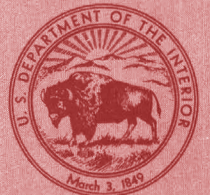


The Alaska Earthquake

March 27, 1964

Effects on Communities



Whittier

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

Effects of the Earthquake Of March 27, 1964 At Whittier, Alaska

By REUBEN KACHADOORIAN

*A description and analysis of damage and loss
of lives resulting from subsidence of the land-
mass, waves generated by submarine landslides,
fire, and seismic shock at the port of Whittier*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 542-B

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*



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THE ALASKA EARTHQUAKE SERIES

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

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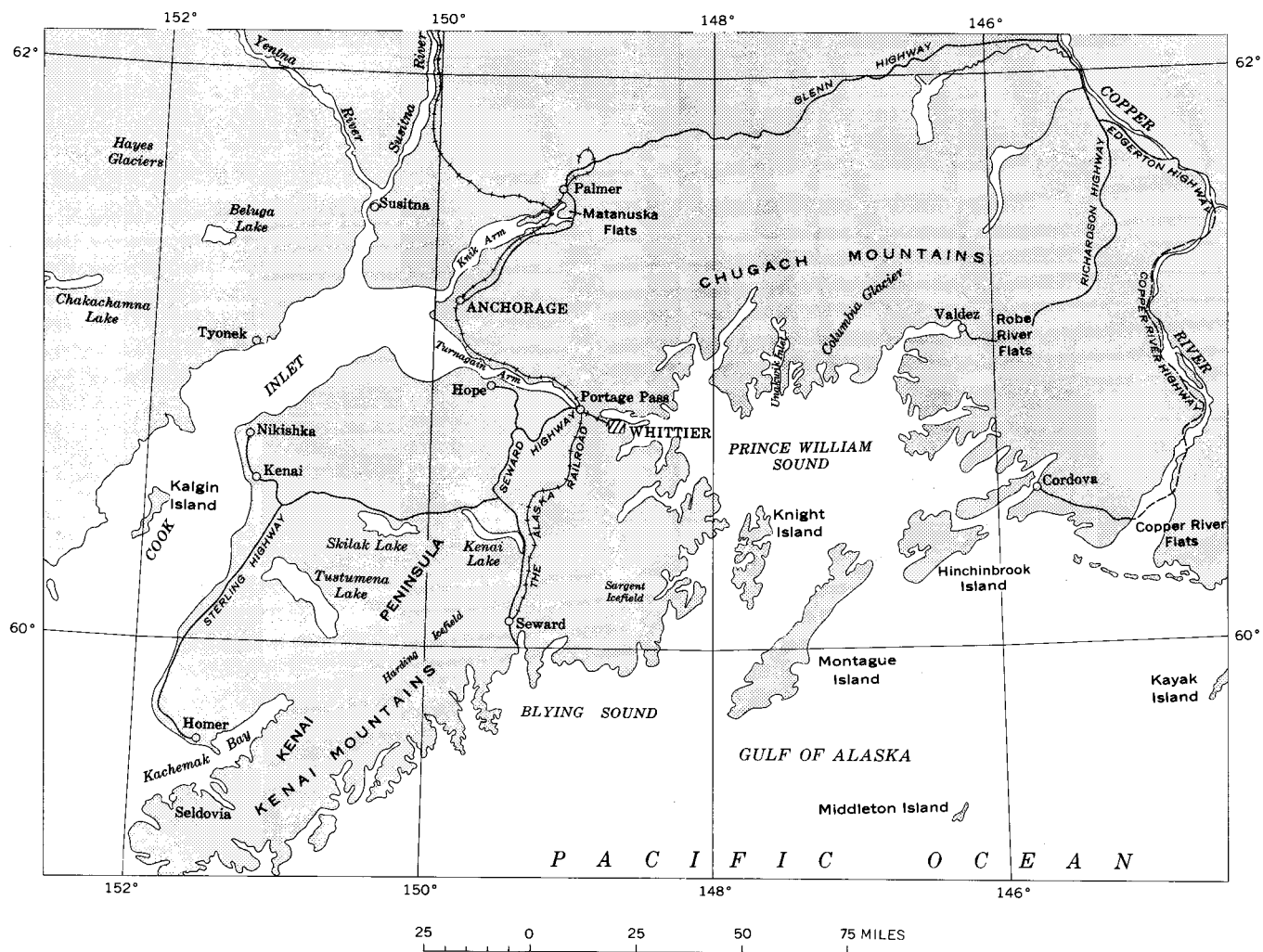
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1.—Index map showing location of Whittier area.

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

EFFECTS OF THE EARTHQUAKE OF MARCH 27, 1964, AT WHITTIER, ALASKA

By Reuben Kachadoorian

ABSTRACT

Whittier, Alaska, lying at the western end of Passage Canal, is an ocean terminal of The Alaska Railroad. The earthquake that shook south-central Alaska at 5:36 p.m. (Alaska Standard Time) on March 27, 1964, took the lives of 13 persons and caused more than \$5 million worth of damage to Government and private property at Whittier.

Seismic motion lasted only 2½-3 minutes, but when it stopped the Whittier waterfront was in shambles and the port facilities were inoperable. Dam-

age was caused by (1) a 5.3-foot subsidence of the landmass, sufficient to put some of the developed land under water during high tides, (2) seismic shock, (3) fracturing of fill and unconsolidated sediments, (4) compaction of fill and unconsolidated deposits, (5) submarine landslides which generated waves that destroyed part of The Alaska Railroad roadbed and other property, (6) at least two, but probably three, waves generated by landslides, which completely wrecked the buildings of two lumber companies, the stub pier, the

small-boat harbor, the car-barge slip dock, and several homes, and (7) fire that destroyed the fuel-storage tanks at the Whittier waterfront.

Many buildings and other facilities were totally wrecked, others were damaged to lesser degrees. For example, the 14-story reinforced-concrete Hodge Building, which rests upon at least 44 feet of sandy gravel, was moderately damaged by seismic shock, but the six-story reinforced-concrete Buckner Building, which rests upon bedrock, was only slightly damaged.

INTRODUCTION

The port of Whittier (fig. 1) was constructed under the supervision of the Corps of Engineers in 1942-43 to provide an all-weather terminal for The Alaska Railroad. During World War II, Whittier and Seward served as the two all-weather railroad ports that safeguarded the flow of military supplies, equipment, and personnel from tidewater to Anchorage and Fairbanks. The town of Whittier is owned and operated by the U.S. Government—specifically by The Alaska Railroad of the Department of the Interior and by the U.S. Army of the Department of Defense. Some of the land has been leased to private enterprise.

Whittier was hard hit by the earthquake of March 27, 1964. Tragically, 13 persons were lost during the earthquake. At the time, only 70 people were living at Whittier. The official 1960 census

lists a population of 800; however, this figure included military personnel who were subsequently transferred when the Army closed its Whittier operation. Only one body was recovered; the remaining 12 persons were presumed dead. In addition, the earthquake destroyed or made inoperable a major part of the port facilities. Total damage to the Federal and privately owned facilities at Whittier was in excess of \$5 million.

The loss of the Whittier port facilities, coupled with destruction of those at both Seward and Valdez, left Alaska without any all-weather port for unloading supplies for movement either by rail or highway to the metropolitan areas of Anchorage and Fairbanks.

FIELDWORK

This report is based on data collected by U.S. Geological Survey

personnel during visits to Whittier, and supplemented by data supplied by The Alaska Railroad, the U.S. Army-Alaska, the U.S. Coast and Geodetic Survey, and many citizens of Alaska, particularly those of Whittier. A 10-day study of south-central Alaska was made by the Geological Survey immediately after the earthquake, and the results were published on April 27, 1964 (Grantz, Plafker, and Kachadoorian, 1964). During the summer of 1964, Whittier was again visited by the author and by George Plafker, D. S. McCulloch, and L. R. Mayo—all of the U.S. Geological Survey. Plafker collected additional data on the onshore effects of the earthquake; McCulloch and Mayo made offshore submarine geologic investigations.

ACKNOWLEDGMENTS

Most of the logistic support for the initial study by the Geological Survey between March 29 and April 9, 1964, was provided by the U.S. Army-Alaska (USARAL); this support was provided under the difficult conditions that existed in Alaska immediately after the earthquake. During the followup studies in the summer of 1964, the U.S. Army again provided support. The author appreciates the efficient and enthusiastic support of Col. M. L. Fallwell and Lt. Col. H. E. Nolde, their staffs, and the officers and men of the USARAL Aviation Company of the 19th Aviation Battalion at Fort Richardson, Alaska.

Officials of The Alaska Railroad also cooperated with the Survey by providing preearthquake maps and photographs of the Whittier area as well as post-

earthquake information. Among the officials who generously supported the investigation were I. P. Cook, C. L. Griffith, T. C. Fugelstad, B. E. Cannon, and J. A. Morrison.

The author also thanks the many residents of the State of Alaska, especially of Whittier, who supplied eyewitness descriptions and other firsthand information about the earthquake.

CLIMATE

Whittier lies in the coastal rain belt, but is surrounded by high mountains. Thus, the climate is intermediate between that of coastal mountains and open coast. Residents and The Alaska Railroad personnel state that Whittier is frequently buffeted by high westerly winds blowing off Portage Pass. Mr. Jack Farnsworth (oral commun., 1965) stated that winds locally have been so strong

that house trailers were blown over by them. The high winds are not restricted to the winter months, as one might expect, but occur the year-round. Climatological data for Whittier are shown on table 1.

TABLE 1.—*Climatological data for Whittier, Alaska*

[U.S. Weather Bureau, 1964]

Month	Average temperature ¹ (°F)	Average total precipitation ² (inches)
January-----	25.7	9.45
February-----	28.3	21.40
March-----	24.5	8.18
April-----	31.3	11.05
May-----	43.7	14.72
June-----	46.3	16.17
July-----	53.8	8.84
August-----	53.8	6.45
September-----	48.1	16.40
October-----	38.4	³ 24.40
November-----	22.8	³ 6.13
December-----	22.9	³ 15.00
Annual average -	37.2	³ 157.89

¹ Based on 14-year record.

² Based on 9-year record.

³ Amount is wholly or partly estimated.

GEOGRAPHIC SETTING

Whittier is at the head of Passage Canal on the northeast side of the Kenai Peninsula in south-central Alaska (fig. 1). It is at lat 60°47' N., long 148°40' W., about 50 miles southeast of Anchorage and 40 miles southwest of the epicenter of the March 27 earthquake. Passage Canal, a west-southwest-trending fiord, is a western arm of Prince William Sound and is about 11 miles long and 1½ miles in average width.

The Kenai Mountains form the backbone of the Kenai Peninsula and rise sharply from tidewater to an altitude of more than 3,500 feet within 2 miles of Whittier.

The large Harding icefield and much smaller Sargent icefield cover much of the higher part of the mountains. The Chugach Mountains to the east do not have a large icefield, but do have several large glaciers. North of Passage Canal the mountains rise abruptly to 4,600 feet, 1.5 miles from the shore.

The boundary between the Chugach and Kenai Mountains is Portage Pass west of Whittier. The pass is 800 feet above sea level; it was used extensively by prospectors during the gold rush as a route from Passage Canal west to Turnagain Arm. The

pass is in part occupied by Portage Glacier and Portage Lake.

The main port facilities of Whittier are on the south shore of Passage Canal about 1 mile east of its western end. The town is built on a fan-shaped delta formed by Whittier Creek—a creek fed by Whittier Glacier. The delta has a maximum width of approximately 2 miles, is about 1½ miles long, and rises from sea level to an altitude of 90 feet with a fairly uniform slope of 60 feet per mile.

At the head of Passage Canal is a low-lying deltaic area about 2.3 miles wide and 2.3 miles long hav-

ing an average seaward slope of 140 feet per mile. The southern part of this lowland consists of coalescing deltas of creeks flowing from Portage Pass, Shakespeare Glacier, and Learnard Glacier. The northern part of the lowland was overridden by a minor advance of Learnard Glacier. When the glacier retreated, it left behind a semicircular moraine with irregular hummocky topography. The margin of the moraine is 10–15 feet high, and the surface of the interior part contains depressions

as much as 5 feet deep and small hillocks as much as 10 feet high.

After the ice that sculptured Passage Canal had retreated, the canal remained as a steep-walled U-shaped fiord locally more than 1,000 feet deep. However, immediately after the retreat of the ice, melt water began to construct deltas at the margins of the fiords—Whittier delta and the delta at the west end of Passage Canal being the largest. Another large delta was formed by Billings Creek on the north side of the

canal about 3 miles northeast of Whittier.

Prior to the earthquake, Passage Canal was approximately 300 feet deep 0.1 mile from shore at its western end. Along the north shore, the depth within 1.5 miles of the head of the canal and within 0.7 mile of shore was 600 feet. Submarine slopes in front of the unconsolidated delta deposits were steeper than the average slope of the Whittier delta which was about 30° at the time of the earthquake.

GEOLOGY

The rocks in the Whittier area are slate and graywacke of probable Cretaceous age, locally overlain by unconsolidated Quaternary deposits consisting of glacial moraine, reworked outwash and stream gravel, and artificial fill (pl. 1). The slate and graywacke were intruded by quartz diorite and diorite during Cretaceous or Tertiary time. Barnes (1943) has given a more detailed description of the geology of the Whittier area.

BEDROCK

The Cretaceous(?) rocks that underlie the Whittier area are predominantly slate containing minor amounts of graywacke locally interbedded. Commonly the slate grades into the graywacke. Barnes (unpub. data, 1939) stated that locally, along the shore of Passage Canal, graywacke that appears massive above high-tide level actually has a platy structure

below. This structure is apparently emphasized by the weathering of the graywacke in the intertidal zone.

The slate and, to a lesser extent, the graywacke have a pronounced cleavage generally parallel to the bedding. The attitude of the cleavage planes ranges from N. 20° E. to N. 30° E., the dips from N. 65° W. to N. 80° W. The strike of the bedding is from N. 20° E. to N. 30° E., and the dips are from N. 60° W. to N. 65° W.

Along the south shore of Passage Canal the slate and graywacke have been intruded by four quartz diorite or diorite dikes or sills, 3, 4, 7, and 100 feet thick, that are approximately parallel to the bedding of the host rock.

UNCONSOLIDATED DEPOSITS

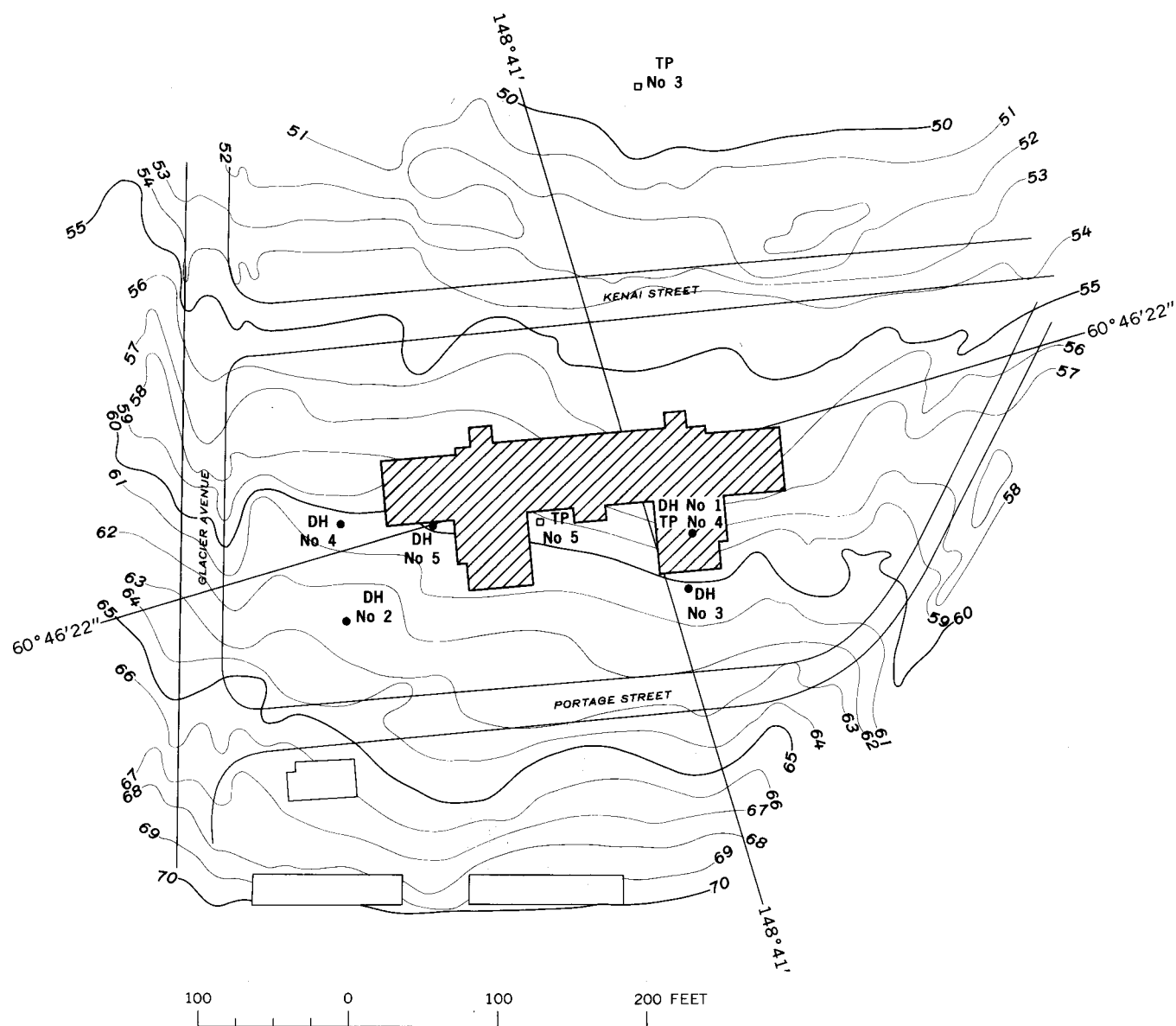
Unconsolidated deposits consisting of outwash and stream gravels form the delta upon which Whit-

tier rests and also the southern part of the delta at the head of Passage Canal.

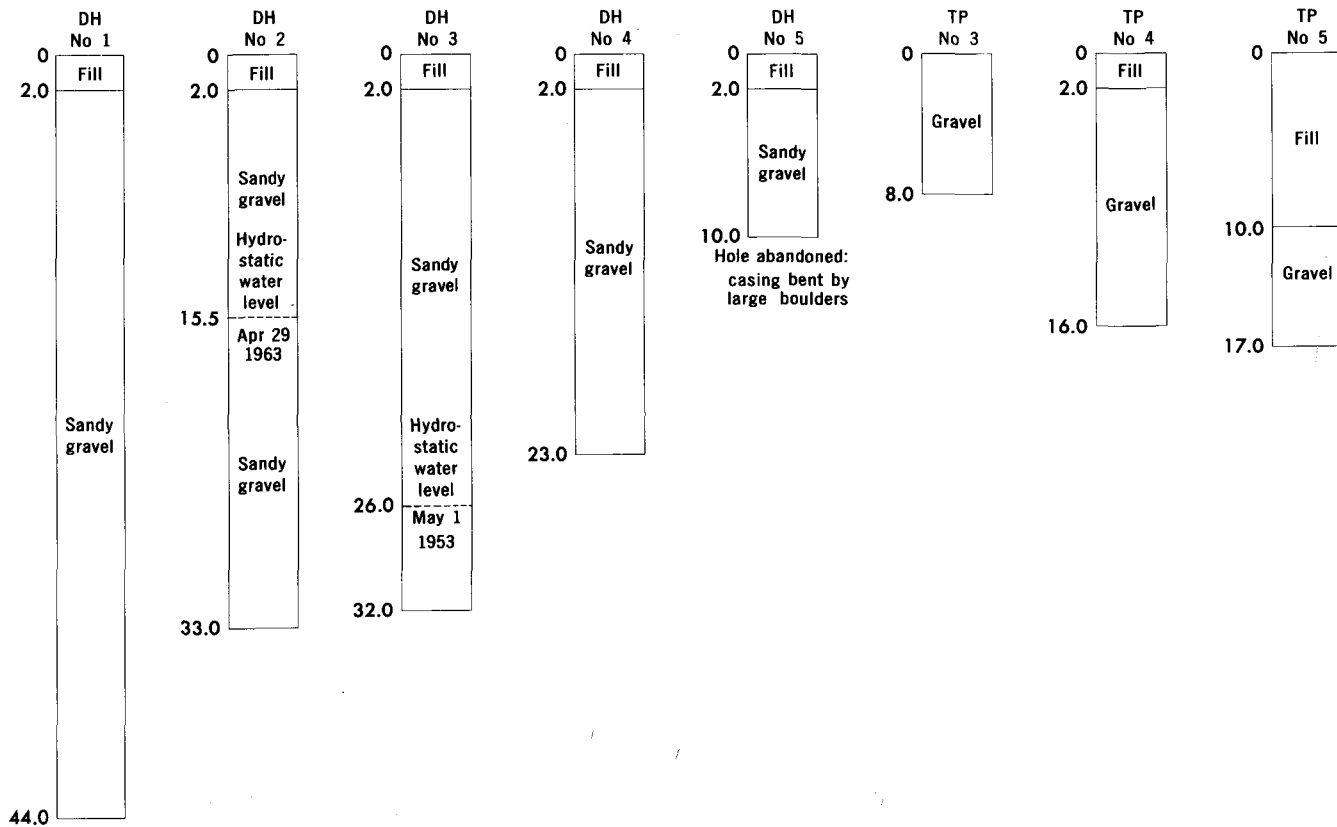
The Whittier delta is composed predominantly of coarse, subangular to subrounded gravel in a matrix of coarse sand. The maximum thickness of the gravel is unknown but is at least 44 feet beneath the Hodge Building (figs. 2 and 3).

The sediments composing the delta at the head of Passage Canal are generally similar to those of the Whittier delta. However, the outwash and stream deposits in the northern part of the delta are overlain by a moraine of the Learnard Glacier. The thickness of the gravel deposits is unknown.

The moraine that overlies the delta deposits at the head of Passage Canal consists primarily of jumbled heaps and ridges of coarse angular blocks of slate and graywacke. Locally, patches of sand and gravel are interspersed with coarse blocks.



2.—Map showing Hodge Building, surrounding area, and location of drill holes. Graphic logs of these holes are shown in figure 3.



3.—Graphic logs of drill holes (DH) and test pits (TP) in the Hodges Building area. Location of holes and pits are shown in figure 2.

ARTIFICIAL FILL

Areas of artificial fill are shown on plate 1. The easternmost 500

feet of the airstrip, an area near the Union Oil Co. fuel tanks, and an extensive area by the marginal wharf are the largest of these

areas. The fill was obtained locally and thus consists predominantly of delta deposits, or glacial outwash and stream deposits.

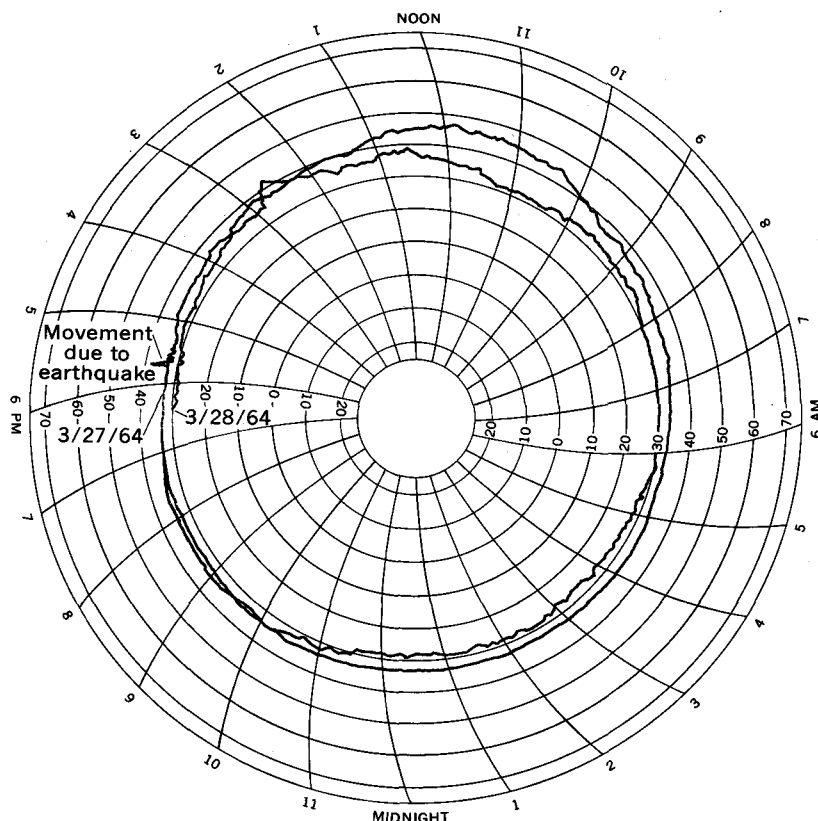
DESCRIPTIONS OF THE EARTHQUAKE

On Good Friday, March 27, 1964, at 5:36 p.m. (Alaska Standard Time) the earthquake struck Whittier. A light snow was falling, the surface of Passage Canal was "glassy," and the tide was at 1 foot above mean lower low water. Seismic motion accelerated to its maximum intensity in about one-half minute, maintained this intensity for 1-1½ minutes, and then gradually subsided. Thus, seismic motion lasted for a total

of approximately 2½-3 minutes. The eyewitness estimates of the time agree closely with charts from automatic recording devices in the powerhouse and salt-water pump-house at Whittier. The most reliable time record—a chart from the outside air-temperature recording gage in the salt-water pump-house—shows that seismic shaking lasted for about 4 minutes (fig. 4).

Residents of Whittier said that

the motion was generally east-west. However, Mr. W. P. LaRue, powerhouse superintendent, stated that the motion was generally north-northwest-south-southeast. People who were on bed-rock at the time of the earthquake said that the motion was of a jarring nature; those on fill or unconsolidated deposits reported more of a rolling or "round-and-round" motion. Most people felt no vertical motion. Mrs. D. Keat-



4.—Chart of outside-air temperature from automatic recording device in salt-water pumphouse in Whittier.

ing, who was in the Hodge Building during the earthquake, said, however, that midway through the violent phase of the shaking, the Hodge Building seemed to have been lifted up and set down.

At least three waves were observed during and immediately after the earthquake. Mr. M. J. Dixon and Mr. Farrian Kolb reported that about 1 minute after the earthquake started, the water in Passage Canal rose rapidly to a maximum altitude of 25–26 feet¹ in the vicinity of the town. The water was still glassy and did not contain any debris.

The water immediately receded, and 1–1½ minutes later a large breaking wave came in. This wave was muddy, contained much debris, and was about 40 feet high

when it reached The Alaska Railroad depot (pl. 1). Mrs. Farrian Kolb, who observed the wave from the second story of the depot, described it as a wall of water 30–50 feet high that rose near the center of Passage Canal. She stated that something seemed to be exploding underneath the water. Mr. L. McDonough said that the water in Passage Canal about 50 yards from shore appeared to be boiling. This wave struck the railroad depot 8–10 feet above the ground surface, or at an altitude of 34–36 feet.

From ½ to 1 minute after the first breaking wave (second rise of sea level), another wave struck Whittier. This wave was similar in nature to the first breaking wave. It reached an altitude of

about 30 feet near The Alaska Railroad depot.

There were no eyewitnesses to the waves that struck the shore in other parts of the area, but high-water marks on snow and trees and deposition of debris indicate that waves in Passage Canal reached their maximum altitude not at Whittier but along the shore to the northwest (as measured by Plafker and Mayo). There the waves reached as high as 104 feet. At the extreme north end of the delta at the head of Passage Canal, a wave reached an altitude of 82 feet.

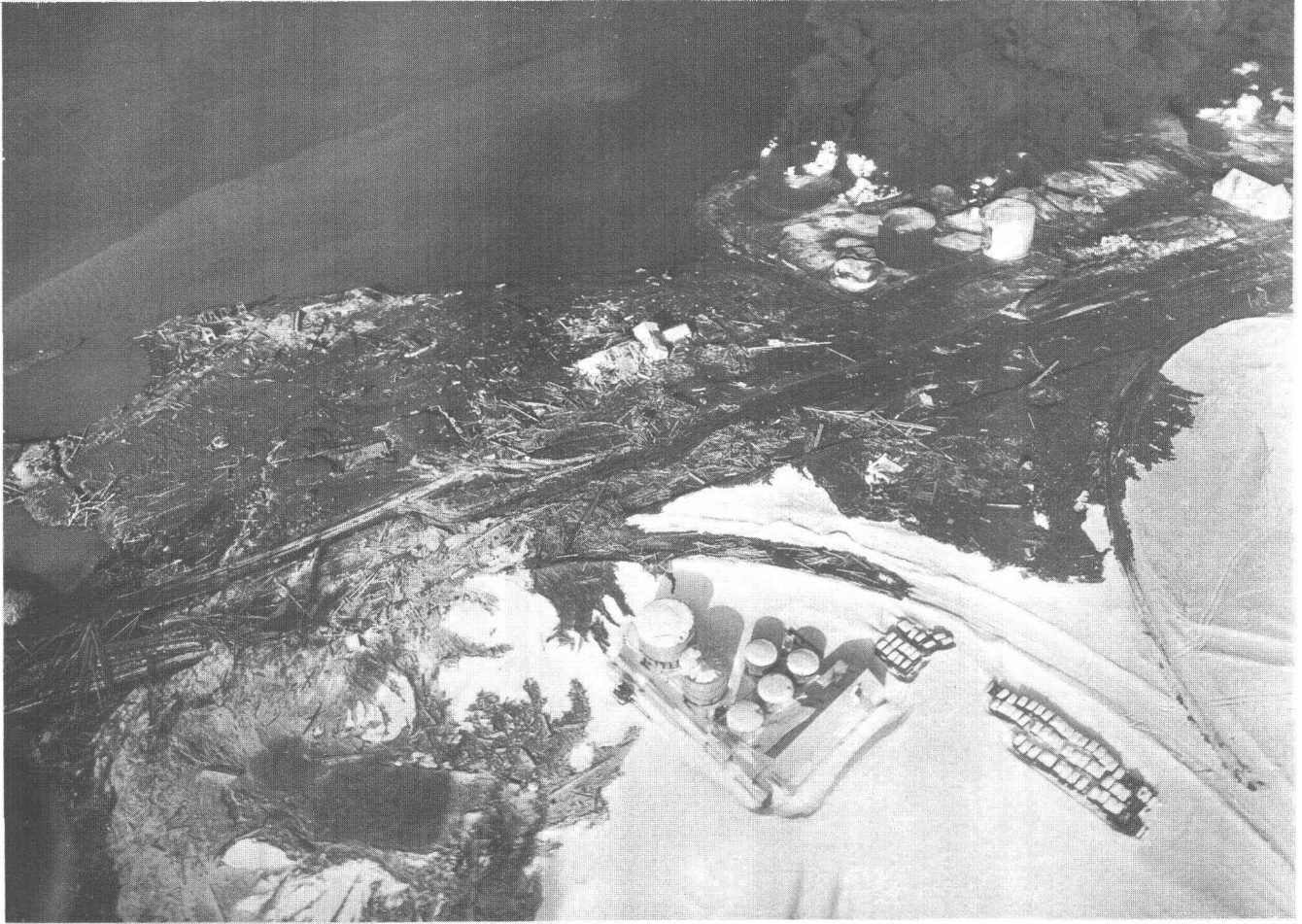
During the earthquake a fire started in the Union Oil Co. and U.S. Army tank-farm area (fig. 5) and burned until March 31; it completely destroyed the fuel-storage tanks.

Thirteen lives were lost at Whittier as the result of wave action. Eyewitnesses state that 10 of the persons lost and presumed dead had gone into the home of one of the Columbia Lumber Co. workers a few minutes before the earthquake struck. The waves totally destroyed both the company's industrial buildings and the homes of the workers (figs. 6 and 7). Two other persons associated with the company are missing and presumed dead. None of the 12

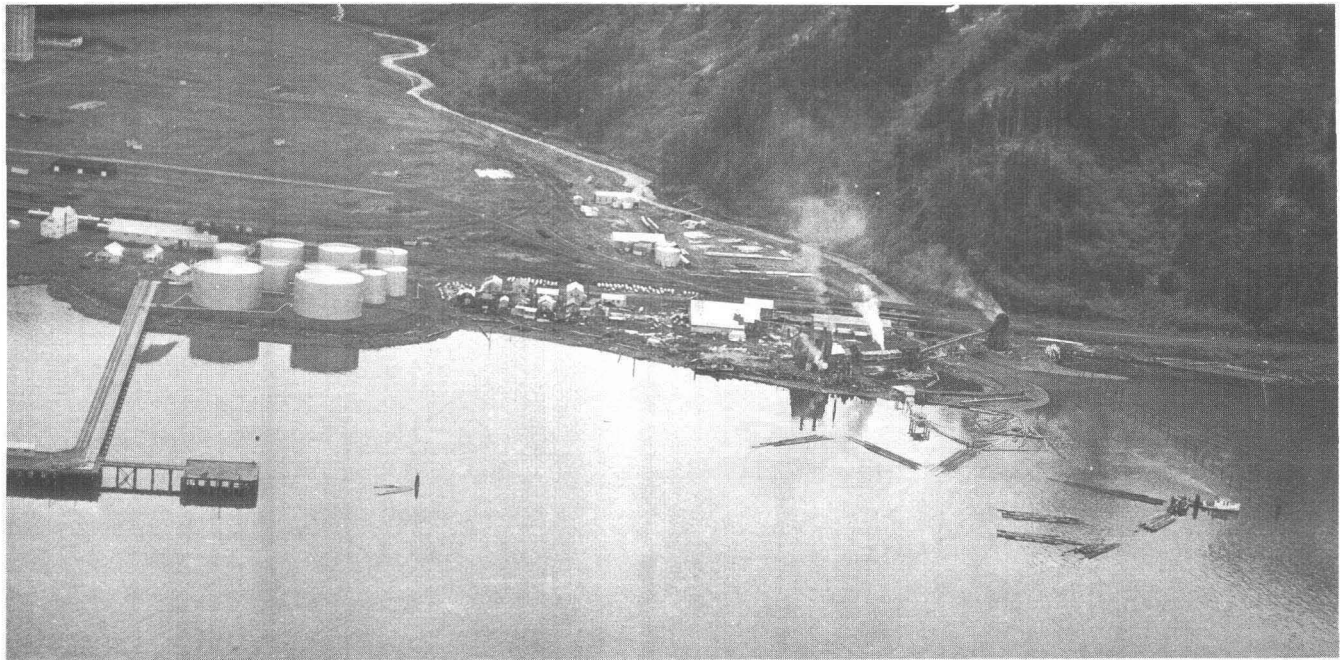
¹ Unless otherwise indicated, altitudes given in this report are based on a pre-earthquake datum and do not reflect the 5.3-foot regional subsidence of the Whittier area during the earthquake because it is not known when the subsidence occurred.

Datum for subaerial contours on all plates is mean sea level; datum for submarine soundings and contours is mean lower low water (MLLW) or 6.3 feet below mean sea level. Height of waves is the actual distance between trough and crest. For example, a 40-foot wave would have an altitude of 34.7 feet because the earthquake occurred at a 1-foot tide or 5.3 feet below mean sea level.

The tide range at Whittier is from a low of -3.8 feet to a high of 15.4 feet (datum is MLLW).



5.—Aerial view, looking northeast, of Union Oil Co. and U.S. Army fuel-storage tanks burning. Note high-water mark where waves washed away snow cover. Photograph by U.S. Army, March 28, 1964.



6.—Preearthquake aerial view, looking south, of Union Oil Co. fuel-storage tanks and Columbia Lumber Co. Photograph by U.S. Army, June 7, 1963.



7.—Postearthquake aerial view, looking north, of destruction of Columbia Lumber Co. Photograph by U.S. Army, March 28, 1964.

bodies was recovered from the wreckage; the only traces found of the missing persons were pieces of children's clothing. It is presumed that all were washed out into Passage Canal. The 13th victim, and the only one whose body was recovered, was a child who lost her life near The Alaska Railroad depot.

Several residents of Whittier commented that on the morning after the earthquake, red snapper

fish, which normally inhabit waters deeper than 400 feet, were floating on the surface of Passage Canal and were also strewn along parts of the shoreline. Everyone who saw the fish remarked that they were larger than those normally caught by local fishermen. Dr. N. J. Wilimovsky, a marine biologist from the University of British Columbia, stated that 26 genera of red snappers are caught commercially in Prince

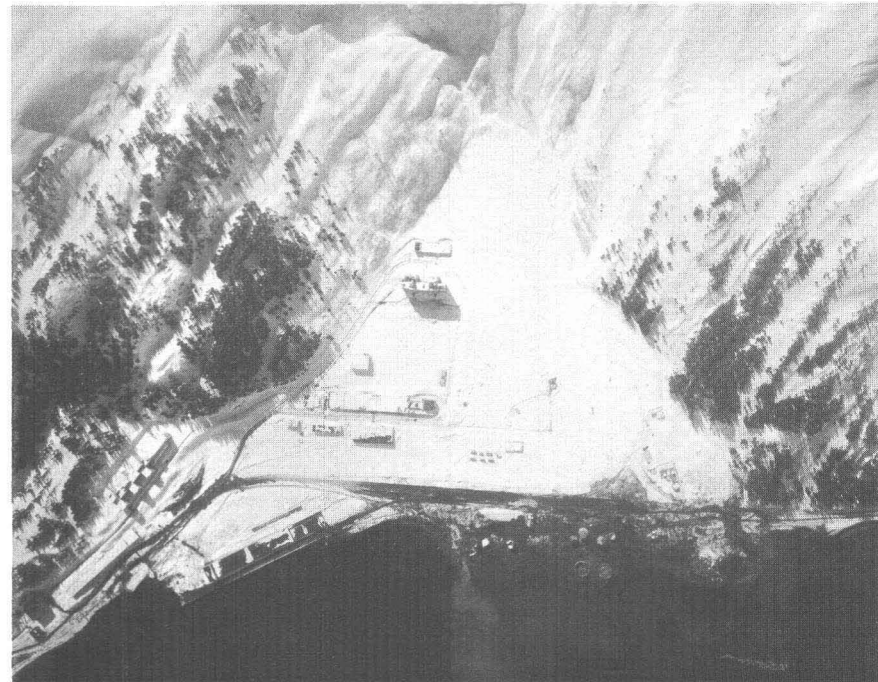
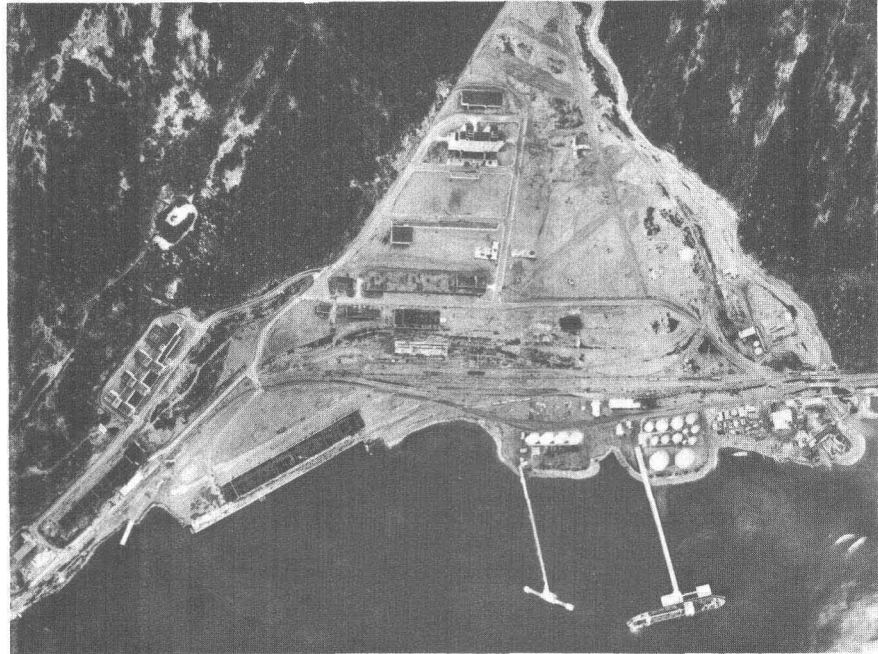
William Sound. Two of these—*Sebastolobus* and *Sebastodes*—increase in abundance with depth. Most of the red snappers found dead along the shore and on the surface of Passage Canal were probably fish of these two genera. The fish apparently were killed by a rapid change of pressure in the water and were then brought to the surface by upwelling of the water or by turbidity currents triggered by the seismic shaking.

EFFECTS OF THE EARTHQUAKE

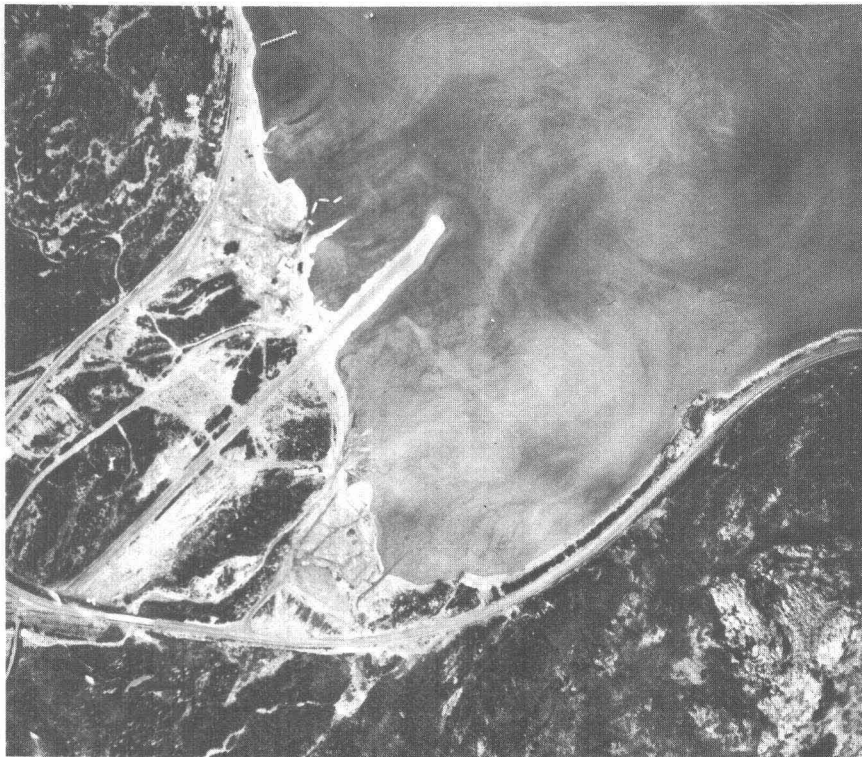
Seven different factors related to the earthquake were responsible for the extensive damage in the Whittier area. These include (1) a change in land level, (2) seismic shock, (3) fracturing of fill and unconsolidated deposits, (4) differential subsidence due to compaction, (5) landslides, (6) waves generated by submarine landslides, and (7) fire. A large avalanche fell on the moraine at the head of Passage Canal; it consisted chiefly of snow debris and did no harm. Plate 1 indicates the nature and extent of damage by seismic shock, compaction, landslides, waves, and fire. Figures 8 and 9 are prequake and postquake aerial photographs of much of the Whittier area.

LAND-LEVEL CHANGES

Studies by the U.S. Geological Survey and the U.S. Coast and Geodetic Survey determined that tectonic subsidence of the land-mass at Whittier was 5.3 feet during the earthquake. Residents of Whittier estimate that only 20 percent of the prequake tidal zone is now exposed during low tides (compare pls. 2 and 3). High tides now inundate some of the delta area at the head of Passage Canal, much land leased by the Two Brothers Lumber Co., and about 350 feet of the eastern end of the airstrip (fig. 10). The 5.3-foot subsidence is not wholly responsible for the change in exposure of the tidal zone; landslides



8.—Vertical aerial photographs of Whittier. Top, Prequake; composite of photographs by Bureau of Land Management, September 23, 1963. Bottom, Postquake; photograph by U.S. Army, March 28, 1964.

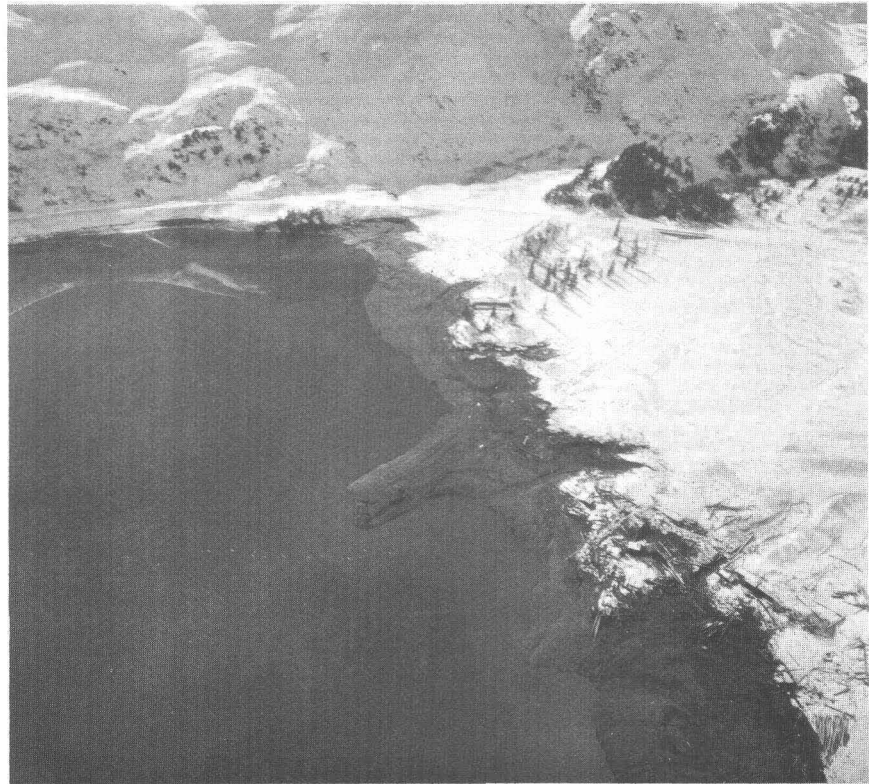


9.—Vertical aerial photographs of delta at west end of Passage Canal. Top, Pre-quake; photograph by Bureau of Land Management, September 23, 1963. Bottom, Postquake; photograph by Air Photo Tech, Anchorage, April 1, 1964.

and compaction (p. B15) also were, in part, responsible.

The most pressing problem at Whittier was to put back into service the port and railroad facilities that were destroyed or damaged by land subsidence. Much of the reconstruction in Alaska depended on immediate use of the car-barge slip dock, which was the only connecting link for transferring supplies and equipment from ships to The Alaska Railroad after the earthquake. To permit maximum use of the dock, which is stationary at the

10.—Aerial photograph, looking south, of delta at head of Passage Canal. Remains of Two Brothers Lumber Co. in right foreground. Projecting into the water is the airstrip. Note high-water mark indicated by snow. Photograph by U.S. Army, March 28, 1964.



land end and free to rise and fall with the tide at the sea end, it was necessary to know the actual amount of subsidence at Whittier. Once the amount of subsidence was determined, the dock was reconstructed and railroad traffic to Anchorage was reestablished in a remarkably short time.

SEISMIC DAMAGE

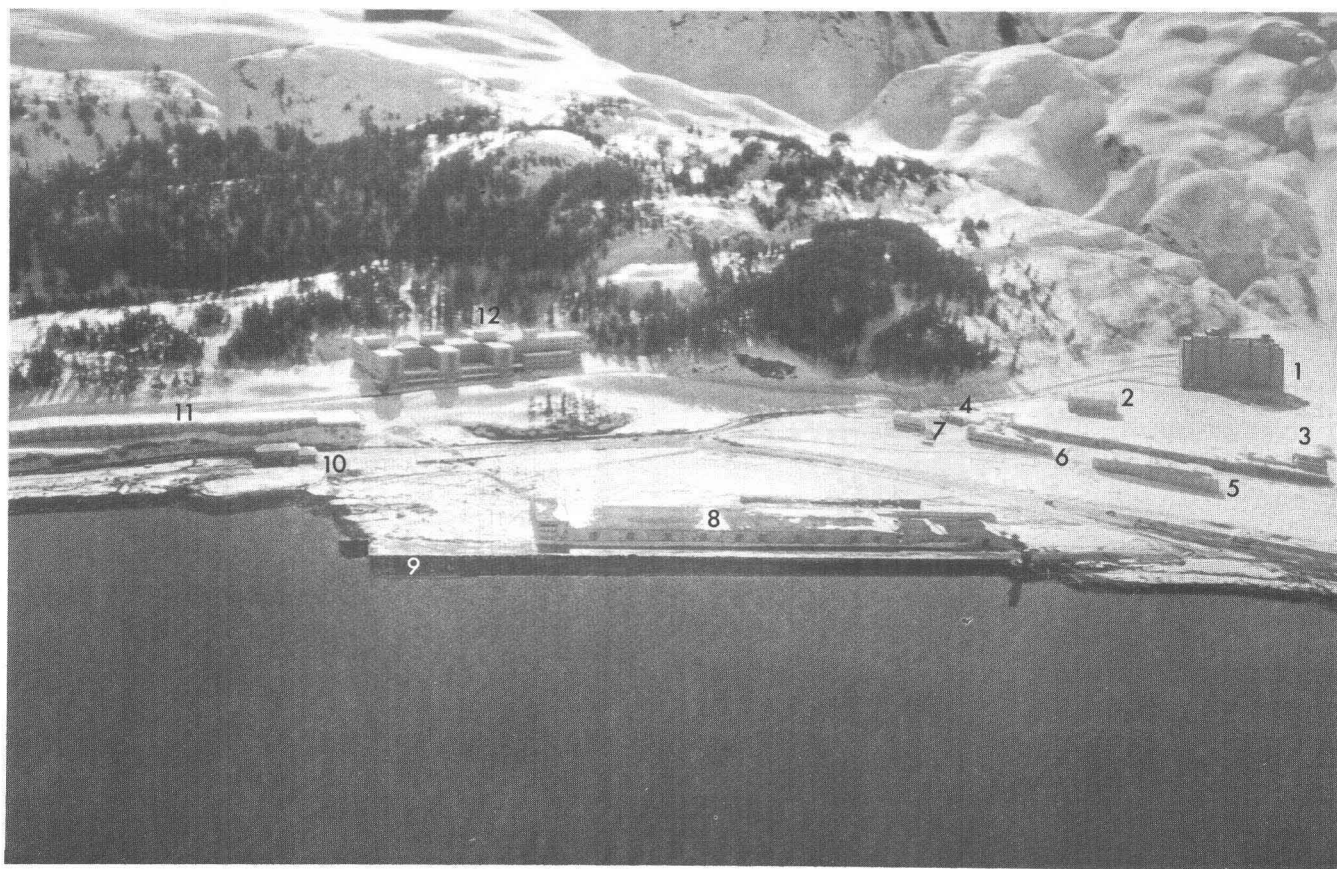
In the downtown area of Whittier away from the waterfront, most of the damage was caused by seismic shock. Within the area inundated by waves (pl. 1), seismic shock severely damaged one of the slip towers of the car-barge slip dock (fig. 11), part of the marginal wharf, one of the storage tanks at the U.S. Army tank farm, and the highway and rail-

11.—View, looking west, of remains of car-barge slip dock. Slip tower only part of structure left. Photograph by The Alaska Railroad, 1964.





12.—View, looking southeast, of Hodge Building. Photograph taken April 4, 1964.



13.—Aerial view, looking south-southeast, of part of postquake Whittier. 1 Hodge Building, 2 gymnasium, 3 composite shop, 4 fire station, 5 station storage warehouse, 6 telephone building, 7 ACS building, 8 intransit storage shed, 9 marginal wharf, 10 The Alaska Railroad depot, 11 FHA housing, and 12 Buckner Building.

road bridges crossing Whittier Creek. Beyond the inundated zone there was moderate damage to the Hodge Building (fig. 12), the composite shop, and part of the station storage warehouse (fig. 13). The Buckner Building (fig. 14), gymnasium, fire station, telephone building, ACS (Alaska Communication System) building, powerhouse, and the railroad bridge near the airstrip were slightly damaged.

The Hodge Building, a reinforced-concrete 14-story structure 265 feet long and 50 and 110 feet wide (figs. 2 and 3), rests on at least 44 feet of unconsolidated sand and gravel. The building was constructed as three structural monolithic units connected by 8-inch expansion joints. In the corridors, metal jumper plates spanned the 8-inch joints; on the exterior, the joints were secured by a weather seal. The long dimension of the building was parallel to the predominant east-west direction of the seismic motion;

the expansion joints were perpendicular to the motion. During the earthquake the individual units banged against each other, the weather seals popped out, and the jumper plates were curled. Damage to the structural connections (weather seals, jumper plates, and spandels) was progressively more intense upward in the structure owing to the larger horizontal component of movement. Jumpers on the top floor were shortened 4 inches by curling, whereas on the third floor they curled only a quarter of an inch.

The interior partition walls of the Hodge Building were constructed of concrete block. Damage to the walls was also greater in the upper floors. The walls on the 13th and 14th floors either collapsed or were cracked. On the fourth floor the blocks were loosened, except near the expansion joints where some of the blocks were dislodged. The exterior of the building was not substantially damaged, even where the units

banged against each other.

The interior and roof of the composite shop were moderately damaged by seismic shaking. Most of the interior blocks and some of the concrete posts and beams were cracked; in numerous places the roof purlins were twisted or separated from the beams. Much of the internal bracing in the building was either broken or strained.

The largest building in Whittier, probably the largest in Alaska, is the Buckner Building (figs. 14, 15, and 16). It is a six-story reinforced-concrete structure about 500 feet long and 50–150 feet wide. The long dimension of the structure runs northeast-southwest, oblique to the seismic motion of the earthquake. The building rests on bedrock and did not receive any significant structural damage. The steam powerhouse near The Alaska Railroad depot also rests on bedrock and was not damaged by seismic motion.

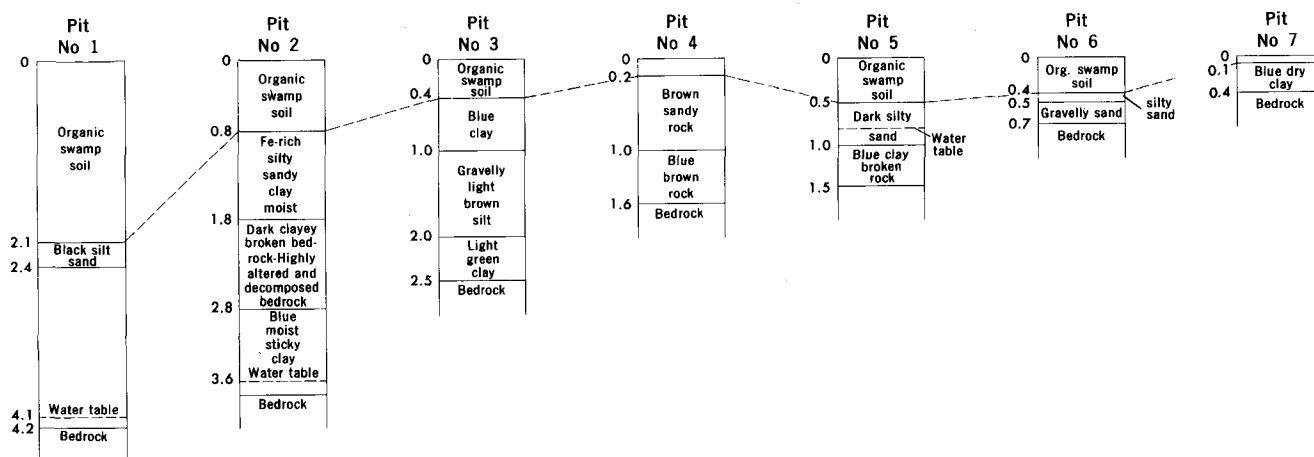
Several small structures on un-



14.—Aerial view, looking southeast, of Buckner Building; building in foreground is intransit storage shed; long structure at left of photograph is FHA housing; structure north of FHA housing is depot. Note high-water mark of wave on snow. Photograph taken April 4, 1964.



15.—Map showing Buckner Building, surrounding area, and location of test pits (Pt). Graphic logs of these pits are shown in fig. 16.



16.—Graphic logs of test pits (Pit) in the Buckner Building area. Locations of the pits are shown in figure 15.

consolidated sandy gravel which were only slightly damaged by seismic activity include (1) the fire station, (2) the telephone building, which cracked at its corners, (3) the ACS building, (4) the gymnasium, which had some cracks at the top of the structure, and (5) the tunnel between the Hodge Building and the school.

The intransit storage shed, which rests upon several feet of fill on top of delta sediments, was slightly to moderately damaged by the combined effects of seismic shaking, subsidence, and wave action. In places the walls of the structure moved as much as 7 inches; subsequently, the building appeared to have been stretched by the earthquake effects.

In addition to surficial damage, seismic shock broke two 10-inch pipelines from the water-storage reservoir. In order to operate the steam powerplant, water was pumped from the salt-water pumphouse through a firehose.

FRACTURING

Only a few fractures occurred in the fill and the unconsolidated sediments and these caused no damage. A ground fracture

formed during the earthquake near The Alaska Railroad depot. This fracture extends beneath the structure and appears to follow the contact between the cut and fill made during the construction of the depot. Minor fracturing in fill occurred near the intransit storage shed. Near the FAA station, a series of cracks parallel to the shore extends about 100 feet inland.

COMPACTION

Compaction of unconsolidated sediments and differential subsidence of the land damaged four structures: the pumphouse near the FAA station, the DeLong Dock, the intransit storage shed, and the marginal wharf. These structures were also damaged by waves. In addition, the pumphouse is now inundated by high tides.

The marginal wharf and the intransit storage shed were constructed on fill overlying delta sediments. The station storage warehouse and the pumphouse near the FAA station are underlain by delta sediments. How much fill, if any, underlies the DeLong Dock is not known.

The maximum recorded subsidence (about 1½ feet) was measured in the area near the marginal wharf and intransit storage shed. Subsidence may have been greater (an estimated 2-3 feet) in the delta area at the head of Passage Canal. The pumphouse here is a concrete structure enclosing two 40-foot wells. The concrete floor subsided 6 inches relative to the well casings during the earthquake.

LANDSLIDES

The landslides triggered by the earthquake (pl. 3) formed in delta sediments at the head of Passage Canal, in delta sediments and fill at Whittier waterfront, and possibly in submarine talus or in a submarine lateral moraine along the north shore of Passage Canal. It is not known if any of the slip surfaces of the landslides are in bedrock.

The profiles of the slides and submarine slopes are shown on plate 3, and the changes in degree of slope are shown in table 2 (next page). The landslides occurred on slopes ranging from 20° offshore of the airstrip to 31° at the marginal wharf. The largest change of sub-

TABLE 2.—*Effect of landslides on average submarine slopes at Whittier, Alaska*

Landslide	Submarine slopes (degrees)	
	Pre- landslide	Post- landslide
Marginal wharf.....	21	23
Airstrip.....	25	15
Tank-farm area.....	25	24
FAA station.....	20	20
Passage Canal, north shore.....	31	27

marine slope, 10° , was produced by the airstrip landslide. The marginal-wharf landslide effected the only increase in slope. The only landslide scarp exposed is at the FAA station landslide.

The only structures damaged by landslides (pl. 1) were the FAA station (fig. 17), a section of the railroad, a small pier near the FAA station, and the extreme eastern end of the airstrip (fig. 10). The slip tower at the car-barge slip dock may have been destroyed by the landslide at the marginal wharf.

The landslides in the Whittier area did not all occur simultaneously. There were two, and possibly three, different periods of sliding during the earthquake.

LANDSLIDE-GENERATED WAVES

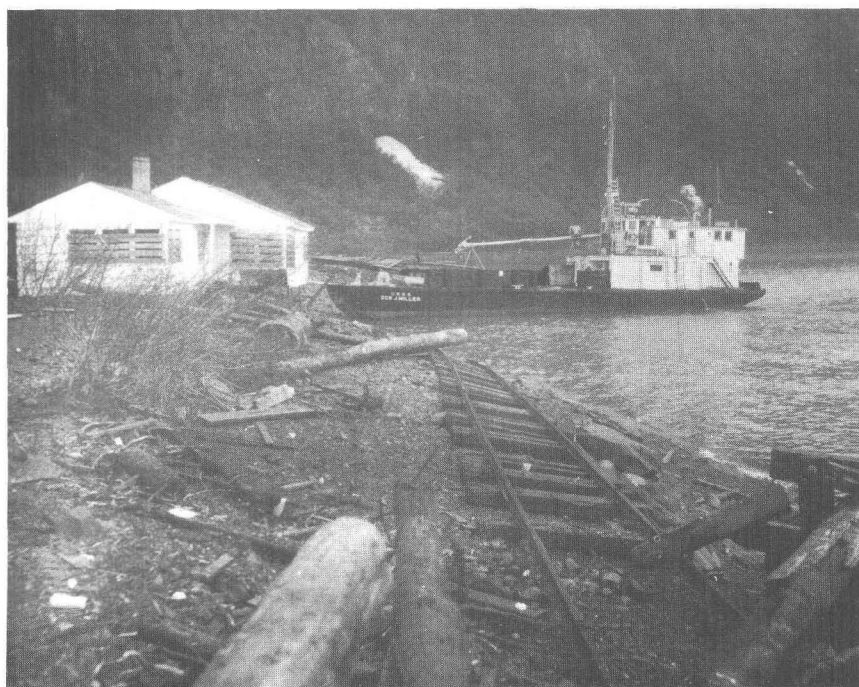
Submarine landslides in Passage Canal generated at least two, and probably three, waves. Plate 1 shows the area inundated and destroyed by waves. The direction and altitude of the highest waves are indicated on plate 3. Only the direction of the highest wave in a particular area can be indicated, because a higher wave would destroy any evidence of an earlier lower wave. A lower wave that followed a higher wave would merely rearrange debris.

The maximum altitude of the waves was 104 feet along the north shore of Passage Canal (pl. 3). About a quarter of a mile north of the FAA station, the wave reached an altitude of 82 feet. Near the airstrip the wave reached 20 feet, and at the extreme south shore of Passage Canal the wave topped the railroad, reaching an altitude of 52 feet. In Whittier the maximum altitude reached by a wave was 43 feet at

the small-boat harbor northeast of The Alaska Railroad depot. On the waterfront area the altitude was 26 feet.

At the Whittier waterfront, submarine landslides apparently generated two different types of waves. Figure 18 illustrates schematically the sequential formation of the waves.

The first wave formed in the scarp area of the submarine landslide. As the landmass slid, a wave was generated by the water rushing in to fill the void formed behind the sliding mass, and a drawdown of water occurred. This wave was directional and its form was chiefly a function of (1) the size and shape of the landslide, (2) the distance of the landslide scarp offshore, (3) the velocity of the sliding mass, and (4) the configuration of the coastline.



17.—View, looking north, of FAA station. Track destroyed by landslide. Bow of boat resting on scarp. Photograph by G. D. Hanna, 1964.

The second type of submarine landslide wave was generated when the landslide came to rest at the bottom of Passage Canal. The volume of the landmass displaced the water and created an upwelling near the margins of the depositional area (fig. 18). When the upwelling water surfaced at Passage Canal, it generated a wave system. This wave system was not as directional as the wave generated at the scarp of the landslide. However, water moved primarily in two directions: (1) toward the scarp area, and (2) toward the landslide movement.

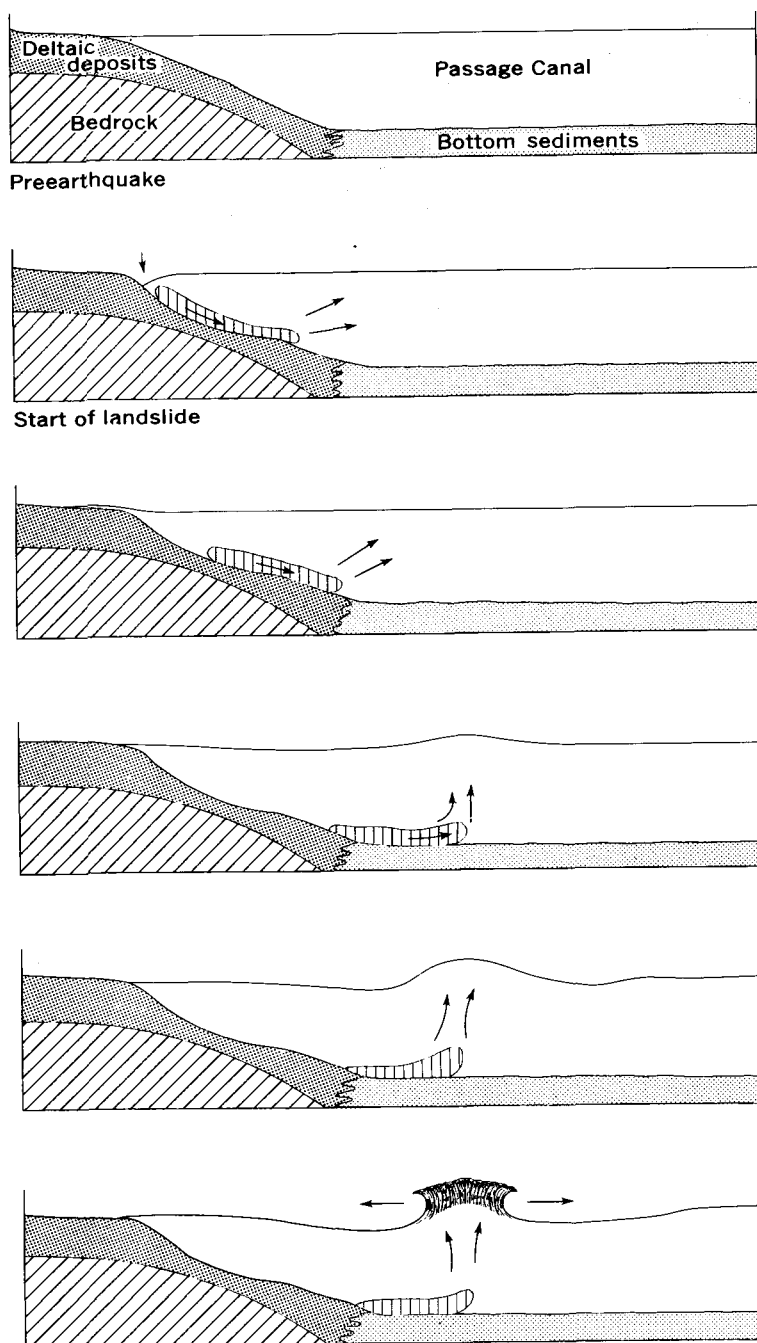
The size and force of the second wave were controlled chiefly by (1) the size and shape of the sliding landmass, (2) the velocity of the sliding mass, (3) the submarine configuration of Passage Canal, (4) the distance offshore at which upwelling occurred, (5) the depth of water in which the slide came to rest, and (6) the configuration of the coastline. The character of the waves may also have been influenced by other landslide-generated waves in nearby areas.

Eyewitness accounts indicate that probably both types of waves inundated parts of Whittier. There were no witnesses to the waves that struck the delta at the west end of Passage Canal or its north shore. The apparent submarine explosion described by Mr. Kolb and the "boiling out" of water in Passage Canal described by Mr. McDonough no doubt, preceded waves of the second type. Eyewitnesses reported that one of the slip towers of the car-barge slip dock collapsed before any wave struck the dock. The author believes that the tower was at the head of the marginal-wharf slide (pl. 3) and that the tower col-

lapsed as the land slid during the early violent phase of seismic shaking.

There are several possible explanations of the glassy wave reported by witnesses. If the sliding mass moved with sufficient velocity, the

volume of drawdown could be large enough to form a wave that would reach an altitude of 25 to 26 feet when water rushed into the vacated area yet which probably would not be highly turbulent.



18.—Schematic sections showing generation of waves associated with submarine landslides.

Another possible explanation for the glassy wave is that it was caused by seiching in Passage Canal. Inasmuch as Passage Canal is in open communication with a large body of water, the period (T) of seiching would occur according to the formula

$$T = \frac{4l}{\sqrt{gh}}$$

where T is period in seconds, l is length of Passage Canal in meters, h is the average depth of Passage Canal in meters, and g is the acceleration of gravity. Assuming l is 15,000 meters and h is 300 meters, the period of seiche waves in Passage Canal would be 1,110 seconds or about 18.5 minutes. The earthquake occurred when the tide was at 1 foot and the land subsided 5.3 feet; thus the seiche waves would have to be at least 18.7 feet high to reach the 25-foot altitude (preearthquake datum) attained by the glassy wave. If such seiching occurred, evidence of a high-water level would be found near this altitude in the cove into which Cove Creek drains. Such evidence was not found in the cove. If seiche waves in Passage Canal had been generated by the earthquake, they would have continued at an 18.5-minute interval throughout the night of March 27, 1964. However, residents of Whittier who worked all night after the earthquake did not report any unusual waves in Passage Canal other than the three waves that struck Whittier during or immediately after the earthquake. Therefore, the glassy wave and the following two breaking waves must have been generated by submarine landslides. The absence of waves throughout the night as reported by the eyewitnesses also rules out the possibility that small seiche



19.—View, looking south, of The Alaska Railroad depot. Wave destroyed waiting room of the depot. Photograph taken April 7, 1964.

waves occurred but did no damage at Whittier.

It is remotely possible that submarine landsliding near Billings Creek was responsible for the glassy wave. However, any land-mass failure there would have had to be immediate—within 45 seconds of the earthquake—to allow sufficient time for the wave to reach Whittier by the time the glassy wave was observed. The area was not included in the study for the present report.

Wave damage in the Whittier area is shown on plate 1. The wave completely destroyed (1) the small-boat harbor, (2) the stub pier, (3) the car-barge slip dock, (4) the waiting room of The Alaska Railroad depot (fig. 19), and (5) the Columbia Lumber Co. structures (fig. 5 and 7). Many facilities were damaged by a combination of destructive forces: (1) the Army tank farm by fire, seismic shaking, and waves, (2) the Union Oil Co. fuel tanks by fire

and waves, (3) the DeLong Dock and part of the marginal wharf by wave action and subsidence, and (4) the intransit storage shed by waves, subsidence, and seismic shaking.

The waves that struck Whittier had sufficient force to carry heavy objects many feet inland. A 4-cubic-yard barnacle-covered boulder was carried about 125 feet and deposited on The Alaska Railroad track near the depot at an altitude of about 26 feet. Boulders as much as 6 feet across were strewn on the road between the small-boat harbor and the Union Oil Co. fuel tanks. One of the Union Oil Co. fuel tanks containing ballast was moved at least 40 feet south by waves, and another tank containing 1 million gallons of fuel was moved 15 feet south (fig. 5).

The waves that struck the shoreline at the head of Passage Canal damaged practically all the structures near the shore. The waves completely destroyed three unoc-



20.—Photograph of 2- by 6-inch plank driven through a 10-ply tire by wave.

cupied homes on the shore, 200–400 feet south of the FAA station, and the buildings of the Two Brothers Lumber Co. The homes were washed away, and the nearby FAA station was partially inundated by the waves but not significantly damaged. The Two Brothers Lumber Co. buildings were carried inland in a southwest direction; the company's trimmer

and conveyor chain were moved 200 feet, the bucking machine 40–50 feet, and the 2,300-pound mill about 100 feet to the southwest. The waves struck the Two Brothers Lumber Co. installation with such force that a 2- by 6-inch plank was driven through a 10-ply forklift tire (fig. 20).

The waves (or single wave) that damaged the west coastline of Pas-

sage Canal originated along the north coastline of the canal and traveled southwest. The wave (or waves) was apparently diverted by the eastern end of the airstrip—the structure about 300 feet south of the airstrip was only moderately damaged (pl. 1).

The southwest- and south-traveling wave struck the point along the south shore, about 4,000 feet

west of Whittier Creek, with tremendous force. The wave reached an altitude of more than 50 feet. It carried a 1-ton winch and a boulder weighing 2-3 tons 120 feet south and deposited them on The Alaska Railroad tracks, which are about 30 feet in altitude.

FIRE

Fire was chiefly responsible for destruction of the Union Oil Co. and the U.S. Army fuel-storage tanks at the Whittier waterfront. Fire, together with damage by wave and seismic action, completely destroyed the tanks. The

cause of the fire is not known, but there are at least two possible explanations: (1) seismic motion may have snapped a live powerline in the area, or (2) fuel from a damaged tank may have flowed into a boiler that was operating in the area.

CONCLUSIONS

The chief conclusion that can be drawn from the Geological Survey's investigation of the effects of the Alaska earthquake of March 27, 1964, on the Whittier area is that damage can be correlated with the local geology.

At Whittier all facilities built on the slate and graywacke bedrock were damaged slightly, or not at all, by seismic shaking. These structures include (1) the six-story Buckner Building, (2) the three-story FHA building, (3) the 1½-million-gallon water tank, (4) the powerhouse, and (5) the salt-water pumphouse. All are concrete except the FHA building, which is a wood frame structure.

In contrast to the facilities on bedrock, most of the buildings on unconsolidated sediments or fill were damaged significantly by seismic activity. These buildings include (1) the 14-story Hodge Building, (2) the gymnasium, (3) the composite shop, (4) the school, (5) the station storage warehouse, (6) the intransit storage shed, (7) the telephone building, (8) the ACS building, (9) the pipe shed, and (10) the fire station. All of the 10 buildings are of concrete construction except the composite shop, intransit storage shed, station storage warehouse, and the pipe shed, which are of various types of construction.

In any earthquake the structural response of a building to a

seismic wave is a function of (1) the amplitude, acceleration, and frequency of the seismic wave, (2) the duration of shaking of the building, (3) the shape, height, and width of the building, (4) the type of construction used in the building, and (5) the orientation of the building to the seismic-wave direction.

Richter (1958) stated that there is an elementary relation between amplitude, acceleration, and frequency. He further stated that "Duration of shaking is the single most important factor in producing excessive damage. It takes time to break buildings up once damage starts. Long duration, reasonably high acceleration, and considerable amplitudes are the combination which does most damage in buildings."

Gutenberg (1957) reported that strong seismic shaking may last several times longer in unconsolidated deposits than in bedrock. He also stated that seismic amplitudes in unconsolidated deposits may be as much as 10 times the amplitudes in bedrock. Therefore, because there is a relation between amplitude, acceleration, and frequency and because of the longer duration of shaking, buildings on unconsolidated sediments are subjected to greater damaging forces than buildings on bedrock. The structural damage at Whittier clearly reflected this relationship.

Not only is there a correlation between damage and the underlying bedrock or unconsolidated deposits, but damage appears to be controlled also by the type, size, and thickness of the unconsolidated sediments. The Hodge Building, a 14-story reinforced-concrete structure which rests on coarse sandy gravel, was just moderately damaged by seismic activity. The Whittier delta at this point is only 1,200 feet wide, and the east end of the building is within 300 feet of bedrock. Therefore, the thickness of the sandy gravel that underlies the structure is probably not more than 150 feet.

The Hodge Building received substantially less damage than buildings of comparable height at Anchorage—a city about twice as far from the epicenter as Whittier. At least three geologic factors are responsible for this marked difference of damage: (1) the Hodge Building rests on a small area of unconsolidated deposits as compared to the structures at Anchorage, where a plain several miles wide is underlain by at least several hundred feet of clay, silt, sand, and gravel; (2) the deep fine-grained sediments that underlie Anchorage magnified the seismic amplitudes substantially more than the shallow coarse-grained sediments that underlie Whittier; (3) because the higher frequency components of ground motion attenuate with distance

more rapidly than the lower frequency components, the tall structures at Anchorage were more nearly attuned to long-period ground motion. Thus, these structures suffered a proportionately greater degree of damage than the 14-story Hodge Building at Whittier.

The duration of ground motion differs not only between bedrock and unconsolidated deposits, but also with the type of unconsolidated deposits. For example, the longest duration of motion reported was at Portage, where ground shaking lasted about 15 minutes. Portage (fig. 1) is on the eastern shore of Turnagain Arm about 10 miles west of Whittier and approximately 40 miles southeast of Anchorage. The longer duration of ground motion at Portage than at either Anchorage or Whittier can be attributed to the finer grained sediments underlying the area, the shallow water table, and the greater size, shape, and depth of the sedimentary basin.

Ground fractures in the coarse-grained unconsolidated delta and moraine deposits at Whittier are uncommon, especially in the Whittier delta. Although the sediments were laterally extended toward free faces during the earth-

quake, the movement of material was not expressed as surface fractures. Extensive ground fracturing occurred at (1) Valdez, (2) Robe River flats, (3) Copper River flats, (4) Matanuska flats, (5) Anchorage, (6) Seward, and (7) the Portage area. In these places, the unconsolidated deposits are finer grained and thicker, and they cover a more extensive area than the unconsolidated sediments at Whittier. Apparently, the coarse-grained texture and, in part, the thinness of the sediments were responsible for the lack of extensive ground fractures at Whittier.

Even the coarse unconsolidated deposits at Whittier were compacted by the seismic shaking. Compaction and subsequent subsidence should be expected in most unconsolidated sediments during an earthquake of large magnitude.

Landslides formed on submarine slopes in unconsolidated material inclined 20° to 25° . The three submarine landslide-generated waves that struck Whittier were of two types. The first type of wave was generated in the scarp area of the submarine landslide, was unidirectional, and damaged only the area behind the

landslide scarp. The glassy rise of water may have been associated with this wave.

The second type of wave was formed by the volume displacement of water offshore. The upwelling water moved primarily in two opposing directions: (1) toward the scarp area, and (2) in the direction of the landslide movement. These waves were not as directional as the waves generated at the scarp of the landslide, but they were far more destructive.

The landslide-generated waves were responsible for the loss of life and were the chief instrument of damage in the Whittier area. Because the submarine slopes in Passage Canal were not significantly decreased by the landsliding during the earthquake, another earthquake of comparable magnitude would probably trigger more submarine landslides. Destructive waves would inevitably follow.

The hazard of fire is always associated with earthquakes. The towns of Seward, Valdez, and Whittier had fires that originated at the fuel-storage tanks in the waterfront area. An immediate power failure spared Anchorage from electrically ignited fires.

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