Offshore Survey of the Pillar Mountain Landslide, Kodiak, Alaska

by

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Work done in cooperation with the City of Kodiak

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INTRODUCTION

A landslide extends to a height of about 340 meters above Kodiak Harbor on the southeast flank of 388-meter-high Pillar Mountain, about 2 kilometers west of the center of the City of Kodiak, Alaska (Fig. 1). The landslide involves thinly interbedded slate and impure sandstone (graywacke) of the Kodiak Formation of Late Cretaceous age. It is overlain on its lower slopes by a talus derived from this rock.

The landslide attracted special attention in 1971, when accelerated growth of the talus temporarily closed the shoreline highway. Subsequent investigation revealed the existence of the landslide in the bedrock (Kachadoorian and Slater, 1978), and, following established procedure (U.S. Government, 1977), the U.S. Geological Survey issued a Notice of Potential Hazard.

The main concern raised in the hazard notice was that at some future time a rock avalanche might descend Pillar Mountain and displace water in the harbor, possibly inundating part of the City of Kodiak. Former glaciers during the Pleistocene Epoch had oversteepened the face of Pillar Mountain, which now has a slope of about 45°, and fast moving landslides on such steep slopes elsewhere have been devastating (Keefer and others, 1978).

After the notice was issued, the City of Kodiak established the Pillar Mountain Geotechnical Committee (Schaff and others, 1979). The committee recommended several studies of the landslide. These included onshore geologic mapping, which delineated the main part of the slide and tension cracks at its head (Brown, 1980); and core drilling, which revealed weathered fractures to a depth of about 140 m at the center of the slide (Lappi, 1980). The city requested assistance from the U.S. Geological Survey to evaluate the earthquake ground motions that might affect the landslide (Moore, Page, and Lahr, 1980), and to conduct a marine-geophysical survey of the area offshore from the slide, which is the subject of this report.

Objectives of the offshore survey were (1) to help define the toe of the landslide; and (2) to gather information about any past rock avalanches that may have originated from Pillar Mountain and left a record offshore.

Other U.S. Geological Survey staff members in the scientific party for the investigation at Kodiak Harbor were Harry R. Hill, Rex Sanders, and A. Richard Tàgg. On behalf of the city, Laurence K. Monroe, Kodiak City Engineer, George McCorkle, Harbormaster, and Dr. Ronald Brockman, owner and captain of the survey vessel, provided valuable support. During the course of this study, I have benefited from suggestions by Robert W. Fleming, David S. McCulloch, Gerald F. Wieczorek, and Raymond C. Wilson.

SURVEY METHODS

The Sea Surgeon, a fishing boat 12 m long chartered by the City of Kodiak, was used to collect the data for this survey on October 15 and 16, 1980. The boat maintained an average speed along the tracklines of 4.2 km/hr (2.3 knots), and a microwave navigation system on the vessel measured ranges from repeater stations set up along the shore. A computer processed the ranges and plotted the track on a chart recorder aboard the vessel. The precision of location is within about 5 meters for points plotted along the track (Fig. 1).

Three acoustic-profiling systems used echoes at different sound frequencies to draw profiles of the seafloor and of the sediment layers below the seafloor. The three systems, which in combination provided both good bed-to-bed resolution and moderately good subbottom penetration, had the following characteristics:

(1) electrically pulsed crystal (echo sounder) produced sound waves at a frequency of 200 kHz, with good resolution of the seafloor and negligible seafloor penetration; (2) pulsed crystal, frequency 3.5 kHz, resolution between subbottom layers 0.5 m, penetration 10 m; (3) electromagnetically pulsed metal plate, frequency 1 kHz, resolution 3 m, penetration 50 m. Records from the three acoustic systems were used to prepare true-vertical-scale longitudinal and transverse profiles of the area offshore from the Pillar Mountain landslide (Fig. 2 and 3).

A side-scan sonar was used to map the harbor floor between the profiles. The sonar (100 kHz), which was towed amidships close to the hull, recorded seafloor irregularities out to a distance of 100 m on the port side of the vessel. Because the trackline grid has a spacing of about 100 m, the side-scan sonar saw most parts of the harbor floor, and it viewed some areas from several directions.

The original records from this survey may be studied at the U.S. Geological Survey Marine Data Center at 3475 Deer Creek Road, Palo Alto, California 94304 (415-856-7132). Microfilm copies of the subbottom, echo-sounding, and side-scan records may be purchased from the National Geophysical and Solar-Terrestri Data Center, Code D621, 325 Broadway, Boulder, Colorado 80303 (303-497-6542).

SURVEY RESULTS

The floor of the harbor between Pillar Mountain and Gull Island, 700 m offshore, is relatively smooth, with an average depth of 20 m. Evidence from onshore areas and the islands indicates that the floor of the harbor, below a layer of weakly consolidated sediment, is underlain by a glacially smoothed bedrock surface. The subbottom profiles show that the average slope of the lower sediment layers from the shoreline to the middle of the basin is about 7°. The total depth of the basin in the center of the harbor, including both the water and the sediment, is about 50 meters.

Holes drilled near the shore during engineering investigations for the Kodiak Container Dock show that the bay-floor sediment there ranges up to 15 m thick (Lamont, 1971). The base of the sediment is a sandy gravel 2 to 8 m thick that rests directly on bedrock. Above the sandy gravel, the sediment is mainly silt.

The subbottom profiles show that many of the sediment layers in the bay-floor sediment are nearly planar, but locally they are folded and fractured (Fig. 2 and 3). Also, some subbottom reflectors cut across the reflections that are interpreted to be from the bedding. These crosscutting reflectors are believed to be low-angle shear surfaces.

The main area of reflections interpreted to be from folded bedding and shear surfaces extends offshore from Pillar Mountain for about 500 m, or about three-quarters of the way to the low glacially sculptured bedrock mound that constitutes Gull Island. It extends from Gibson Cove to a position halfway between the Kodiak City Dock and the Inner Harbor breakwater, a length along the shore of about 1500 m.

A conspicuous but relatively short 3-m uplift marks the seafloor outcrop of an apparent subbottom shear surface 150 m beyond the northeast end of the Kodiak Container Dock on trackline 30 (Fig. 2 and 4). It probably is not simply a heave ridge from artificial loading at the container dock, because the radii of ridges from such loading usually do not much exceed the thickness of the mud, there about 15 m thick. This shear surface and uplift may represent a place where fairly recent movement associated with the landslide has broken to the seafloor.

Prominent features of the deformed sediment in the harbor are several broad anticlinal ridges, generally parallel with the shore (Fig. 1). These features are about 200 m wide and as much as 9 m high. They contain slightly arched but otherwise fairly regular internal stratification. They are underlain by crosscutting reflectors, interpreted to be shear surfaces (Fig. 2 and 4, line 30).

The regular internal stratification indicates that the ridges are not rubbly mounds of landslide material that moved downward from the face of Pillar Mountain and across the basin to their present position. They are also unlike constructional glacial features such as drumlins, which generally lack internal reflections on subbottom profiles.

I interpret the deformation of the harbor sediment as being related to push from the Pillar Mountain landslide (Fig. 5). Why the deformation should occur so far from the onshore landslide is puzzling. Possibly the deformation occurred during major earthquakes, when the bay sediment was being shaken at the same time that the onshore landslide moved slowly downward.

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FIGURE CAPTIONS

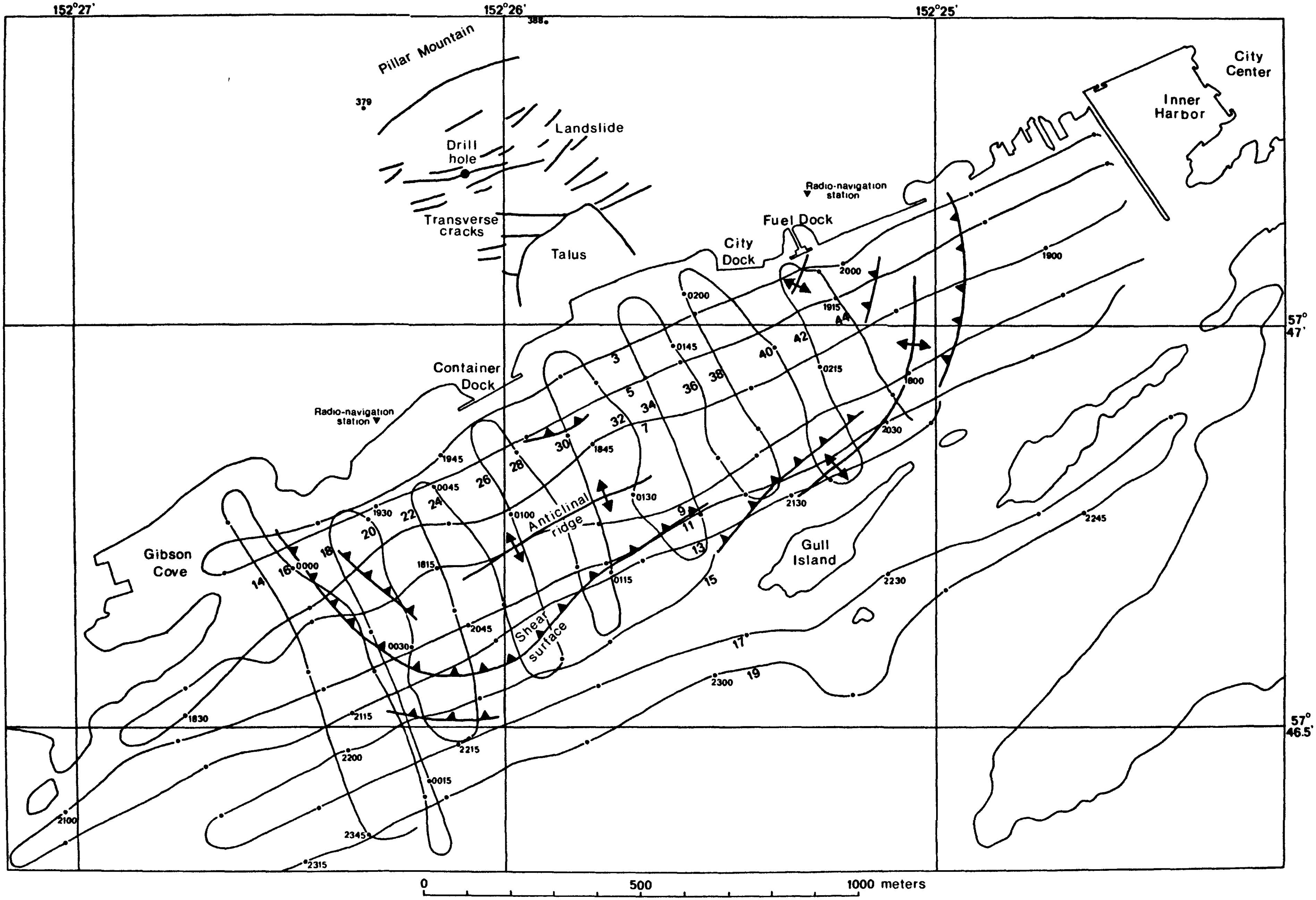
Figure 1. Survey tracklines, onshore landslide features, and offshore geologic structures extrapolated to the seafloor near Kodiak, Alaska; 5-minute time marks along the tracklines are in Greenwich mean time, 15-16 October 1980.

Figure 2. Selected longitudinal profiles off the Pillar Mountain landslide, perpendicular to the shoreline and approximately 100 meters apart, showing subbottom reflectors interpreted to be sediment beds and shear surfaces. Time marks on the profiles are located on the tracklines of Figure 1. The profiles are mainly based on acoustic-reflection profiles at a sound frequency of 1 kHz, supplemented by profiles at 3.5 kHz and 200 kHz. The sound velocity assumed for the water is 1.5 km/s, and for the strata, 2.0 km/s. The datum is mean sea level, 1980.

Figure 3. Selected transverse profiles off the Pillar Mountain landslide, parallel with the shoreline and approximately 100 meters apart. Time marks on the profiles are located on the tracklines of Figure 1.

Figure 4. Nearshore half of the 1-kHz subbottom profile along trackline 30, perpendicular to the shoreline and approximately off the middle of the Pillar Mountain landslide. The distance between sea level and the crest of the anticlinal ridge is 15 meters, giving a vertical exaggeration of 3.9 times.

Figure 5. Sketch of relations between the Pillar Mountain landslide, the offshore anticlinal ridge, and the inferred 10° shear surface below the ridge.



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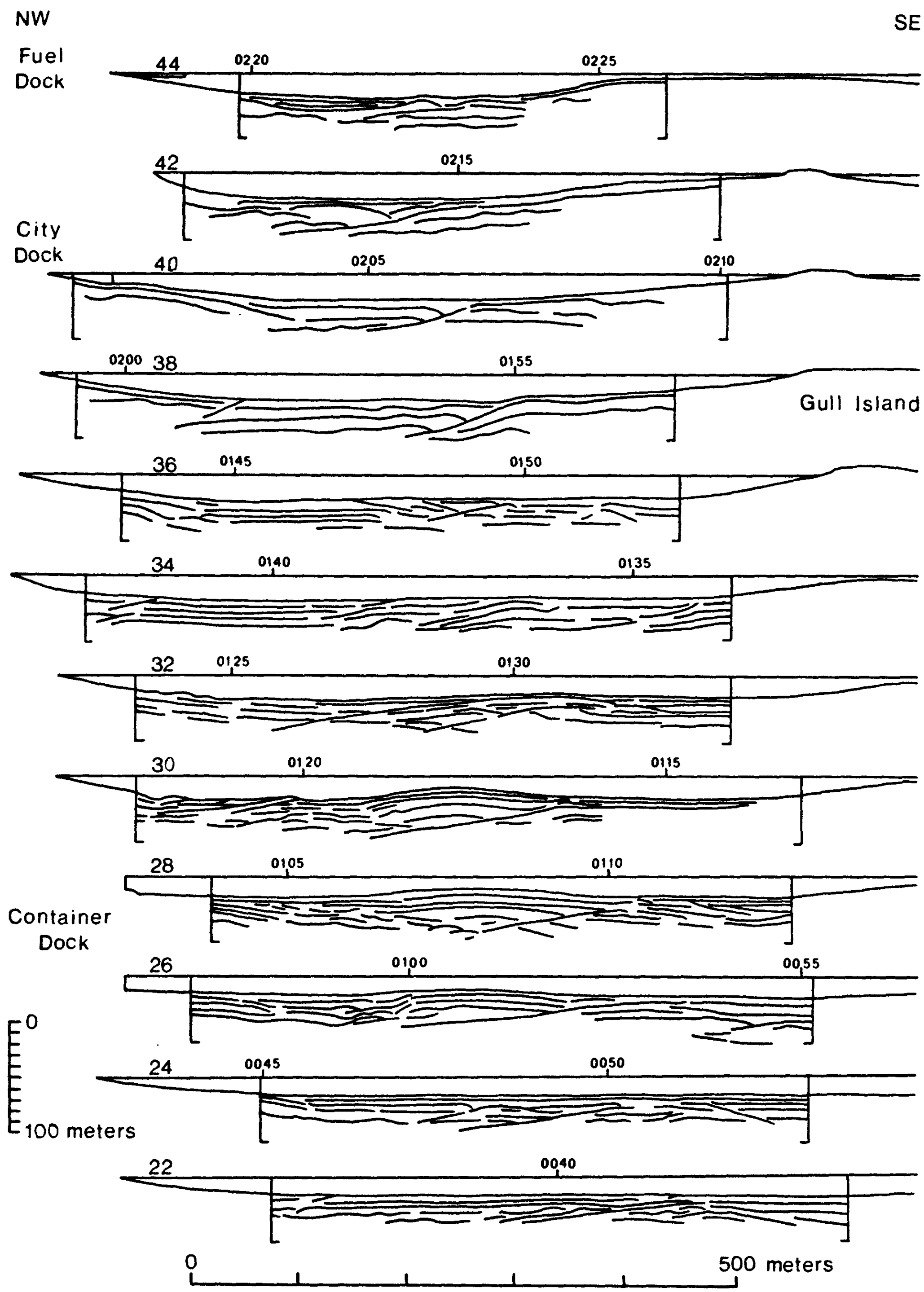

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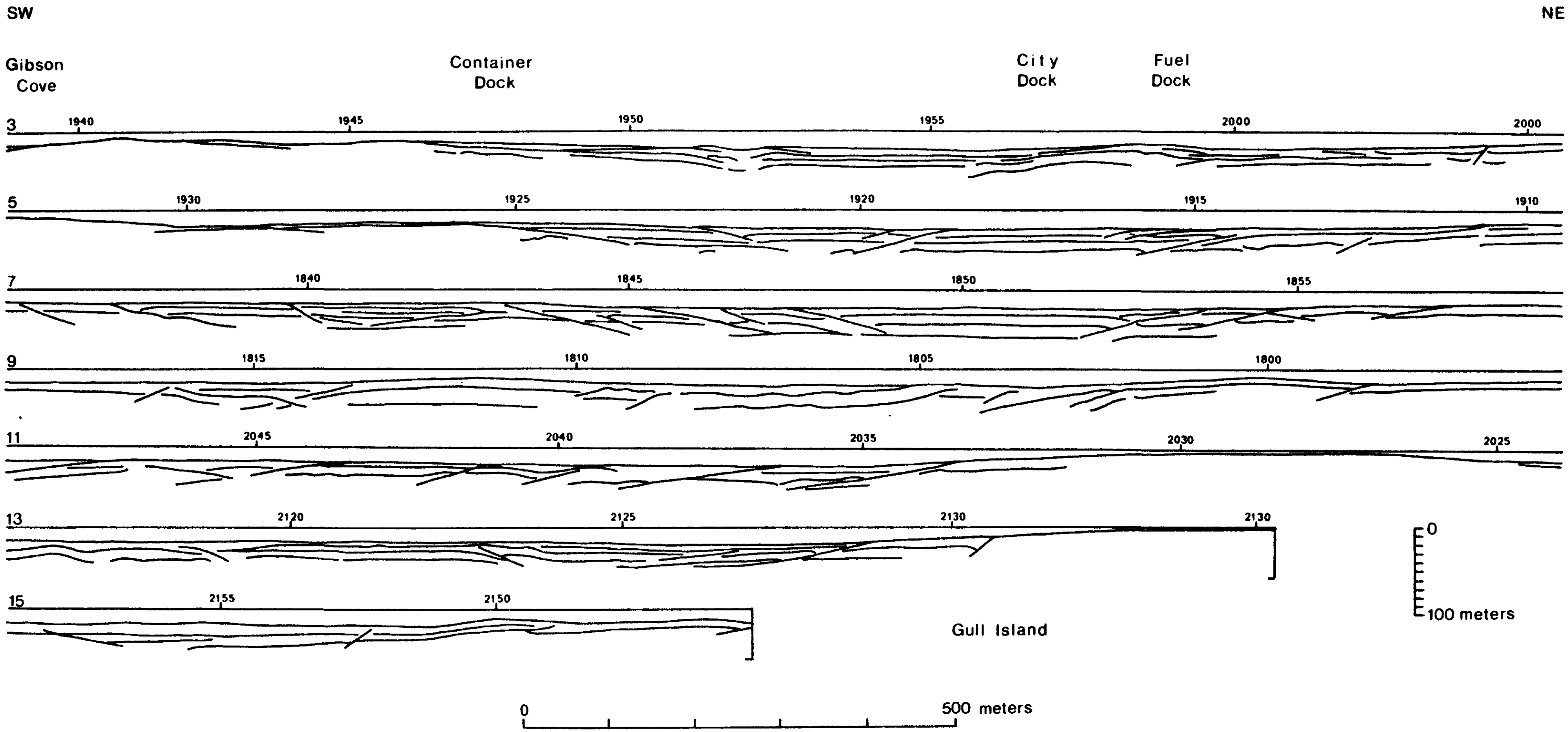
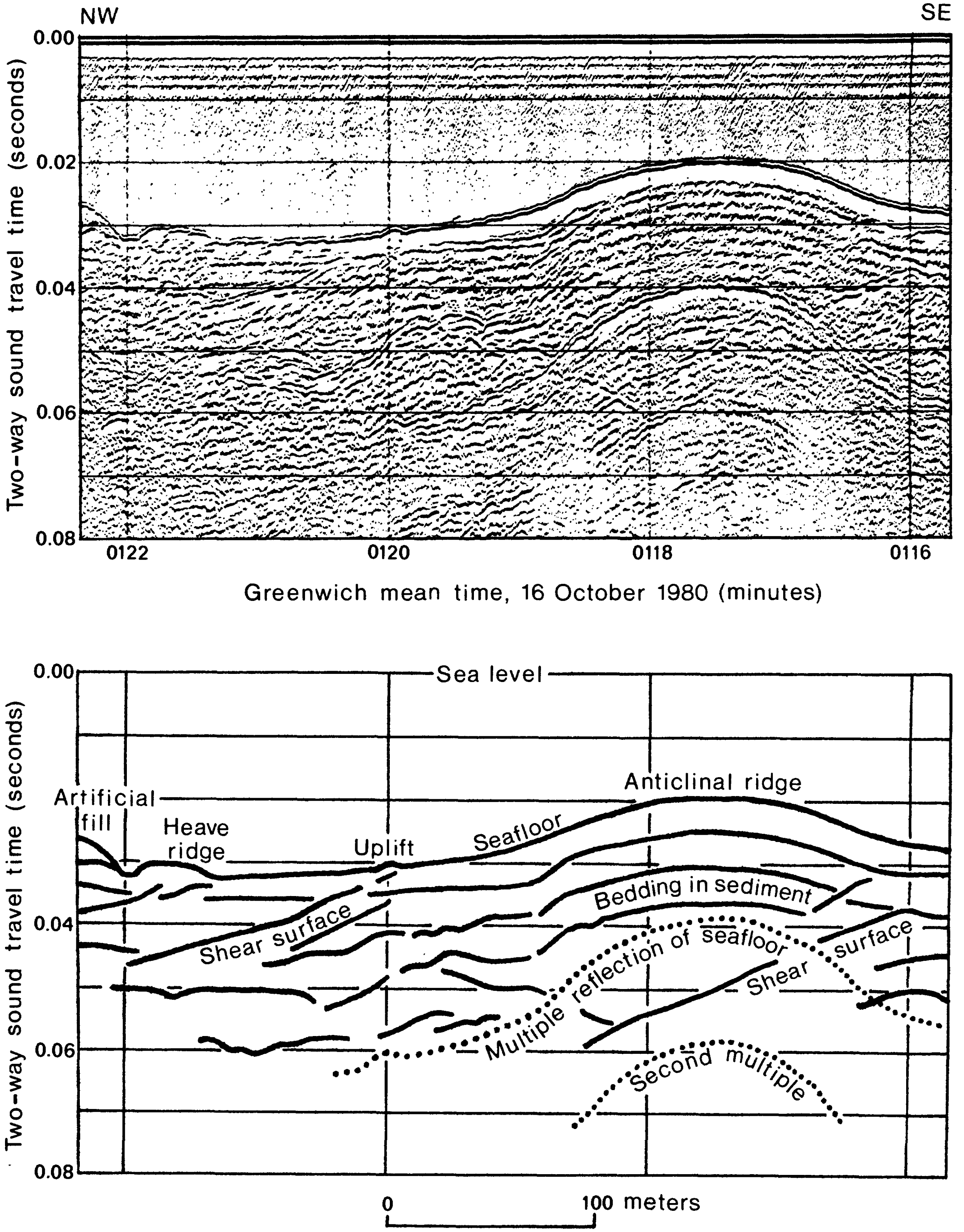


Figure 3. Selected transverse profiles off the Pillar Mountain landslide, parallel with the shoreline and approximately 100 meters apart. Time marks on the profiles are located on the tracklines of Figure 1.



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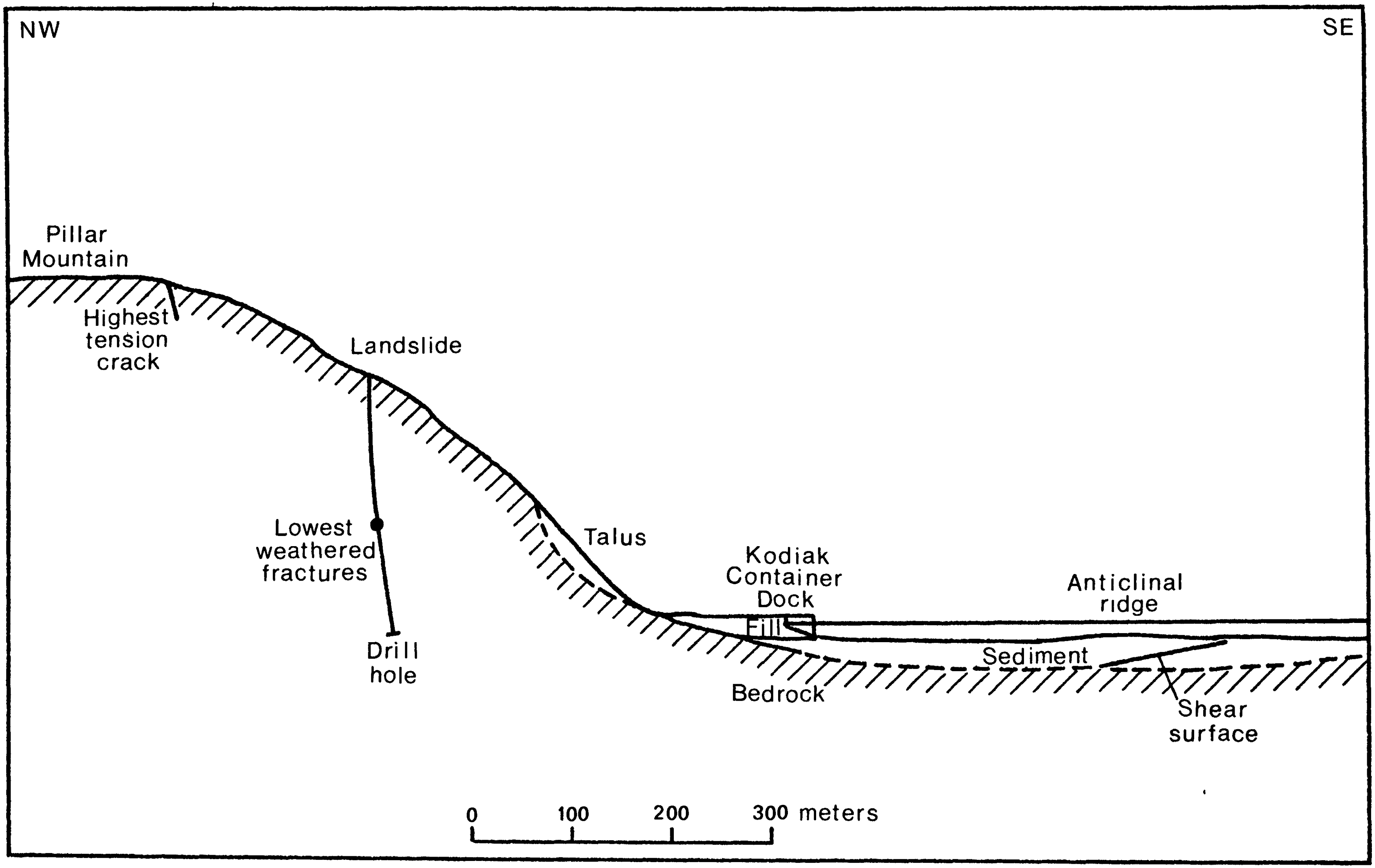

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