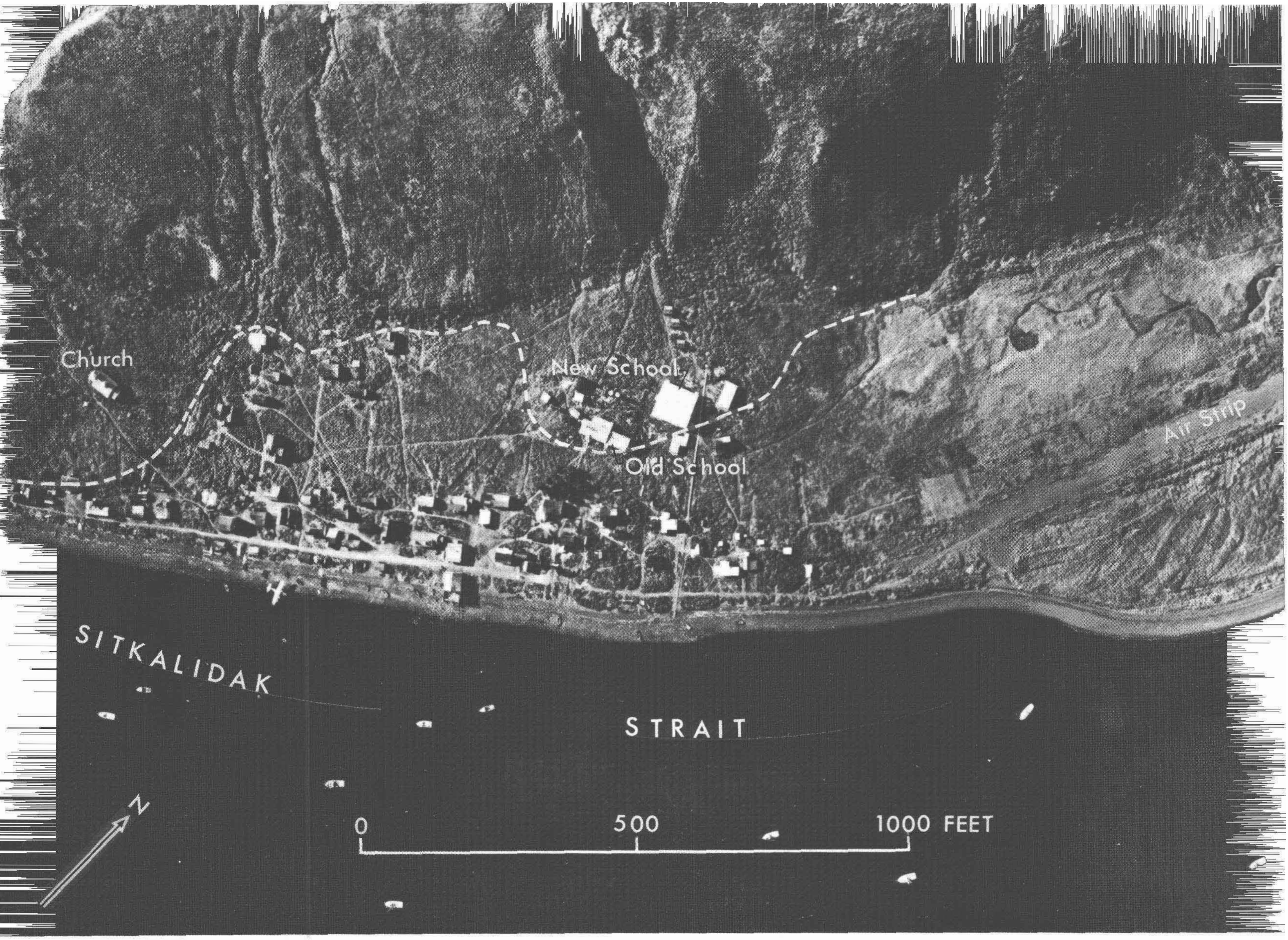
GEOGRAPHIC AND GEOLOGIC SETTING

The village of Old Harbor is on the southeast coast of Kodiak Island immediately northwest of Sitkalidak Island (fig. 1). Just south of the village, Sitkalidak Strait, which separates the two islands, is 1½ miles wide and about 60 feet deep. It narrows to 0.2 mile and shoals to a low-tide depth of 12 feet at Sitkalidak Passage about 1½ miles northeast of the village. Old Harbor is situated on a narrow shelf that slopes gently from the strait to the base of a steep grass-covered mountain front. The mountain, which consists of slate and graywacke of probable Mesozoic age, rises abruptly to a summit altitude of about 1,900 feet. The low-lying ground at the village is underlain mainly by the unconsolidated deposits of two coalescing alluvial fans that were built out into the strait from the mouths of small deeply incised streams. The Greek Orthodox church and cemetery occupy the high ground at the apex of the more southerly fan, and the old and new schools are on the high ground near the apex of the more northerly fan (fig. 26). The residential area was on the lower parts of, and between, these two fans. Immediately north of the village site, prevailing currents have formed compound beach cusps, with intervening low swampy lagoons. The airstrip was built on the beach deposits, and small boats were beached in the sheltered lagoons behind the cusps. The water table beneath the village is shallow, only 8 feet deep at the lower part of the village site and less than 17 feet deep near the school.

DIRECT SEISMIC EFFECTS

The earthquake was very strongly felt at Old Harbor although the tremors caused only a minor amount of damage. The strong tremors, which reportedly lasted 2–3 minutes, began as a slow roll which soon changed to a fast jarring motion. During the earthquake, a few ground cracks formed in the swampy lagoon area north of the village and numerous small landslides developed on the steep mountain slopes nearby. Cracking of the ground in the lagoon area was accompanied by differential subsidence of about 2–3 feet, presumably because of compaction and (or) lateral spreading through flow or sliding of the unconsolidated surficial deposits.

The tremors shifted and toppled some large heavy objects, including stoves and water heaters, and broke dishes, pictures, lamps, and knicknacks. The water pipe from a small reservoir that provides part of the village water supply was broken. All but one of the 35 wood-frame homes in the village were set on short piling foundations dug ½–1 foot into the ground; the other one had a concrete foundation. Two houses had cinder-block chimneys instead of stovepipes. Both cinder-block chimneys broke off during the earthquake, although the stovepipes remained intact. Except for minor cracking of interior plaster walls of these two houses, there



26.—Aerial mosaic of Old Harbor showing approximate inland limit of inundation by seismic sea waves (dashed line). Mosaic by U.S. Bureau of Land Management, 1962.

was no significant structural damage from the tremors to any of the 35 residences—the great destruction was from the seismic sea waves. The schools and Greek Orthodox church came through the shaking completely undamaged. The earthquake effects on structures and their contents suggest that the Mercalli intensity at the village was about VII–VIII, significantly higher than at Kodiak, Afognak, and Uzinki. The relatively greater intensity of shaking at Old Harbor is believed to be largely due to local geologic conditions at the village site. Old Harbor is built on a thick alluvial fill saturated to within 8 feet of the surface, whereas the other three communities are either on bedrock or on bedrock mantled by a thin veneer of unconsolidated deposits.

TECTONIC SUBSIDENCE

Old Harbor is within the zone affected by regional tectonic subsidence during the earthquake. The exact amount of this subsidence, however, is uncertain because surficial compaction of unconsolidated deposits also took place along the shore at and near the village site. Mr. Sven Haakansan of Old Harbor estimates that tides now run 2–3 feet higher than before the earthquake, a figure in reasonably good agreement with Plafker's measurement of about 3 feet of subsidence on bedrock (Plafker and Kachadoorian, 1966, fig. 16). Approximately a quarter of a million yards of fill was required along the waterfront and at the airstrip to raise these areas above the new relatively higher high tides. The school water well, which was 17 feet deep, became permanently salty and unusable, according to Mr. Larry Matfay of Old Harbor. The salinity most probably resulted from encroach-

27.—Oblique aerial view of school area, Old Harbor, showing approximate inland limit of seismic sea wave inundation (dashed line). The area below the high-water line had been cleared of debris by the time this photo was taken (July 15, 1964). The structures near the apex of the alluvial fan are temporary shelters.

ment of sea water into the aquifer as a result of the combined tectonic and surficial subsidence.

SEISMIC SEA WAVES

The train of seismic sea waves that followed the earthquake virtually wiped out the residential area of Old Harbor and presumably took the life of an old man who lived alone on Sitkalidak Island opposite Old Harbor. The cost of replacing the homes and auxiliary buildings is estimated at $707,000, not including the personal effects of the residents or damage to their vessels. Radio warnings of the destructive waves from Kodiak and Kaguyak were received in time for the village residents to flee to nearby high ground.

The initial wave at Old Harbor struck at about 6:24 p.m., 48 minutes after the start of the earthquake and approximately at zero tide stage (Van Dorn, 1964, table 1). Mr. Matfay, who was in a fishing boat offshore from the village, stated that the wave moved in from both the north and south ends of Sitkalidak Strait in the form of a fast-rising tide accompanied by swift currents. The fifth wave of the train, which came in at the 4-foot tide stage at 9:28 p.m., rose the highest in the village. The initial wave and the successive waves were preceded by withdrawals that sucked the channel dry and lowered the water an estimated 30 feet, according to Mr. Matfay.

The approximate extent of wave inundation at Old Harbor is shown on figure 26. All but one of the 35 structures in the flooded area were floated from their foundations and either seriously damaged or destroyed (fig. 27). The exception was the one home that was securely tied to a concrete foundation. The waterline in this house indicated flooding almost to the ceiling of the first floor, but the house remained on its foundation and was otherwise undamaged. (Alaska Dept. Health and Welfare, 1964, p. 27). The only other structures in the village are the school buildings (fig. 27), which received minor water damage from the waves, and the church, which was safely above the highest water level.

The maximum runup height, marked on the foundation of the new school building, is 17.7 feet above preearthquake MLLW. If the minimum combined tectonic and surficial subsidence at the village site was 2 feet and the normal tide was about 3.8 feet at the time of the highest wave, the maximum height of the seismic sea wave above the normal postearthquake tide level must have been about 12 feet.

KAGUYAK

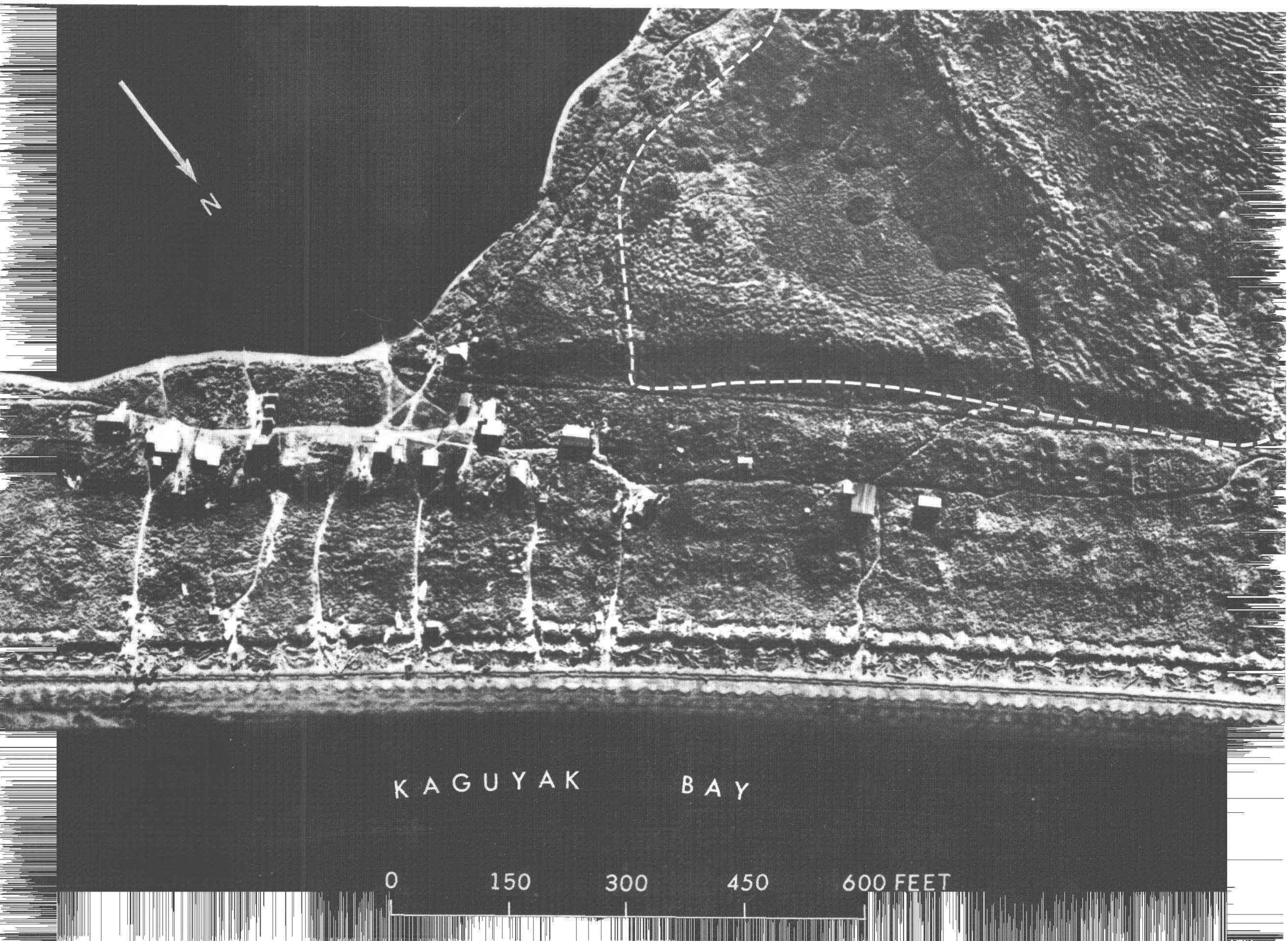
The small native fishing village of Kaguyak, which prior to the earthquake consisted of nine residences and a Greek Orthodox church, was wiped out by seismic sea waves, and three lives were lost. The village site has been abandoned and its 34 surviving residents have moved to Akhiok and Old Harbor.

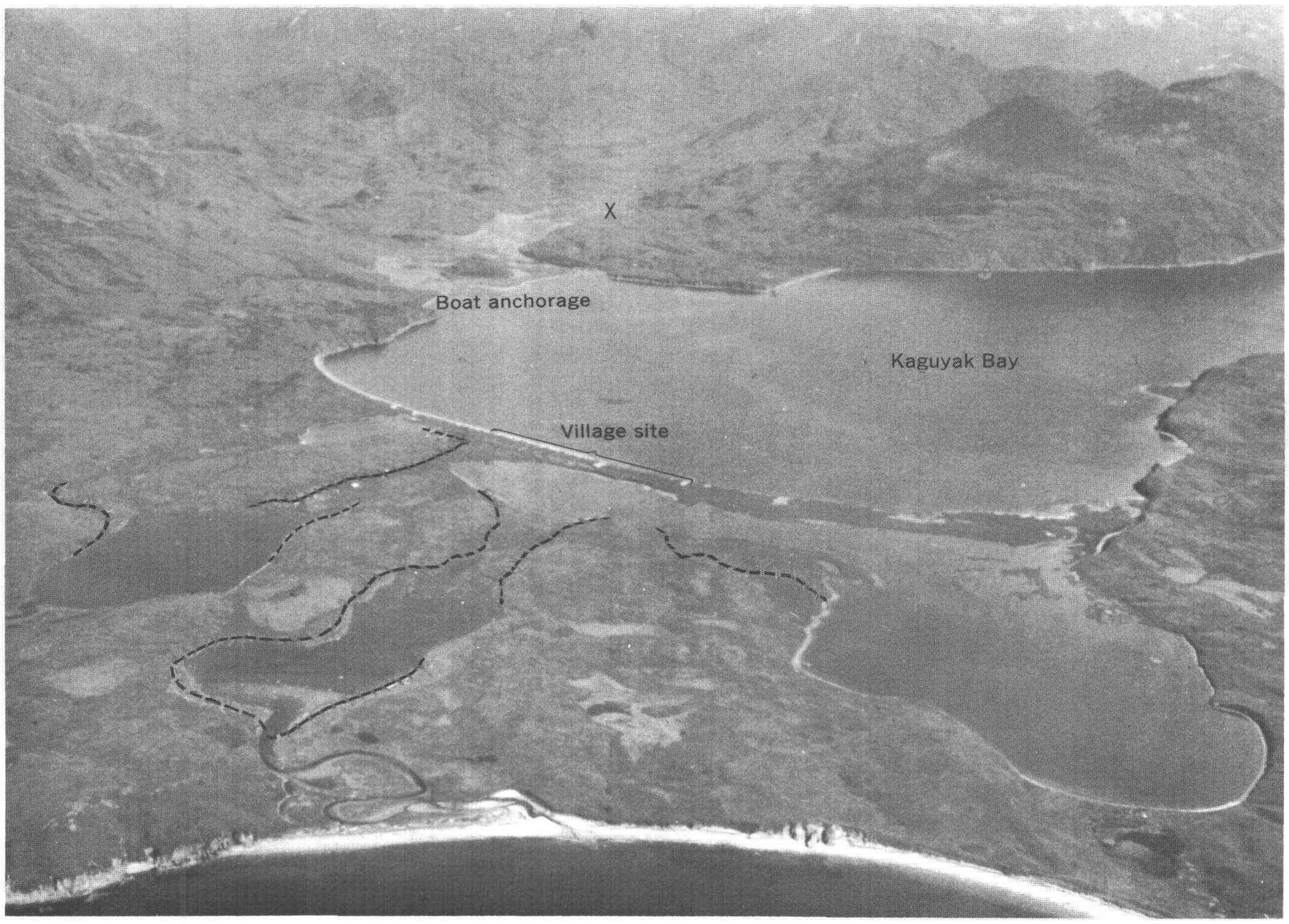
GEOGRAPHIC AND GEOLOGIC SETTING

Kaguyak is located on the east side of the Aliulik Peninsula near the southeast tip of Kodiak Island (fig. 1) at the head of Kaguyak Bay. The bay is about 2 miles long, 0.6–0.9 mile wide, and as much as 180 feet deep; it opens toward the northeast into the Gulf of Alaska. Unlike most of the larger bays along the coast of Kodiak Island, Kaguyak Bay does not have a large river delta at its head, so water depths in excess of 18 feet occur immediately offshore from the village. The village is built on a compound beach about 300 feet wide that lies between the head of Kaguyak Bay and a large lagoon (figs. 28, below; 29, next page).

The highest point at the site is only about 20 feet above MLLW and less than 10 feet above the level

28.—Aerial mosaic of Kaguyak in 1962. Dashed line shows approximate inland limit of seismic sea wave inundation. Mosaic by U.S. Bureau of Land Management.





29.—Oblique aerial view of the head of Kaguyak Bay showing site of Kaguyak (fig. 28), approximate inland limits of debris deposited by seismic sea waves (dashed line), and location of small-boat anchorage. X marks position at which one 30-foot salmon trawler was stranded by the waves.

of mean annual high tide. Complexly folded clastic rocks of probable Tertiary age underlie the low rolling hills in the vicinity of the village (G. W. Moore, oral commun., 1965). During inclement weather, small boats from Kaguyak anchored in the shelter of the sandbar at the mouth of a stream that enters Kaguyak Bay from the northwest (fig. 29).

DIRECT SEISMIC EFFECTS

No significant damage was done to structures or personal property at Kaguyak as a result of the earth tremors; specific data on the direct seismic effects, however, are not known.

TECTONIC SUBSIDENCE

Measurement of the height of the upper growth limits of barnacles and marine algae relative to tide level at the head of Kaguyak Bay suggests that the area has subsided slightly, perhaps 1–1½ feet. Part of the apparent subsidence may be due to local surficial compaction and slumping of the beach deposits on which the village was situated. This small amount of subsidence has had little obvious effect on the shoreline other than the killing and subsequent discoloration of a narrow fringe of near-shore terrestrial vegetation.

SEISMIC SEA WAVES

All the significant earthquake-related damage and loss of life at Kaguyak resulted from inundation by seismic sea waves. The nine residences and their appurtenant structures and the church (fig. 28) were floated from their foundations and were either washed out to sea or were stranded virtually intact as much as half a mile inland (fig. 30). One of several 30-foot salmon trawlers that were in the small-boat anchorage at the mouth of the river (fig. 29) was floated 1.8 miles upstream and stranded. Flooding of the village site also caused brine pollution of

30.—Wood-frame houses that were floated inland from Kaguyak by seismic sea waves and deposited almost undamaged.

two small fresh-water lakes and two shallow dug wells that were used as a water supply (Alaska Dept. Health and Welfare, 1964, p. 28). Estimated replacement cost of public and private property lost at Kaguyak is $321,000 (Bur. Indian Affairs, written commun. Sept. 25, 1965).

The villagers were evacuated to the hill immediately behind the site before the largest waves struck. Several of the men went out in a skiff to assist two temporary residents of the village, Mr. and Mrs. Donald Wyatt, when they attempted to cross low ground during a lull between wave crests. The skiff was swamped by a wave during the rescue operation, and Mr. Wyatt, the village chief, and one other native were drowned.

The approximate extent of wave inundation at the village site, as indicated by the distribution of debris, is shown in figure 28. Maximum measured runup height on the hill behind the village was about 25 feet above the postearthquake MLLW. If the highest wave occurred at the same stage of tide as the highest wave at Old Harbor, its runup height above normal tide level would have been about 21 feet, almost twice that of the waves at Kodiak, Afognak, and Old Harbor. This unusual runup at Kaguyak must be related to the location of the village at the head of a large deep bay that is open to waves from the Gulf of Alaska. Critical details of the wave spectrum in the bay are unavailable, so there is no way to determine whether the runup resulted from a resonant amplification of waves in the bay, development of a bore at the bay head, or possibly some other related phenomenon.

AKHIOK

The native fishing village of Akhiok, on southern Kodiak Island (fig. 1) has a population of 72–75 and 16 residences. It was not damaged either by the earthquake or by subsequent seismic sea waves. Regional tectonic subsidence of 1–1½ feet has caused no significant inundation at the village nor has it had any obvious effect on shoreline morphology in the area. Seismic shock at the large Pacific American Fishery cannery installation at Lazy Bay 4½ miles southwest of Akhoik caused no damage other than a slight parting between floorboards at one place, according to Mr. W. F. Brindle, cannery superintendent. The estimated Mercalli intensity at the village and cannery is about VI; both are located on indurated metamorphic and granitic rocks.

KARLUK

The native fishing village of Karluk on western Kodiak Island (fig. 1), which has a population of about 129, sustained no significant damage as a result of the earthquake. The village is built on unconsolidated deposits along the shore of a lagoon and on the spit that separates the lagoon from Shelikof Strait. Karluk was not visited during this investigation.

In answer to a questionnaire, Mr. Roy James of Karluk reported that the earthquake was felt strongly as a rolling motion in a northeast-southwest direction and lasted an estimated 3–4 minutes. The shaking had no other effect than to cause some small objects in homes to move about or fall over. The Mercalli intensity at Karluk probably was about VI and certainly no more than VII.

Low, quiet sea-level rises were observed beginning about 1½ hours after the earthquake, but the waves apparently did not flood above the shoreline or cause any damage. Mr. James estimated that 1½ feet of subsidence has occurred at the village site, and he noted that tides in the area are running about 20 minutes earlier than they did prior to the earthquake. The slight amount of subsidence has apparently had no adverse effect at Karluk.

LARSEN BAY

Larsen Bay survived the earthquake and ensuing seismic sea waves undamaged, but long-term damage to waterfront facilities occurred as a result of tectonic subsidence. Larsen Bay consists of a small community of natives and a sizable cannery of the Alaska Packers Association on the west shore of Uyak Bay, Kodiak Island (fig. 1). The permanent population of the area is estimated at 35–40. The cannery is built on a beach spit at the mouth of Larsen Bay—a bay extending westward from Uyak Bay—and most of the homes are along the shore on beach deposits or bedrock.

According to Mrs. Lloyd Howe of Larsen Bay, the earthquake was strongly felt as a north-south rolling motion that overturned some small objects in her home, shifted a few large heavy objects about, but caused no structural damage. Mr. Howe, the cannery watchman, stated that a few items were knocked off kitchen shelves, stock in the store and stockroom was dumped from shelves, and stacked cases of 5-gallon oilcans were toppled. One heavy item, a food grinder, was shaken down from a table and broken. Some electrical conduits had parted fittings or short circuits, and a few water pipelines were pulled apart at the joints. There was no damage to the cannery buildings or docks. These seismic effects suggest a Mercalli intensity at Larsen Bay of about VI–VII.

The main cause of damage at Larsen Bay was tectonic subsidence, which may have been accentuated locally by surficial subsidence of unconsolidated deposits. The amount of subsidence is estimated by Mr. Howe to be 2–2½ feet. This estimate agrees with pre- and postearthquake tide measurements at the cannery that indicate 2.5 feet of subsidence (U.S. Coast and Geod. Survey, 1964b, p. 3) and with Plafker's estimate of 2¼ feet of subsidence based on measurements of the position of upper growth limits of marine organisms relative to tides. The subsidence has caused inundation by tides of low-lying areas along the coast and consequent destruction of terrestrial vegetation in the flooded areas. It has also made it necessary to raise the cannery dock level above the reach of high tides, at an estimated cost of $80,000 (Alaska Dept. Fish and Game, 1965, p. 21).

At about 1:00 a.m. on the morning after the earthquake, Mr. Howe noted an extremely high high tide that put 2 feet of water over the warehouse floor and floated one boat off the drydock but caused no noteworthy damage. If 2 feet of tectonic subsidence occurred during the earthquake and if high water coincided with the 14.8-foot predicted astronomical tide at 1:24 a.m., the high-water mark in the cannery warehouse was about 4 feet above normal tide level.

REFERENCES

Alaska Department of Fish and Game, 1965, Post-earthquake fisheries evaluation; an interim report on the March 1964 earthquake effects on Alaska's fishery resources: Juneau, 72 p.

Alaska Department of Health and Welfare, 1964, Preliminary report of earthquake damage to environmental health facilities and services in Alaska: Juneau, 46 p.

Capps, S. R., 1937, Kodiak and adjacent islands: U.S. Geol. Survey Bull. 880–C, p. 111–184.

Kodiak Mirror: v. 24, no. 15, Apr. 10, 1964.

Moore, G. W., 1964, Magnetic disturbances preceding the 1964 Alaska earthquake: Nature, v. 203, no. 4944, p. 508–509.

Plafker, George, and Kachadoorian, Reuben, 1966, Geologic effects of the March 1964 earthquake and associated seismic sea waves on Kodiak and nearby islands, Alaska: U.S. Geol. Survey Prof. Paper 543–D, 46 p.

Tudor, W. J., 1964, Tsunami damage at Kodiak, Alaska, and Crescent City, California, from Alaskan earthquake of 27 March, 1964: U.S. Naval Civil Eng. Lab., Port Hueneme, Calif., Tech. Note N–622, 124 p.

U.S. Bureau of the Census, 1963, U.S. Census of population, 1960: v. 1, pt. 3.

U.S. Coast and Geodetic Survey, 1964a, Tide tables, high and low water predictions, 1964, West Coast North and South America including the Hawaiian Islands: 224 p.

——— 1964b, Prince William Sound, Alaskan earthquakes, March–April, 1964: Seismology Div. Prelim. Rept., 83 p.

U.S. Weather Bureau, 1964, Climatological Data, Alaska: v. 50, no. 13 (Annual Summary), p. 234–243.

Van Dorn, W. G., 1964, Source mechanism of the tsunami of March 28, 1964, in Alaska: Coastal Engr. Conf., 9th, Lisbon 1964, Proc., chap. 10, p. 166–190.