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SUBMARINE FAULTS AND SLIDES THAT DISRUPT SURFICIAL SEDIMENTARY UNITS, NORTHERN GULF OF ALASKA

OPEN-FILE REPORT 76-294

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature

Menlo Park, California
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Submarine faults and slides that disrupt surficial sedimentary units, northern Gulf of Alaska

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Abstract

Faults and submarine slides or slumps of Quaternary age are potential environmental hazards on the outer continental shelf (OCS) of the northern Gulf of Alaska. Most of the faults that approach or reach the seafloor cut strata that may be equivalent to the upper Yakataga Formation (Pliocene-Pleistocene). Along several faults the seafloor is offset from 5 to 20 m. A few faults appear to cut Holocene sediments, but none of these show offset at the seafloor.

Submarine slides or slumps have been found in two places in the OCS region: (1) seaward of the Malaspina Glacier and Icy Bay, an affected area of 1,770 km^2 with a slope of less than one-half degree, and (2) across the entire span of the Copper River prodelta, an area of 1,730 km^2, having a slope of about one-half degree. Seismic profiles across these slide areas show disrupted reflectors and irregular topography commonly associated with submarine slides or slumps. Potential slide or slump areas have been delineated in areas of thick sediment accumulation and relatively steep slopes. These areas include (1) Kayak Trough, (2) parts of Hinchinbrook Entrance and Sea Valley, (3) parts of the outer shelf and upper slope between Kayak Island and Yakutat Bay and (4) Bering Trough.

Introduction

The continental shelf of the northern Gulf of Alaska between Prince William Sound and Yakutat Bay (cross-hatched area in fig. 1) frequently is exposed to powerful natural forces. Intense seismic activity (Page, 1975), which results in severe ground shaking, may cause widespread ground failure. Destructive and sometimes death-dealing tsunamis may originate from local earthquakes, from subsea earthquakes with epicenters far out in the Pacific Ocean or from large slumps. The winter season of intense low-pressure activity in the Gulf of Alaska produces frequent storms with large and forceful waves; the battleship U.S.S. Pennsylvania was lost there in a severe storm in January, 1952, with estimated significant wave heights of 50 feet (Danielson and others, 1957). Waves of this magnitude could wreak havoc on coastal and seafloor installations and could move bottom sediment even on the outer shelf.

The intensified petroleum-related activities in the outer continental shelf (OCS) region from Prince William Sound to Yakutat Bay, spurred on by oil and gas lease sales, make it imperative to explore and evaluate carefully the natural hazards of this region before marine construction begins.

This report points out areas on the seafloor that pose hazards that must be considered in the design of offshore facilities.

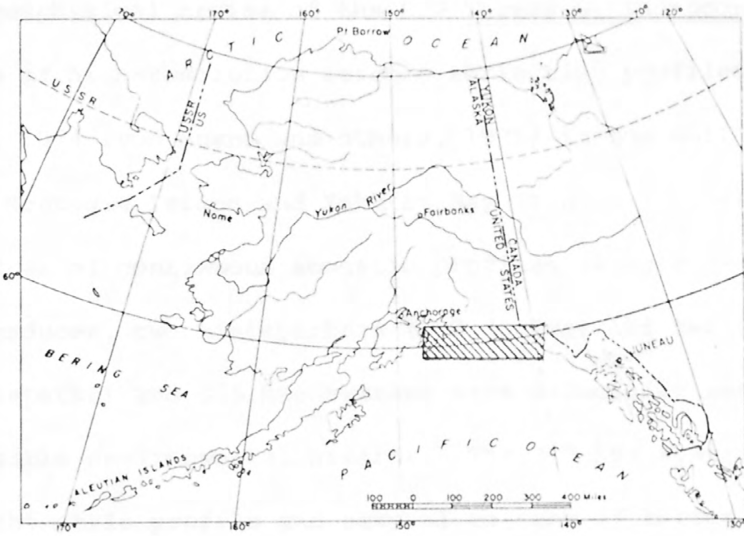


Figure 1. Location of study area.

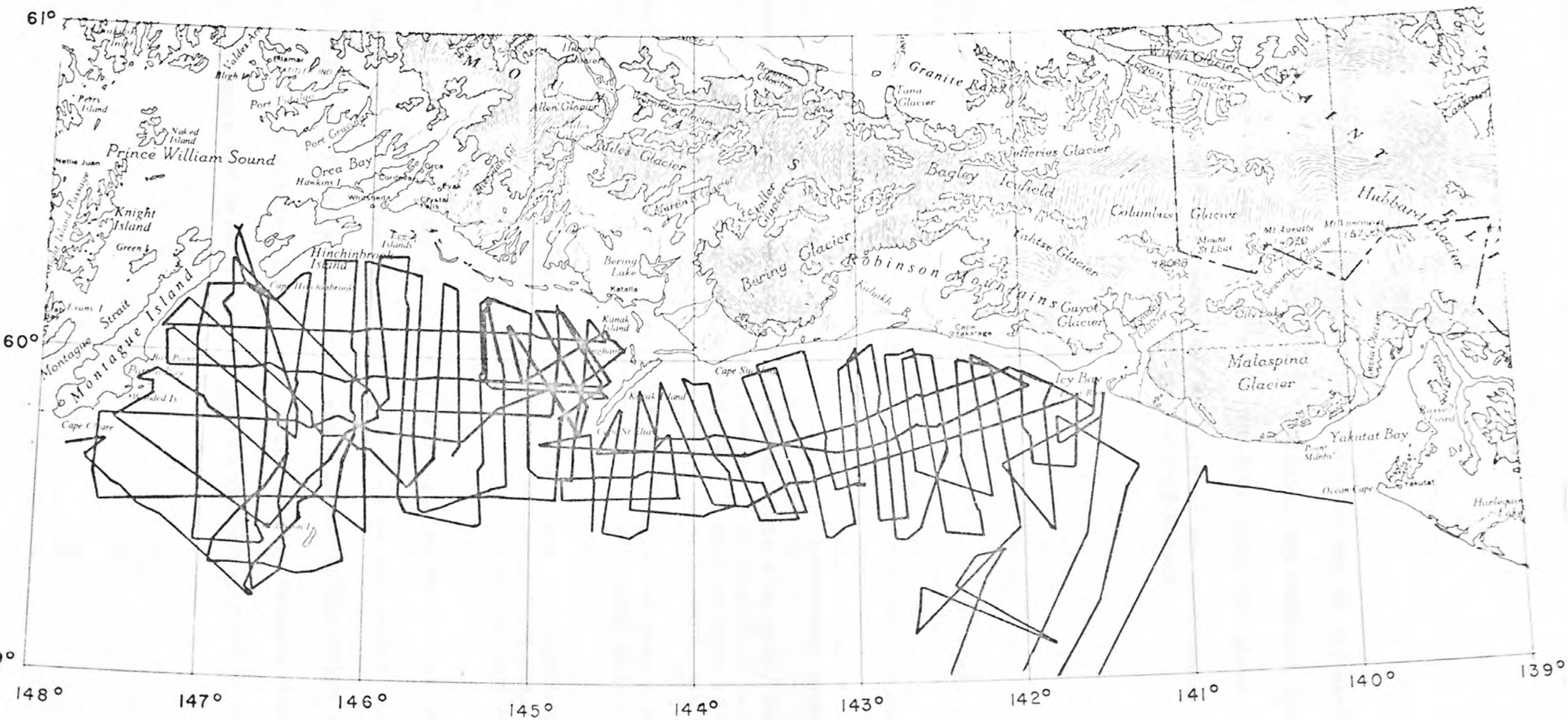
Helpful discussions and constructive reviews were provided by David McCulloch and Erk Reimnitz.

Data Collection

A geophysical cruise of the R/V Thomas G. Thompson collected about 6,500 km of high-resolution seismic reflection profiles during September-October, 1974 (von Huene and others, 1975) in the Gulf of Alaska between Montague Island and Yakutat Bay (fig. 2). These data include three types of continuous acoustic profiles using as sound sources a 3.5 kHz transducer, two minisparkers (800 joules) and two 40-in^3 air guns. The minisparker and 3.5 kHz systems were especially useful in studying the possible environmental hazards. The 3.5 kHz system provides a good bathymetric profile and several to tens of metres of penetration in the Holocene muds that blanket much of the nearshore zone. The minisparker system provides penetration of a few hundred metres and resolution of 2-3 metres. Interpretation of the seismic data was aided by supplemental information provided by shipboard sediment descriptions recorded on the cruise of the F.R.S. Cromwell, May-June, 1975.

Stratigraphy

Four different sedimentary units have been delineated in the OCS area (Molnia and Carlson, 1975b). The units have been identified by their seismic signatures, geometry, physiographic location, and stratigraphic position. The established seismic reflection units then were field-checked by a reconnaissance sampling of the seafloor sediment.



Figures 2. Trackline map of the R/V THOMAS G. THOMPSON cruise (September-October, 1974).

Although no isotopic age dates are available on any of the seafloor material, the relative stratigraphic position, the inferred lithologic description and seismic character of the four units are shown in table 1.

Table 1. Marine sedimentary units on the continental shelf of the northern Gulf of Alaska.

Unit	Seismic reflection characteristics	Description
Holocene sediments	Relatively horizontal and parallel reflectors except where slumped, then very disrupted.	Olive to gray, under-consolidated, clayey silt and silty clay; fine sand in nearshore zone; interlayered sand and mud units in transition zone.
Holocene end moraines	Jumbled mass of irregular reflectors, very irregular surface morphology.	Olive to gray, unsorted, unstratified heterogeneous mixture of clay, silt, sand, and gravel.
Quaternary glacial-marine sediments	Very irregular, confused, distorted reflectors	Olive to gray pebbly mud and sandy shelly mud.
Tertiary-Pleistocene sedimentary rocks	Well-developed reflectors indicating folded, faulted, and truncated lithified sedimentary strata.	Semi- to well-indurated pebbly and sandy mud, siltstone, and sandstone.

Their distribution on the seafloor is discussed by Molnia (in press). The lowermost of the four units is believed to be equivalent variously to the Yakataga, Katalla-Poul Creek, and Orca Formations which Plafker (1967, 1974) and Winkler (1973) have mapped in the onshore coastal zone. The ages and descriptions of these units are listed in table 2 and discussed in some detail by Plafker and others (in press).

Table 2. Ages and descriptions of selected Tertiary sedimentary strata of the Gulf of Alaska Tertiary province (after Plafker, 1967 and Winkler, 1973).

Formation	Age	Description
Yakataga	Middle Miocene to lower Pleistocene	Mudstone, siltstone, sandstone, and minor conglomerate interbedded with abundant conglomeratic sandy mudstone.
Katalla	Lower(?) and middle(?) Miocene	Pebbly siltstone, siltstone, pebbly conglomerate, and sandstone.
Poul Creek	Middle(?) and upper Oligocene and lower Miocene	Calcareous siltstone with minor sandstone, glauconite, and pyroclastic volcanic rocks.
Orca	Middle and late Paleocene	Lithofeldspathic sandstone and siltstone interbedded with mudstone and altered pillow basalts, breccias and shallow intrusives.

Faults

The general trend of the near-surface faults in the study area is northeast-southwest to east-west (fig. 3), subparallel to major onshore structures (Plafker, 1967). These near-surface faults probably are related to the development of the deeper structures on the continental margin as shown by Bruns and Plafker (1975) and generalized by Plafker and others (in press).

Near-surface faults thus far detected are in four main parts of the OCS area: (1) south of Cape Yakataga, (2) on or adjacent to the Kayak Island platform (3) on Tarr Bank and (4) near Middleton Island (fig. 3). In most cases the faults cut strata which are probably of Tertiary age (fig. 4). Commonly these Tertiary strata are covered only by a thin

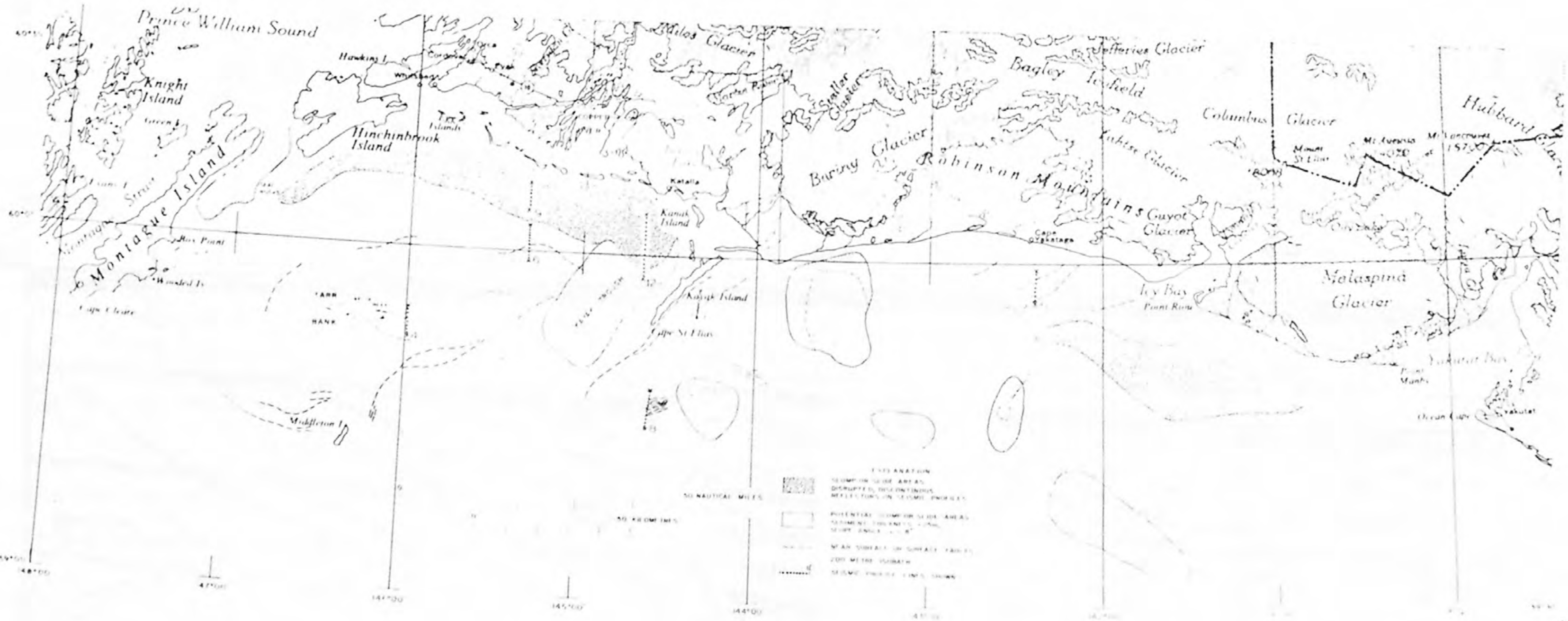


Figure 3. Preliminary map of submarine slides and nearsurface faults, northern Gulf of Alaska. Modified from Carlson and others, 1975. Numbers by the heavy dashed lines indicate figure number of profile.

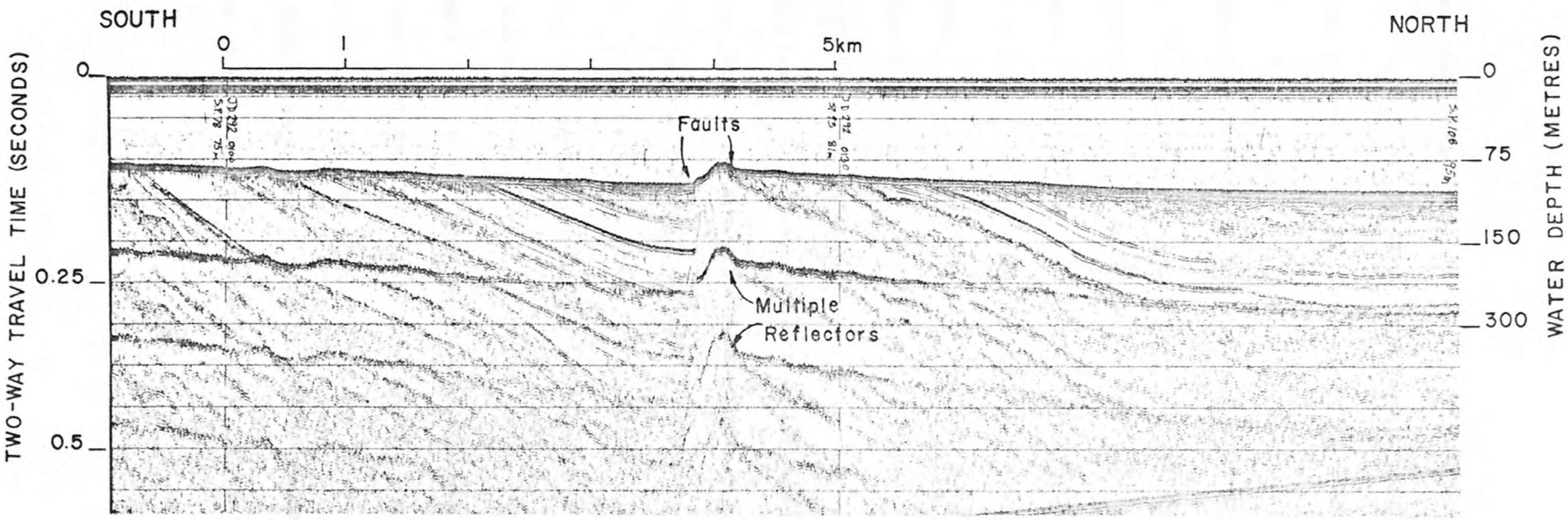


Figure 4. Minisparker profile showing older faulted and folded strata (Tertiary-Pleistocene) cropping out at the seafloor. (Vertical Exaggeration (V.E.) = 10X).

veneer of Holocene sediment (fig. 5) and in many places crop out at the seafloor (fig. 4). A few of the faults appear to cut Holocene sediments (fig. 6), but none were found that unequivocally offset Holocene sediment at the seafloor.

The most prominent clearly fault-associated scarp has a relief of about 20 m (fig. 4). This fault, which is upthrown on the north side, also has been recorded on 3 other lines (offsets of seafloor vary from 5-10 m) and appears to be 18 km long. Bonilla and Buchanan (1970) have plotted lengths of historic surface faults (from all parts of the world) versus surface displacements and their graph suggests that a fault with 20 m of displacement should be nearly 600 km long in order for that amount of displacement to have occurred as a single event. Five metres of displacement requires a fault length of over 100 km. Conversely, the amount of displacement expected along a 20 km fault is less than 1 m. It appears, therefore, that episodic movement is required to account for the 5-20 m of displacement. The fault illustrated in figure 4 is associated with several other faults branching from the Wessels Reef complex on Tarr Bank (fig. 3), extending the overall length to 35 km (maximum single event displacement ∿1.5 m). Three seismic events (all less than magnitude 4 earthquakes) recorded in the period September 1974 - May 1975, whose epicenters were plotted in the vicinity of the Wessels Reef fault complex, (John Lahr and Robert Page, oral commun., 1976) emphasize the currently active nature of these faults. These faults offset the seafloor, which

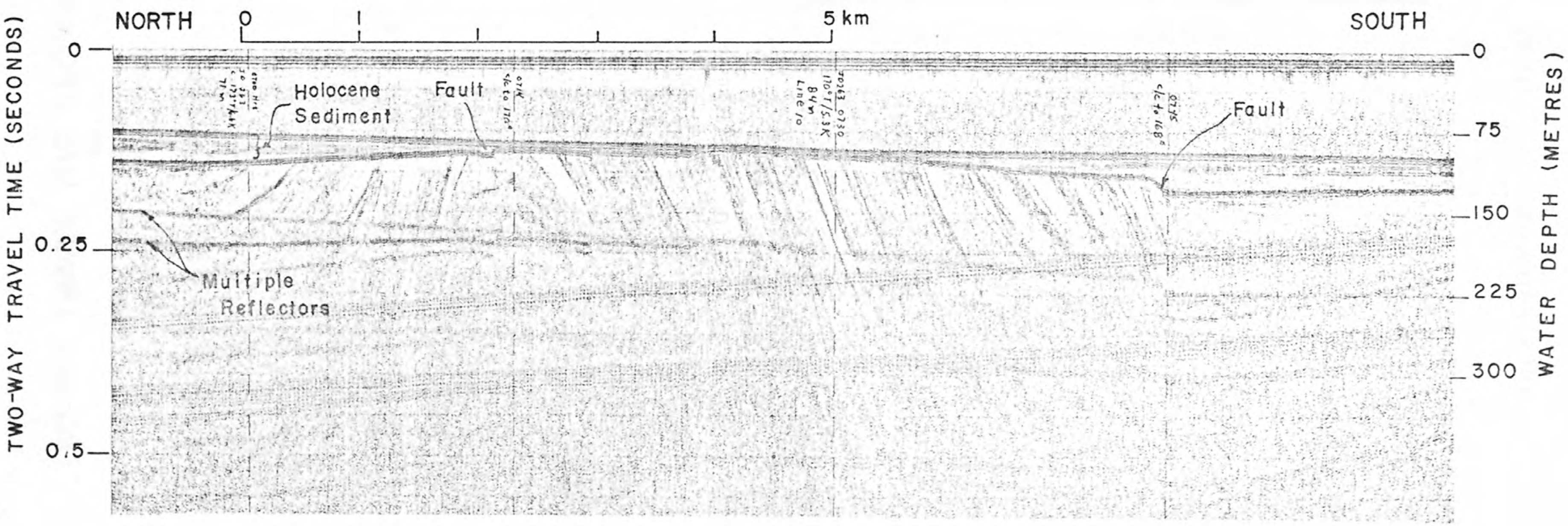


Figure 5. Minisparker profile south of Cape Yakataga showing older faulted and folded strata (Tertiary-Pleistocene?) overlain by thin blanket of Holocene sediment. (V.E. ≈ 10X).

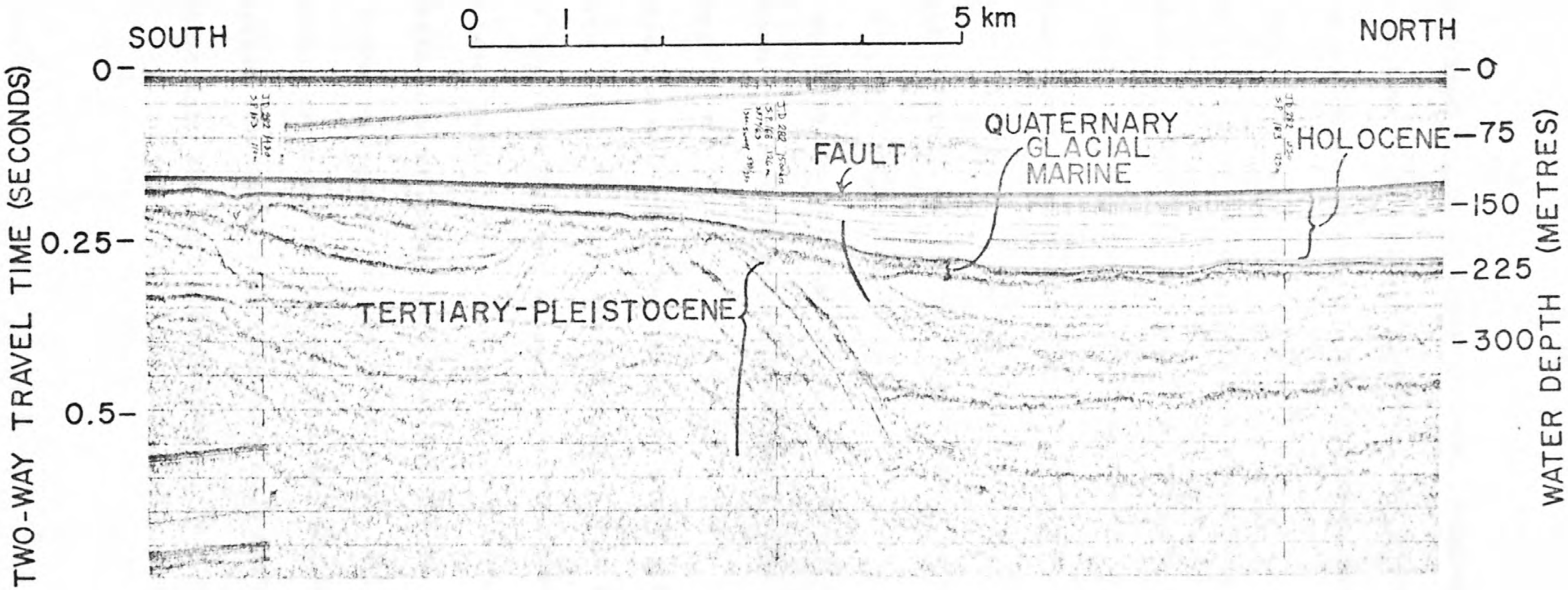


Figure 6. Minisparker profile south of the Copper River showing fault (sketched in) cutting lower part of Holocene sedimentary sequence. The fault also cuts through the underlying glacial marine unit and into the steeply dipping Tertiary sedimentary rocks. (V.E. ≈ 10X).

appears to be folded truncated Tertiary rock. Samples collected from Wessels Reef in June 1975 (friable sandstone and granule conglomerate) are similar to rocks assigned by Plafker (1974) to Katalla-Poul Creek Formations (Gary Winkler, oral commun., 1975).

A series of east-west-trending faults of varying lengths cut the folded truncated Tertiary strata (probably Yakataga) west of Middleton Island (fig. 3). The southernmost of these faults is more than 30 km long, identified on six separate seismic lines. The relative movement along these faults appears to be north side up.

Northeast of Middleton Island, a 50-km-long curving complex fault zone (fig. 3) cuts Tertiary strata. The middle part of this fault zone reaches the seafloor, but at each end the faulted strata are covered by a thin veneer (5-10 m) of Holocene sediment. The relative motion is up on the north side.

The longest near-surface faults in the study area are southeast of Kayak Island (fig. 3). The seaward side of this fault zone extends southwest of Cape Suckling and appears to cut Tertiary strata and perhaps the lower part of the overlying 10-20 m of Holocene sediment. Disrupted reflectors on minisparker profiles may be gas-charged Holocene sediment along part of the fault trace (fig. 7). The gas could be methane generated within the Holocene sediment or it could be gas liberated from underlying reservoir rock that has migrated up the fault plane into the surficial sediment. This fault zone nearly

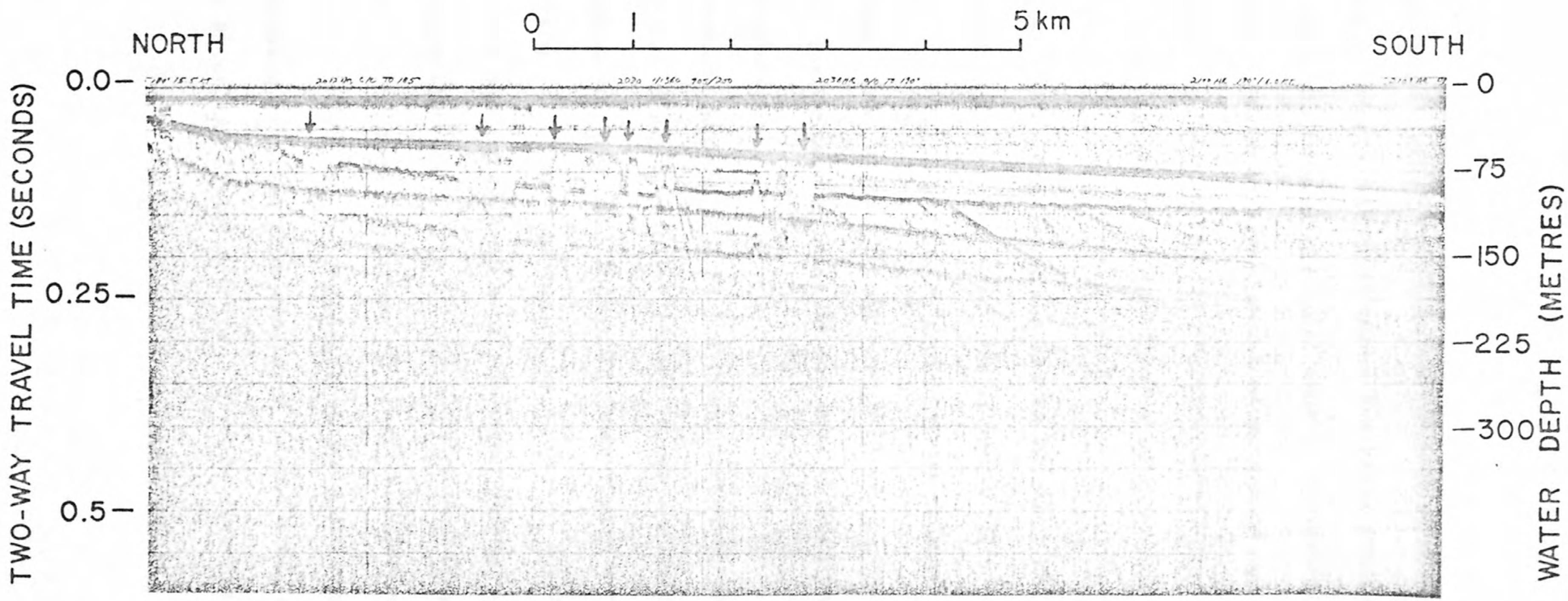


Figure 7. Minisparker profile east of Kayak Island showing gas-charged sediments (arrows point to disrupted reflectors, believed due to gas in the sediment). (V.E. ≃ 10X).

parallels Kayak Island, probably includes Plafker's (1974) 10 Fathom fault and continues southwest along the Kayak platform. The total length of this near-surface fault zone is approximately 70 m. This fault also appears to have a sense of motion of up on the northwest.

Swarms of small discontinuous step faults were found along several seismic lines at the outer edge of the continental shelf south of Kayak Island (fig. 8). Tertiary strata are disrupted at the seafloor and the relief along these numerous scarps is about 2-5 m. These scarps may delineate slump blocks at the edge of the shelf. Along some of the profile lines, masses of what appear to be slumped sediment are seen on the slope. Some of the blocks show evidence of backward rotation; however, the seismic records do not show outward curvature of the fault or slip planes.

Several near-surface faults trend northeast-southwest parallel to the Icy Bay major structural trends (Bruns and Plafker, 1975) south of Cape Yakataga. The two longest of these faults can be traced for about 30 km (fig. 3). Sense of motion is up on the northwest. Most of these faults are covered by 5-10 m of Holocene sediments (fig. 5) and in one of the profiles one of the faults may continue upward into the Holocene sediments, but does not appear to break the surface.

Submarine slides and slumps

Seismic profiles from two parts of the study area seaward of the Copper River and of Icy Bay (fig. 3) show disrupted bedding and

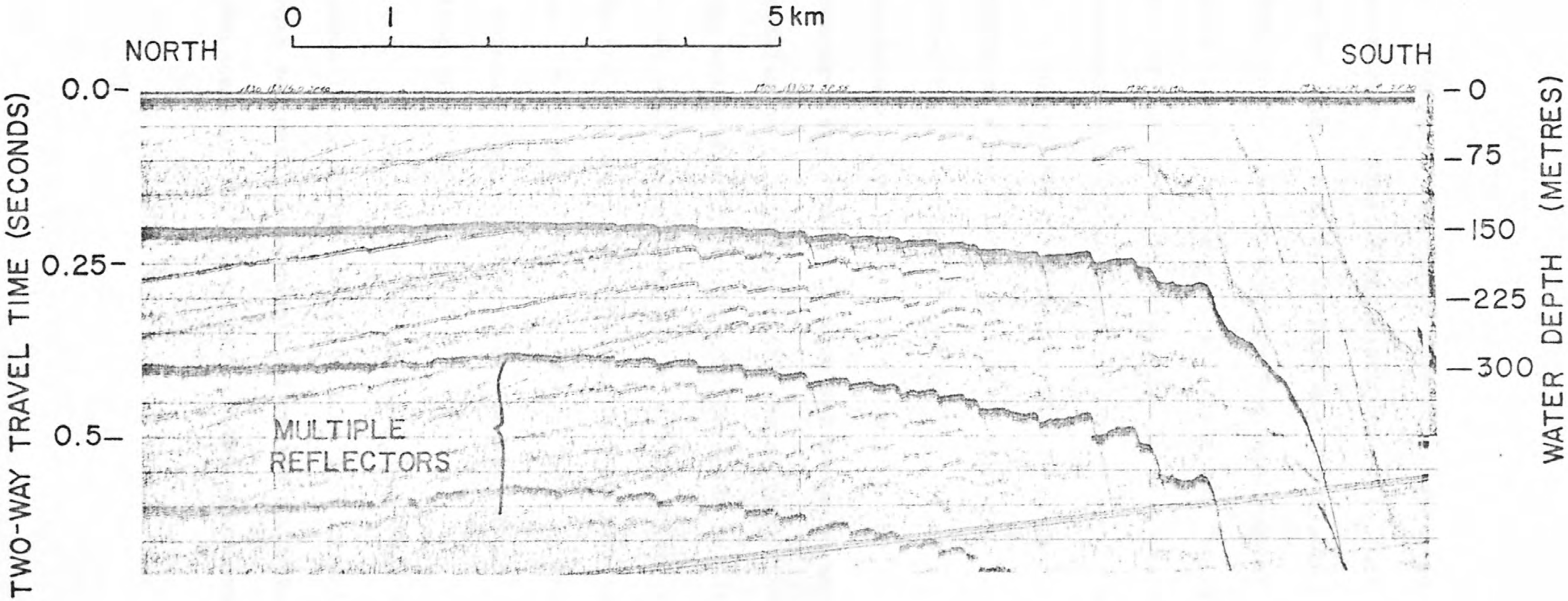


Figure 8. Minisparker profile of stepfaults at edge of shelf south of Kayak Island. (V.E.≃ 10X).

irregular topographic expression commonly associated with submarine slides and slumps. Some of the disrupted reflectors visible on a few of the profiles (fig. 9) perhaps are due to the presence of gas-charged sediment. These reflectors are very similar to those off Kayak Island (fig. 7). However, all along the Copper River prodelta, which has a gradual slope of less than one-half degree, the seismic profiles showed zones of a second type of disrupted or discontinuous reflector in the Holocene sediments (fig. 9). The Copper River prodelta was investigated with seismic profiling equipment by Reimnitz (1972) shortly after the 1964 Alaskan earthquake. He attributed slump structures seen on high-resolution seismic records to this earthquake. These structures are similar in size and shape to the structures visible on our profiles over this same area. We conclude that these slump structures, which show progressive failure due to lateral extension of a sedimentary unit at the base of the slump blocks, were probably created by the intense ground shaking that accompanied the 1964 Alaskan earthquake. These structures are present over an area of about 1,730 km^2 that extends about 20 km offshore between Hinchinbrook Island and Kayak Island (fig. 3).

The Copper River is a major source of Holocene sediment in this region, annually supplying 107×10^6 tonnes of detritus (Reimnitz, 1966). Much of this sediment has accumulated on the prodelta, reaching a maximum thickness of 355 m southeast of the main channel and averaging

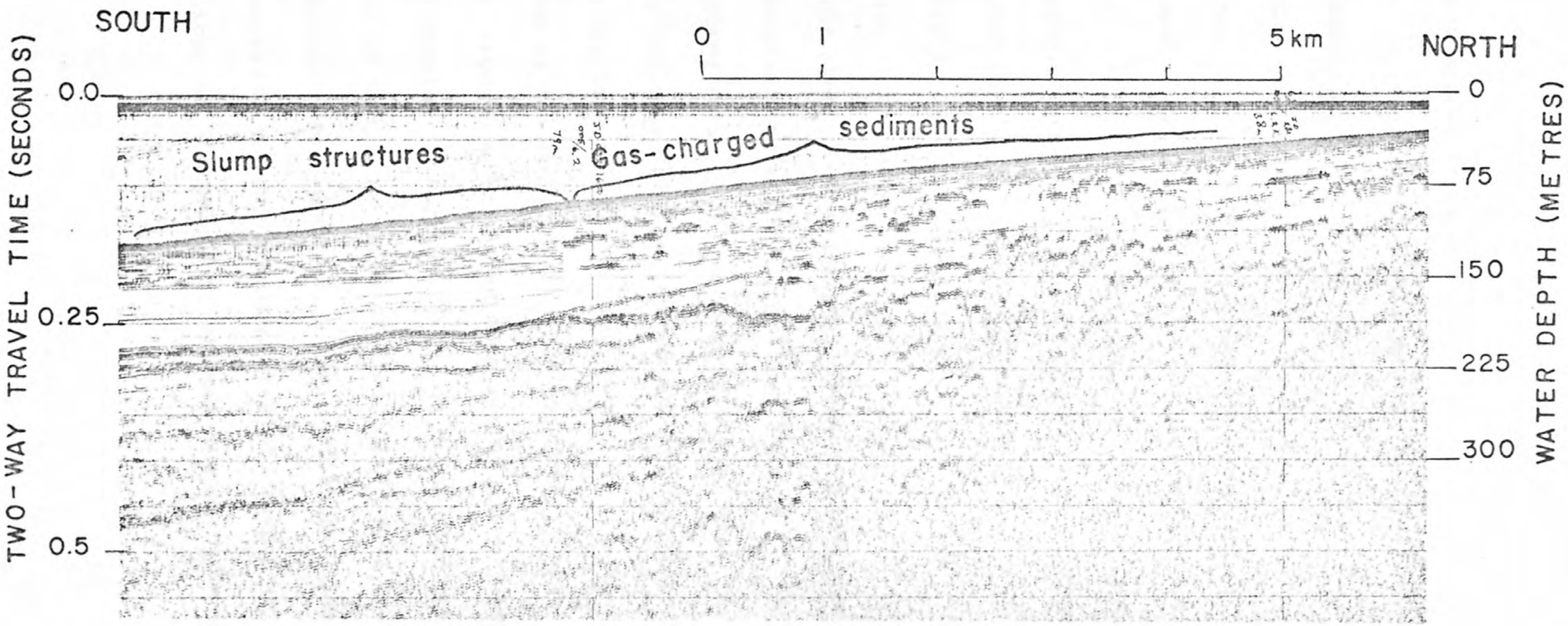


Figure 9. Minisparker profile showing two types of disrupted reflectors (slump and gas-charged) in nearsurface sediments along the Copper River prodelta. (V.E. ≈ 10X).

about 150 m thick across the entire prodelta (fig. 10). In regions with high rates of sedimentation such as the Copper River delta, the lag between accumulation and consolidation gives rise to excess pore pressure, and the sediment is prone to sliding.

The most spectacular example of mass movement in this study area is a large submarine slide located at the eastern edge of the Copper River (fig. 11). This slide has a length of 17 km, a maximum width of 12 km and a maximum thickness of about 115 m. The estimated volume of material affected by this slide is approximately 5.9×10^{11} m^3. In addition to very irregular surface morphology and disrupted internal reflectors, this slide has a fairly well preserved pull-apart scarp with a relief of about 10 m and a well-developed toe that is 20 m thick about 2 km from the distal end (fig. 12). The toe of the slide is partly buried, suggesting erosion of the underlying sediment as the slide moved down the one-degree slope into Kayak Trough; post-slide deposition also accounts for some of the sediment cover. Apparently there was enough momentum at the toe of the slide to carry it past the thalweg of the trough, imparting to the surface a very slight upward concavity.

Sediment samples collected with a box corer from the upper 50 cm of the surface of this slide consisted of gray clayey silt that was seemingly structureless. However, X-radiographs of slabs of the sediment revealed contorted disturbed bedding, some crossbedding, and chaotic mixtures of irregular fragments of various shapes. The sediment was

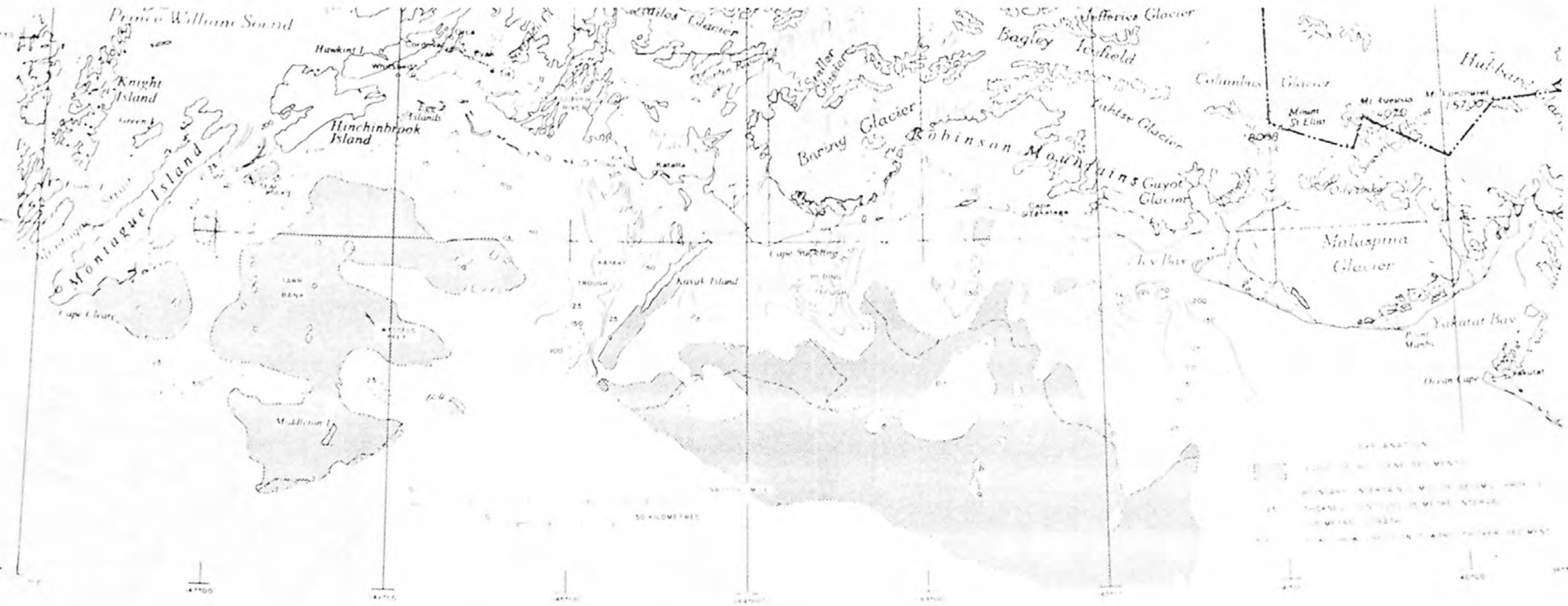


Figure 10. Preliminary isopach map of Holocene sediments, northern Gulf of Alaska. Modified from Carlson and Molnia, 1975.

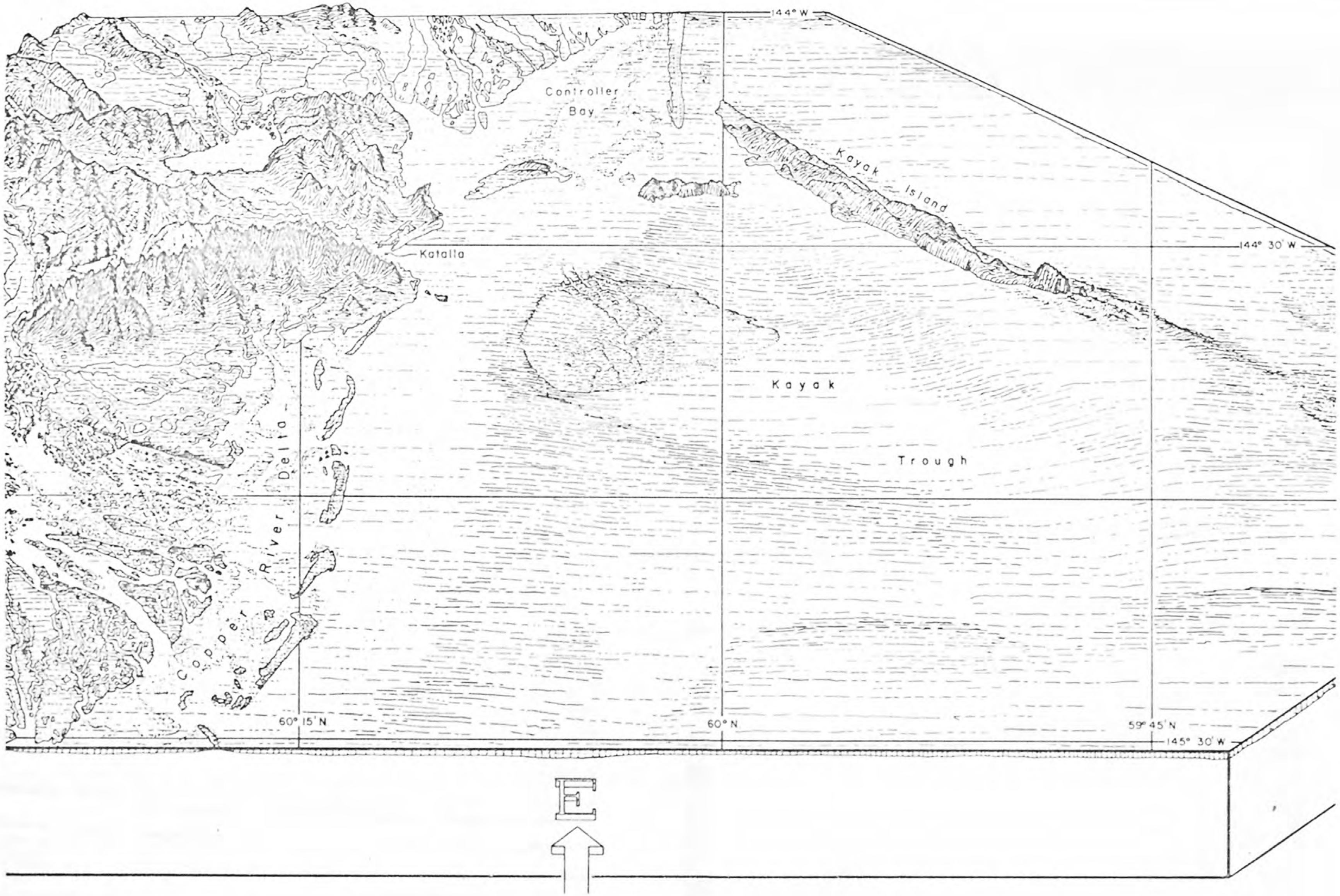


Figure 11. Physiographic diagram of Kayak Trough showing massive submarine slide. Orthographic drawing by Tau Rho Alpha; vertical exaggeration 3:1. Bathymetry based on U.S. Geological Survey soundings (Molnia and Carlson, 1975a; von Huene and others, 1975). Topography from U.S. Geological Survey 1:250,000 maps Cordova, 1959 and Middleton Island, 1955.

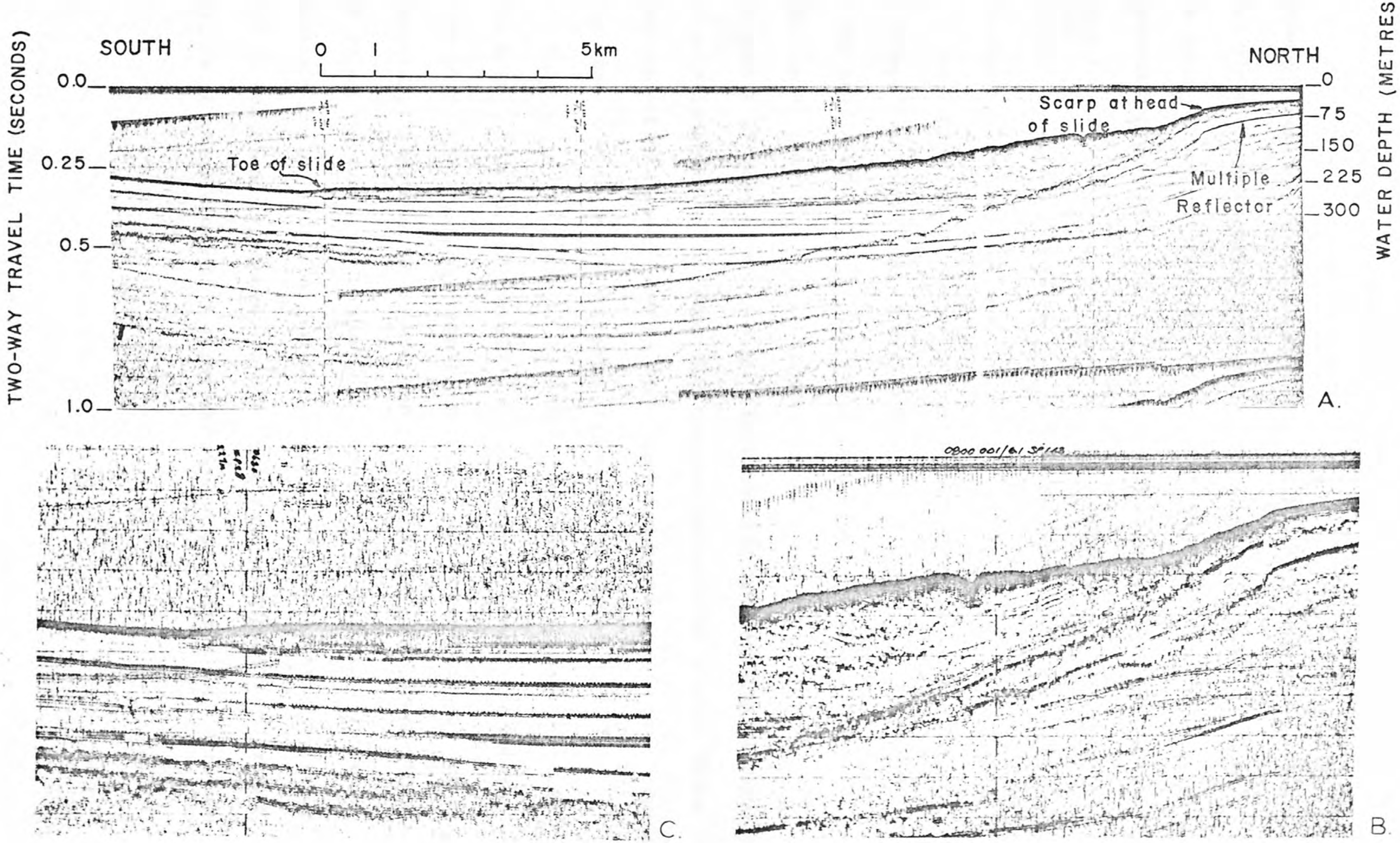


Figure 12. A. Longitudinal profile of submarine slide at north end of Kayak Trough (V.E. ≈ 10X) (see fig. 11).
B. Close-up of scarp at head of slide.
C. Close-up of toe of slide.

extremely weak as shown by laboratory tests with a vane shear apparatus that yielded a peak shear strength of 0.02 kg/cm^2. These tests were run about two months after the cruise, and the samples could have been weakened by possible remolding due to jostling in transit. However, the extremely-weak nature of some of the samples was underscored by sediment flowage when the box cores were opened on board ship to permit description and subsampling.

The second large area of disrupted reflectors connoting slides or slumps was found seaward of Icy Bay and covered about 1,770 km^2 of the seafloor (fig. 3). The slope is gradual (<1/2°), but the Holocene sediment reaches a thickness of more than 150 m (fig. 10). The source of much of the sediment is probably the Malaspina Glacier. Sediment-laden meltwater from this impressive piedmont glacier flows into the Gulf of Alaska and is moved westward by the dominating counter-clockwise flow of the Alaskan Gyre (Reimnitz and Carlson, 1975).

In addition to areas in the OCS where slump or slide structures were seen on the seismic profiles, we have mapped areas that appear to be potential slide or slump zones (fig. 3). Delineation of these potentially hazardous areas was based on thickness of Holocene sediment and relative steepness of slope. Slump or slide features were not prominent on the profiles; however, because of the sediment thickness (>25 m) and slope steepness (>1-8°) there is a possibility of ground failure in these areas if a large earthquake provides a long duration of rapid ground acceleration or if large tsunamis or storm waves disrupt the seafloor.

Summary and conclusions

Numerous nearsurface faults were found in the northern Gulf of Alaska OCS region. Most of these faults cut Tertiary marine sedimentary rocks, and along several faults the seafloor was offset from 5 to 20 m. The relatively short lengths of the faults compared to amounts of displacement suggest episodic movements. A few of the faults may cut Holocene sediments, but none of these showed offset at the seafloor. Of those faults where sense of motion could be determined, the north or northwest side was upthrown.

Two large areas of seafloor in the OCS region show evidence of submarine slides and slumps. Several other areas because of their relatively steep slopes and thick accumulations of Holocene sediment are vulnerable to submarine sliding. Slides may occur if the sediment is disturbed by (1) prolonged ground shaking triggered by earthquakes, (2) oversteepening due to erosion of the seafloor by tsunamis or storm waves, or (3) overloading by seafloor construction activities.

These nearsurface faults and submarine slides are seafloor hazards that need to be included in design criteria for subsea construction.

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